Journal of Foraminiferal Research, v. 30, no. 4, p. 310–320, October 2000

ASSESSMENT OF ARCELLACEAN (THECAMOEBIAN) ASSEMBLAGES, SPECIES, AND STRAINS AS CONTAMINANT INDICATORS IN JAMES LAKE, NORTHEASTERN ONTARIO, CANADA

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ABSTRACT

Conditions in James Lake vary from uncontaminated and nearly neutral pH conditions through most of the lake, to extremely low pH conditions (2.1 in places) contaminated with Fe, Al and SO_4 adjacent to an abandoned pyrite mine near the lake outlet. Six assemblages representative of distinct arcellacean habitats were recognized in sediment-water interface samples collected in the lake using Q-mode Cluster Analysis. R-Mode analysis of this distributional data corroborates previous results indicating that arcellacean strains from within the same species are useful for discriminating environments.

Cucurbitella tricuspis **dominates most samples and had to be deleted from analysis to determine benthic faunal relationships. This species is seasonally planktic and thus readily transported; it should not be considered in intralake studies.** ***Arcella vulgaris*** **overwhelmingly dominates extremely hostile low pH environments (<5.5) near the old mine site in samples where Shannon Diversity Index values of <1.000 are recorded. The highly variable pH in James Lake permitted the determination of precise boundary conditions for distribution of this species. These results indicate that** ***Difflugia protaeiformis*** **"claviformis" is an ideal indicator of industrial contamination under higher pH conditions. The** ***D. protaeiformis*** **"amphoralis" and "acuminata" strains are more closely linked to uncontaminated muddy substrates characterized by high proportions of diatoms, a probable important food source. The presence of** ***Lesquerasia spiralis*** **seems to be partially linked to substrate type with greater numbers typically found in coarser sediments.**

INTRODUCTION

The utility of arcellaceans (thecamoebians) as sensitive paleoenvironmental indicators has been widely demonstrated (Medioli and Scott, 1988; Patterson and others, 1996; Reinhardt and others, 1998). Particularly significant have been studies in Canada and Italy that have linked various arcellacean faunas and pollution levels (Asioli and others, 1996; Patterson and Kumar, 2000). These studies show that various arcellacean species are differentially affected by industrial pollutants. In addition, there is increased intraspecific variability in these asexually reproducing organisms in response to environmental stresses (Reinhardt and others, 1998; see Kumar and Dalby, 1998, for a complete illustrated guide). Because they reproduce rapidly (generation times of only a few days), they are excellent ongoing indicators of an ecosystem's health. Their agglutinated tests preserve well making them useful for recognizing long-term temporal variation in environmental parameters.

James Lake in northeastern Ontario, provides a unique opportunity for assessing the sensitivity of arcellaceans to industrial pollutants as most small lakes in natural settings are characterized by only a single environment (Smol, 1992). Paleolimnological studies therefore usually require proxy data collected from several lakes, each characterized by distinct environmental conditions and fauna. However, in James Lake the flow of lake water from north to south, exiting near the pollution point source at the old mine site, has created habitats that range from unimpacted conditions in the northern basin to extremely contaminated conditions near the mine site itself. The gradation of environmental conditions in James Lake permits the more precise assessment of the limiting factors that control arcellacean distribution and individual taxa.

James Lake has been impacted by the dumping of waste rock from a pyrite mine (Fig. 1). Adjacent to the mine, high levels of Fe, Al, SO_4, and low pH values (2.0–5.5) are recorded, whereas near neutral pH and low metal levels predominate elsewhere in the lake. Kumar and Patterson (2000) have previously determined that one species, *Arcella vulgaris,* is able to thrive in even the most hostile low-pH areas of the lake. The low-pH parts of James Lake lack arcellacean taxa such as centropyxids and *Difflugia protaeiformis,* strains that normally populate contaminated substrates in higher pH lakes, suggesting that pH is the dominant control on faunal distribution adjacent to the mine site.

The long narrow shape and prevailing current direction in the lake result in the restriction of contaminated areas to the southwestern portion of the lake. In this paper we document the distribution of arcellacean assemblages in this ideal natural laboratory where conditions grade from uncontaminated and near neutral pH conditions in the north to extremely contaminated and low pH conditions in the south. These results will permit a more precise determination of the conditions that constrain the distribution of arcellacean species, strains and assemblages.

JAMES LAKE PHYSIOGRAPHY AND GEOCHEMISTRY

James Lake is a narrow curved lake, elongated in a north-south direction, covering an area of 45.3[2] hectares along Highway 11 north of Temagami in northeastern Ontario (Fig. 1). This mesotrophic lake is fed by an inlet stream at the north end and drained by an outlet stream at the south end. The lake is divided into northern (80%) and southern (20%) basins separated by a narrows. The smaller southern basin is quite shallow, reaching a maximum depth of only

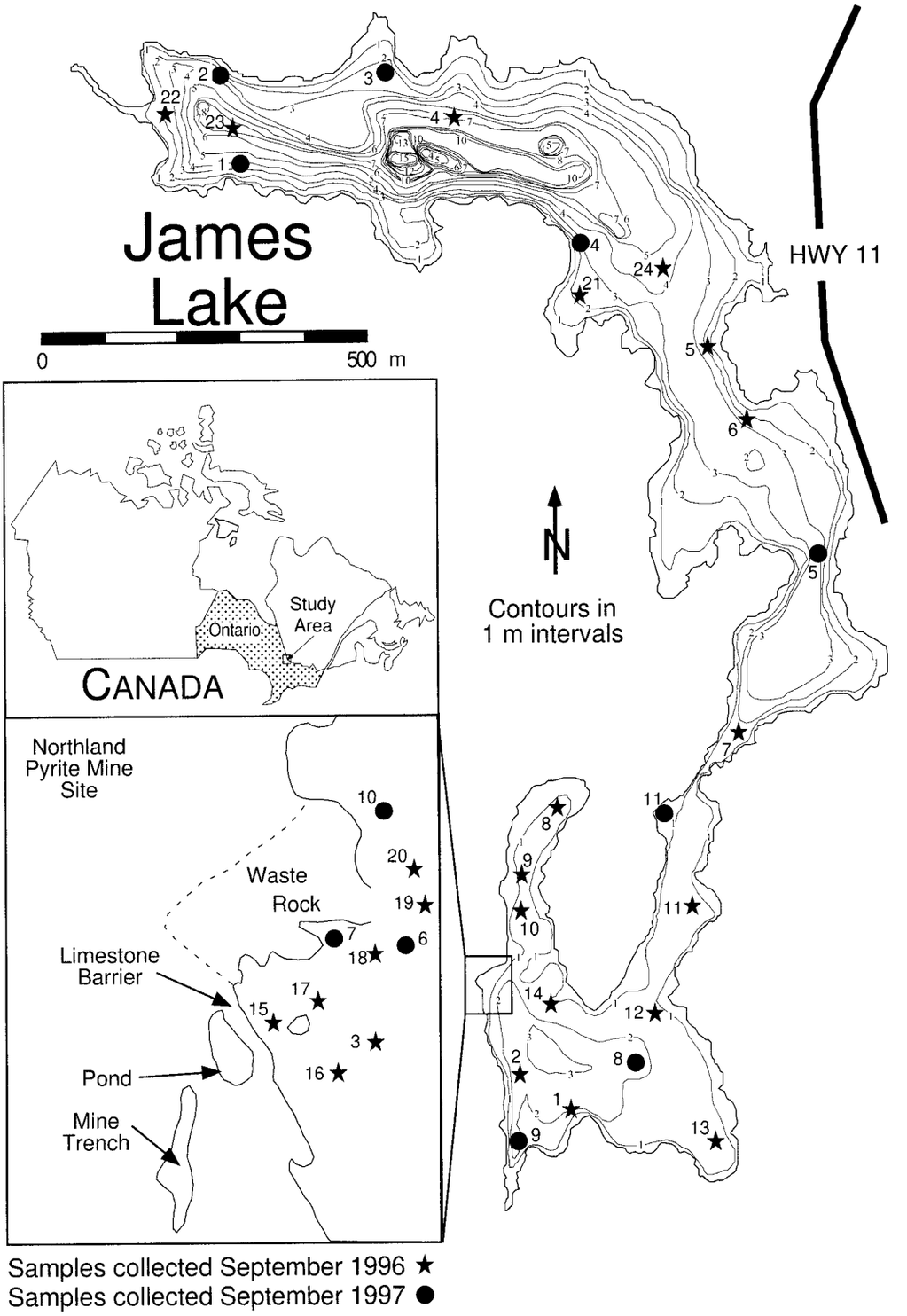

FIGURE 1. Location Map showing position of James Lake in northeastern Ontario. Bathymetric map of lake shows relative position of sample and core stations as well as general layout of abandoned Northland Pyrite Mine Co. site.

4.0 m. The northern basin with a maximum depth of 15.0 m (Fig. 1) is sufficiently deep for summer stratification to occur. Both oxygen levels and temperature drop significantly below 5.0 m water depth. Temperature and oxygen levels in the upper epilimnion are 25° C and 9.0 mg/L, respectively during summer. Temperature and oxygen concentration drops to 10° C and 2.0 mg/L respectively in the lower hypolimnion.

The Keewatin age volcanic rocks along the southwest shore of the lake are quite rich in massive sulfides, particularly pyrite. Massive lenses of pyrite were discovered within soft green schists in 1903. From February 1906, to March 1911 the Northland Pyrite Mine Co. shipped more than 38,000 tons of pyrite to Cobalt. Most mine waste rock (about 3,500 m^3 containing 25% pyrite with lesser amounts of pyrrhotite and traces of chalcopyrite and gold) was dumped on the southwest lakeshore, resulting in the acidification of the adjacent lake water and bottom sediments. The flow of rain water also leaches sulfate from the pyrite and pyrrhotite present in the waste rock.

A Ministry of the Environment (MOE) study in 1989 (Gale, 1990) found that three key water quality parameters (iron, aluminum and sulfate) exceeded provincial guidelines. The results of our geochemical analysis also indicate that the concentration of these three parameters in pore waters also exceed provincial guidelines.

In areas near the waste rock pile, sulfate concentrations in the sediment are extremely high, up to 7500 μg/g. Sulfate ions and hydrogen ions from water interact to produce sulfuric acid. Localized bacterial reduction of some sulfate to H_2S may also contribute to development of a benthic environment that is toxic to many aquatic invertebrates (Environment Canada, 1979). During our sampling we observed a gradation from a low of pH (2.0) in some bottom sediments adjacent to the waste rock piles to almost neutral conditions (pH 6.8) in more distant areas of the southern basin of the lake. The position of the outlet stream immediately adjacent to the mine site coupled with the overall north-south flow of water in the lake helps maintain this gradient.

Several metals, most notably Al and Fe, are being leached out of the waste rock. Aluminum concentrations in pore water varied between 0.19 mg/L to 415 mg/L near the waste rock pile. Aluminum values in the lake water itself varied from 0.24 mg/L near the waste rock pile to 0.05 mg/L in the northern basin (Gale, 1990). Although aluminum is not essential for survival it is found in almost all plant and animal species. Aluminum complexes into relatively stable forms mostly unabsorbable by organisms in higher pH regimes (Plankey and Patterson, 1987, 1988). However, in lower pH environments (<pH 5.5) like that found in the southern basin of James Lake aluminum mobilizes into biologically useable forms (Burrows, 1977). There are differing opinions as to the degree of hazard posed by aluminum in drinking water. Thus the guidelines for control of aluminum are highly variable. However, 0.2 mg/L seems to be the maximum allowable concentration agreed to by most agencies (Moore, 1991). In Canada and several European nations the guidelines for the protection of aquatic life are 0.1 mg/L at pH $>$ 6.5 and 0.005 mg/L at pH $<$ 6.5 (Burrows, 1977).

Sediment pore water iron levels vary from a high of 11,800 mg/L near the waste rock pile to only 1.52 mg/L in the northern basin (Table 1). Iron concentration in lake water varies from 0.09 mg/L in the northern basin to 2.4 mg/L near the waste rock pile (Gale, 1990). The pH of the lake water rises to nearly neutral values throughout the lake during freshet and particularly during spring turnover (Gale, 1990). When near neutral water found in most parts of the lake mixes with acidic, metal-laden water near the waste dump, the metal precipitates out as iron hydroxide (FeOH). All measured pore water and lake water iron concentrations were found to be well in excess of the maximum value (0.3 mg/L) set by the Ontario provincial drinking water guideline. Iron is so plentiful in the environment that very high levels often accumulate in invertebrates. Since iron is an essential trace element, a certain amount of bioconcentration can occur with little ill effect and others, (Vymazal, 1984; Tessier, 1984). Low drinking water guidelines are based primarily on aesthetics rather than any serious health concerns. Although guidelines for the protection for aquatic life range from 0.3 mg/L to 1.0 mg/L their tolerance is much higher (>10 mg/L; Moore, 1991). The observation by both Gale (1990) and ourselves of a large number of vertebrates (fish and amphibians) in the southern basin, corroborates this finding.

TABLE 1. Pore-water pH and geochemistry values for Al, Fe and sulfate in mg/L from selected sample stations. Al and Fe values determined by microwave digestion for inductively coupled plasma atomic emission spectroscopy (ICP-AES) and granite furnace atomic absorption spectroscopy (GFAAS, 26 element scan). Sulfate values were determined by ion chromatography.

Sample	pH	Al (mg/L)	Fe (mg/L)	Sulfate (mg/L)
JL 97-2	6.73	0.46	2.44	7.5
JL 97-3	6.51	0.38	2.84	7.5
JL 97-4	6.55	0.37	2.36	9.2
JL 97-5	6.33	0.19	1.52	12.4
JL 97-6	2.49	64	1240	2884
JL 97-7	2.12	415	11800	17238
JL 97-8	6.24	1.11	59.7	9.9
JL 97-9	5.56	0.94	64.9	25.2
JL 97-10	2.69	146	6200	682
JL 97-11	6.31	0.43	14.3	18.8
JL 97-12	2.07	155.5	4190	668
JL 97-15	3.46	1.13	32.4	396

MATERIALS AND METHODS

FIELD AND LABORATORY

Thirty-five samples collected over two field seasons were used in this study. Twenty-four samples were collected from James Lake in September 1996 and eleven additional samples were collected in September 1997 (Fig. 1). Sediment-water interface samples were collected using an Eckman box corer. Fractional abundance of each species, water depth, sedimentology, pH, water temperature, and other physical characteristics were recorded for each location (Table 2). The exact geographic location of each sample was determined using a Trimble Scout Global Positioning System unit and corroborated by triangulating with landmarks on the shoreline.

A commercial sonar device (fish finder) equipped with bottom hardness indicator was used for sample site selection. Where possible samples were collected from muddy substrates, as winnowed sandy substrates generally have only small allochthonous arcellacean communities and rocky substrates are normally barren.

The upper few mm of sediment from each Eckman grab were removed to isolate the epifaunal arcellacean fauna inhabiting the sediment-water interface. Samples for micro-

TABLE 2. Arcellacean occurrences in samples from James Lake. Samples were quantitatively analyzed and are recorded as fractional abundances. Total counts, water depth, assemblage designation, Shannon Diversity, and various other physiographic parameters are also indicated.

Sample	JL96-1	JL96-2	JL96-3	JL96-4	JL96-5	JL96-6	JL96-7	JL96-8	JL96-9	JL96-10	JL96-11	JL96-12	JL96-13	JL96-14	JL96-15	JL96-16	JL96-17	JL96-18	JL96-19	JL96-20	JL96-21	JL96-22	JL96-23	JL96-24	JL97-1	JL97-2	JL97-3	JL97-4	JL97-5	JL97-6	JL97-7	JL97-8	JL97-9	JL97-10	JL97-11
Total Count	221	201	271	531	515	513	505	310	328	325	315	311	346	305	339	410	172	311	310	307	306	541	348	312	326	348	306	318	347	147	507	352	329	89	363
Specimens/cc	74	67	90	177	344	228	224	207	128	130	210	138	230	205	226	136	58	124	207	205	204	541	233	208	218	232	153	318	232	294	507	235	132	178	242
Shannon Diversity	2.422	0.784	0.718	1.402	2.339	2.256	2.439	2.348	2.097	0.772	2.354	2.364	2.302	2.351	0.719	0.803	0.625	0.912	0.542	1.466	2.392	2.358	1.629	2.196	2.393	2.400	2.483	2.426	2.487	0.615	1.572	2.398	2.462	0.454	2.321
Number of Species	16	6	4	16	18	16	17	17	18	5	18	18	19	19	5	11	3	10	2	11	19	18	14	17	17	19	20	19	20	3	11	20	17	2	18
Assemblage	3	2	1	—	4	3	3	5	5	2	3	3	3	3	1	2	1	1	1	2	3	3	—	4	—	3	5	5	5	1	2	5	5	1	6
Water Depth (m)	1.8	2.6	0.9	9.8	4.2	2.4	1	1.8	1.4	0.6	1.4	0.9	1.1	1.1	1.3	0.8	1	0.8	1.3	0.7	1	3	6.7	5.5	7.8	3	3.9	3.1	3.5	1.4	0.7	1.4	1.6	1.1	1.5
Sediment/Water Interface pH	6.7	3.9	3.9	7.1	6.9	7.3	6.5	6.9	6.5	2.5	6.5	6.6	6.7	6.7	2.6	2.1	4.1	5.3	5.5	2.2	6.4	6.7	—	6.7	6.7	7	7.3	7.3	6.6	5.7	4.3	6.6	6.1	4.4	6.4
Sediment/Water Interface O2	8.2	5.6	6.9	1.4	7.5	7.4	7.1	6	7.3	7.4	7.2	7.4	7.4	7.4	6.9	6.1	7.4	6.9	5.9	5.2	6.8	7.3	8.9	7.2	2.4	—	8.1	8.1	8.6	8.8	8.4	8.1	8.2	7.9	8
Sediment/Water Interface Temperature	20.7	20.4	21	6.7	20.3	20.8	20.8	21.3	21.4	21.5	21.5	22.3	21.5	22.5	22.9	23.4	23.4	23.7	23.9	25	22.7	20.7		19	—	17.5	17.1	17.7	17.1	16.8	17.1	17	—	—	18
Sediment Texture	Mud	Mud	Mud	Slt/Md	Mud	Mud	Slt/Md	Mud	Slt/Md	Snd/Md	Slt/Md	Snd/Md	Snd/Md	Mud	Slt/Md	Snd/Md	Silt	Snd/Md	Mud	Mud	Mud	Mud	Mud	Mud	Mud	Mud	Slt/Md	Fn Snd	Fn Snd	Mud	Mud	Mud	Mud	Phls Md	Slt/Md
Arcella vulgaris	13	68	158	14	4	5	3	12	9	155	4	1	2	1	216	59	117	189	238	35	1	1	26	7	32	3	12	11	6	107	129	5	15	74	5
Fractional Abundance	0.059	0.338	0.583	0.026	0.008	0.010	0.006	0.039	0.027	0.477	0.013	0.003	0.006	0.003	0.637	0.144	0.680	0.608	0.768	0.114	0.003	0.002	0.075	0.022	0.098	0.009	0.039	0.035	0.017	0.728	0.254	0.014	0.046	0.831	0.014
standard error (±)	0.031	0.065	0.059	0.014	0.008	0.009	0.007	0.021	0.018	0.054	0.012	0.006	0.008	0.006	0.051	0.034	0.070	0.054	0.047	0.036	0.006	0.004	0.028	0.016	0.032	0.010	0.022	0.020	0.014	0.072	0.038	0.012	0.023	0.078	0.012
***Centropyxis aculeata* "aculeata"**	7	1	0	11	6	11	25	22	29	1	21	20	12	17	0	5	0	1	0	34	19	24	11	4	20	21	10	20	9	0	29	19	15	0	90
Fractional Abundance	0.032	0.005	0.000	0.021	0.012	0.021	0.050	0.071	0.088	0.003	0.067	0.064	0.035	0.056	0.000	0.012	0.000	0.003	0.000	0.111	0.062	0.044	0.032	0.013	0.061	0.060	0.033	0.063	0.026	0.000	0.057	0.054	0.046	0.000	0.248
standard error (±)	0.023	0.010	0.000	0.012	0.009	0.013	0.019	0.029	0.031	0.006	0.028	0.027	0.019	0.026	0.000	0.011	0.000	0.006	0.000	0.035	0.027	0.017	0.018	0.012	0.026	0.025	0.020	0.027	0.017	0.000	0.020	0.024	0.023	0.000	0.044
***Centropyxis aculeata* "discoides"**	15	2	0	11	21	36	44	12	8	0	21	14	34	20	0	1	0	3	0	16	32	74	16	9	37	12	20	13	14	0	10	41	37	0	54
Fractional Abundance	0.068	0.010	0.000	0.021	0.041	0.070	0.087	0.039	0.024	0.000	0.067	0.045	0.098	0.066	0.000	0.002	0.000	0.010	0.000	0.052	0.105	0.137	0.046	0.029	0.113	0.034	0.065	0.041	0.040	0.000	0.020	0.116	0.112	0.000	0.149
standard error (±)	0.033	0.014	0.000	0.012	0.017	0.022	0.025	0.021	0.017	0.000	0.028	0.023	0.031	0.028	0.000	0.005	0.000	0.011	0.000	0.025	0.034	0.029	0.022	0.019	0.034	0.019	0.028	0.022	0.021	0.000	0.012	0.034	0.034	0.000	0.037
***Centropyxis constricta* "spinosa"**	3	0	0	7	1	0	0	2	5	1	4	4	6	3	0	3	2	0	0	2	8	2	1	1	0	1	1	1	0	0	0	0	0	0	0
Fractional Abundance	0.014	0.000	0.000	0.013	0.002	0.000	0.000	0.006	0.015	0.003	0.013	0.013	0.017	0.010	0.000	0.007	0.012	0.000	0.000	0.007	0.026	0.004	0.003	0.003	0.000	0.003	0.003	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error (±)	0.015	0.000	0.000	0.010	0.004	0.000	0.000	0.009	0.013	0.006	0.012	0.013	0.014	0.011	0.000	0.008	0.016	0.000	0.000	0.009	0.018	0.005	0.006	0.006	0.000	0.006	0.006	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
***Centropyxis constricta* "constricta"**	29	0	0	0	29	38	24	16	15	0	27	15	40	18	0	0	0	0	0	0	19	29	0	12	14	19	20	15	16	0	0	30	7	0	15
Fractional Abundance	0.131	0.000	0.000	0.000	0.056	0.074	0.048	0.052	0.046	0.000	0.086	0.048	0.116	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.062	0.054	0.000	0.038	0.043	0.055	0.065	0.047	0.046	0.000	0.000	0.085	0.021	0.000	0.041
standard error (±)	0.045	0.000	0.000	0.000	0.020	0.023	0.019	0.025	0.023	0.000	0.031	0.024	0.034	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.019	0.000	0.021	0.022	0.024	0.028	0.023	0.022	0.000	0.000	0.029	0.016	0.000	0.020
***Centropyxis constricta* "aerophila"**	14	0	0	0	4	0	2	1	5	0	7	9	8	5	0	0	0	0	0	0	7	13	2	1	7	0	3	4	6	0	7	9	15	0	6
Fractional Abundance	0.063	0.000	0.000	0.000	0.008	0.000	0.004	0.003	0.015	0.000	0.022	0.029	0.023	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.024	0.006	0.003	0.021	0.000	0.010	0.013	0.017	0.000	0.014	0.026	0.046	0.000	0.017
standard error (±)	0.032	0.000	0.000	0.000	0.008	0.000	0.005	0.006	0.013	0.000	0.016	0.019	0.016	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.013	0.008	0.006	0.016	0.000	0.011	0.012	0.014	0.000	0.010	0.016	0.023	0.000	0.013
Cucurbitella tricuspis	20	126	107	343	82	84	81	96	127	162	63	69	52	77	119	316	53	107	72	169	46	21	194	62	81	31	61	73	71	38	237	96	99	15	48
Fractional Abundance	0.090	0.627	0.395	0.646	0.159	0.164	0.160	0.310	0.387	0.498	0.200	0.222	0.150	0.252	0.351	0.771	0.308	0.344	0.232	0.550	0.150	0.039	0.557	0.199	0.248	0.089	0.199	0.230	0.205	0.259	0.467	0.273	0.301	0.169	0.132
standard error (±)	0.038	0.067	0.058	0.041	0.032	0.032	0.032	0.051	0.053	0.054	0.044	0.046	0.038	0.049	0.051	0.041	0.069	0.053	0.047	0.056	0.040	0.016	0.052	0.044	0.047	0.030	0.045	0.046	0.042	0.071	0.043	0.047	0.050	0.078	0.035
Difflugia corona	7	1	2	2	11	8	14	12	3	4	14	11	8	12	0	3	0	1	0	0	4	11	2	3	11	1	8	8	10	1	8	10	11	0	1
Fractional Abundance	0.032	0.005	0.007	0.004	0.021	0.016	0.028	0.039	0.009	0.012	0.044	0.035	0.023	0.039	0.000	0.007	0.000	0.003	0.000	0.000	0.013	0.020	0.006	0.010	0.034	0.003	0.026	0.025	0.029	0.007	0.016	0.028	0.033	0.000	0.003
standard error (±)	0.023	0.010	0.010	0.005	0.012	0.011	0.014	0.021	0.010	0.012	0.023	0.021	0.016	0.022	0.000	0.008	0.000	0.006	0.000	0.000	0.013	0.012	0.008	0.011	0.020	0.006	0.018	0.017	0.018	0.013	0.011	0.017	0.019	0.000	0.005
***Difflugia oblonga* "glans"**	30	0	0	41	50	49	59	27	27	0	35	35	36	33	0	5	0	2	0	2	31	85	13	31	15	22	23	19	24	0	0	37	27	0	21
Fractional Abundance	0.136	0.000	0.000	0.077	0.097	0.096	0.117	0.087	0.082	0.000	0.111	0.113	0.104	0.108	0.000	0.012	0.000	0.006	0.000	0.007	0.101	0.157	0.037	0.099	0.046	0.063	0.075	0.060	0.069	0.000	0.000	0.105	0.082	0.000	0.058
standard error (±)	0.045	0.000	0.000	0.023	0.026	0.025	0.028	0.031	0.030	0.000	0.035	0.035	0.032	0.035	0.000	0.011	0.000	0.009	0.000	0.009	0.034	0.031	0.020	0.033	0.023	0.026	0.030	0.026	0.027	0.000	0.000	0.032	0.030	0.000	0.024
***Difflugia oblonga* "lineatis"**	5	0	2	1	7	17	5	0	1	0	9	1	12	2	0	1	0	0	0	0	12	32	1	6	0	8	1	0	1	0	0	1	0	0	0
Fractional Abundance	0.023	0.000	0.007	0.002	0.014	0.033	0.010	0.000	0.003	0.000	0.029	0.003	0.035	0.007	0.000	0.002	0.000	0.000	0.000	0.000	0.039	0.059	0.003	0.019	0.000	0.023	0.003	0.000	0.003	0.000	0.000	0.003	0.000	0.000	0.000
standard error (±)	0.020	0.000	0.010	0.004	0.010	0.015	0.009	0.000	0.006	0.000	0.018	0.006	0.019	0.009	0.000	0.005	0.000	0.000	0.000	0.000	0.022	0.020	0.006	0.015	0.000	0.016	0.006	0.000	0.006	0.000	0.000	0.006	0.000	0.000	0.000
***Difflugia oblonga* "bryophila"**	29	0	0	9	34	129	81	30	14	0	35	36	50	32	0	0	0	2	0	0	32	85	0	17	3	37	7	12	3	0	0	13	1	0	5
Fractional Abundance	0.131	0.000	0.000	0.017	0.066	0.251	0.160	0.097	0.043	0.000	0.111	0.116	0.145	0.105	0.000	0.000	0.000	0.006	0.000	0.000	0.105	0.157	0.000	0.054	0.009	0.106	0.023	0.038	0.009	0.000	0.000	0.037	0.003	0.000	0.014
standard error (±)	0.045	0.000	0.000	0.011	0.021	0.038	0.032	0.033	0.022	0.000	0.035	0.036	0.037	0.034	0.000	0.000	0.000	0.009	0.000	0.000	0.034	0.031	0.000	0.025	0.010	0.032	0.017	0.021	0.010	0.000	0.000	0.020	0.006	0.000	0.012
***Difflugia oblonga* "oblonga"**	6	0	0	7	17	13	18	5	2	0	6	3	7	5	1	0	0	0	0	9	9	37	2	0	0	81	12	1	11	0	22	4	6	0	0
Fractional Abundance	0.027	0.000	0.000	0.013	0.033	0.025	0.036	0.016	0.006	0.000	0.019	0.010	0.020	0.016	0.003	0.000	0.000	0.000	0.000	0.029	0.039	0.068	0.006	0.000	0.000	0.233	0.039	0.003	0.032	0.000	0.043	0.011	0.018	0.000	0.000
standard error (±)	0.021	0.000	0.000	0.010	0.015	0.014	0.016	0.014	0.008	0.000	0.015	0.011	0.015	0.014	0.006	0.000	0.000	0.000	0.000	0.019	0.019	0.021	0.008	0.000	0.000	0.044	0.022	0.006	0.018	0.000	0.018	0.011	0.014	0.000	0.000
***Difflugia oblonga* "spinosa"**	0	0	0	3	9	9	8	4	0	0	1	0	1	3	0	0	0	0	0	0	5	12	0	3	3	17	1	2	4	0	0	5	4	0	3
Fractional Abundance	0.000	0.000	0.000	0.006	0.017	0.018	0.016	0.013	0.000	0.000	0.003	0.000	0.003	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.022	0.000	0.010	0.009	0.049	0.003	0.006	0.012	0.000	0.000	0.014	0.012	0.000	0.008
standard error (±)	0.000	0.000	0.000	0.006	0.011	0.011	0.011	0.013	0.000	0.000	0.006	0.000	0.006	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.012	0.000	0.011	0.010	0.023	0.006	0.009	0.011	0.000	0.000	0.012	0.012	0.000	0.009
***Difflugia protaeiformis* "acuminata"**	3	0	0	21	29	26	37	20	26	0	12	16	7	14	1	1	0	3	0	4	20	23	19	17	8	19	24	37	26	0	8	10	20	0	17
Fractional Abundance	0.014	0.000	0.000	0.040	0.056	0.051	0.073	0.065	0.079	0.000	0.038	0.051	0.020	0.046	0.003	0.002	0.000	0.010	0.000	0.013	0.065	0.043	0.055	0.054	0.025	0.055	0.078	0.116	0.075	0.000	0.016	0.028	0.061	0.000	0.047
standard error (±)	0.015	0.000	0.000	0.017	0.020	0.019	0.023	0.027	0.029	0.000	0.021	0.025	0.015	0.023	0.006	0.005	0.000	0.011	0.000	0.013	0.028	0.017	0.024	0.025	0.017	0.024	0.030	0.035	0.028	0.000	0.011	0.017	0.026	0.000	0.022
***Difflugia protaeiformis* "amphoralis"**	0	0	0	17	122	28	36	5	10	0	11	19	9	8	0	0	0	1	0	0	8	6	28	69	13	8	23	22	33	0	0	3	11	0	16
Fractional Abundance	0.000	0.000	0.000	0.032	0.237	0.055	0.071	0.016	0.030	0.000	0.035	0.061	0.026	0.026	0.000	0.000	0.000	0.003	0.000	0.000	0.026	0.011	0.080	0.221	0.040	0.023	0.075	0.069	0.095	0.000	0.000	0.009	0.033	0.000	0.044
standard error (±)	0.000	0.000	0.000	0.015	0.037	0.020	0.022	0.014	0.019	0.000	0.020	0.027	0.017	0.018	0.000	0.000	0.000	0.006	0.000	0.000	0.018	0.009	0.029	0.046	0.021	0.016	0.030	0.028	0.031	0.000	0.000	0.010	0.019	0.000	0.021
***Difflugia protaeiformis* "claviformis"**	7	0	0	8	21	8	9	15	13	0	0	9	6	8	0	0	0	0	0	3	17	20	12	41	8	14	17	3	15	0	0	4	12	0	10
Fractional Abundance	0.032	0.000	0.000	0.015	0.041	0.016	0.018	0.048	0.040	0.000	0.000	0.029	0.017	0.026	0.000	0.000	0.000	0.000	0.000	0.010	0.056	0.037	0.034	0.131	0.025	0.040	0.056	0.009	0.043	0.000	0.000	0.011	0.036	0.000	0.028
standard error (±)	0.023	0.000	0.000	0.010	0.017	0.011	0.012	0.024	0.021	0.000	0.000	0.019	0.014	0.018	0.000	0.000	0.000	0.000	0.000	0.011	0.026	0.016	0.019	0.037	0.017	0.021	0.026	0.011	0.021	0.000	0.000	0.011	0.020	0.000	0.017
Difflugia urceolata	25	0	0	1	13	11	12	12	10	0	17	13	20	17	0	5	0	0	0	1	7	50	0	3	19	13	7	13	20	0	0	25	12	0	13
Fractional Abundance	0.113	0.000	0.000	0.002	0.025	0.021	0.024	0.039	0.030	0.000	0.054	0.042	0.058	0.056	0.000	0.012	0.000	0.000	0.000	0.003	0.023	0.092	0.000	0.010	0.058	0.037	0.023	0.041	0.058	0.000	0.000	0.071	0.036	0.000	0.036
standard error (±)	0.042	0.000	0.000	0.004	0.014	0.013	0.013	0.021	0.019	0.000	0.025	0.022	0.025	0.026	0.000	0.011	0.000	0.000	0.000	0.006	0.017	0.024	0.000	0.011	0.025	0.020	0.017	0.022	0.025	0.000	0.000	0.027	0.020	0.000	0.019
Lagenodifflugia vas	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	6	8	15	21	0	11	22	13	0	34
Fractional Abundance	0.018	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	0.000	0.000	0.000	0.020	0.014	0.018	0.023	0.025	0.000	0.013	0.025	0.021	0.000	0.030
standard error (±)	0.018	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	0.000	0.000	0.000	0.020	0.014	0.018	0.023	0.025	0.000	0.013	0.025	0.021	0.000	0.030
Lesquerasia spiralis	4	1	0	34	51	39	46	19	19	0	25	31	27	24	2	11	0	2	0	32	25	17	21	26	36	31	39	46	50	0	46	17	34	0	21
Fractional Abundance	0.018	0.005	0.000	0.064	0.099	0.076	0.091	0.061	0.058	0.000	0.079	0.100	0.078	0.079	0.006	0.027	0.000	0.006	0.000	0.104	0.082	0.031	0.060	0.083	0.110	0.089	0.127	0.145	0.144	0.000	0.091	0.048	0.103	0.000	0.058
standard error (±)	0.018	0.010	0.000	0.021	0.026	0.023	0.025	0.027	0.025	0.000	0.030	0.033	0.028	0.030	0.008	0.016	0.000	0.009	0.000	0.034	0.031	0.015	0.025	0.031	0.034	0.030	0.037	0.039	0.037	0.000	0.025	0.022	0.033	0.000	0.024

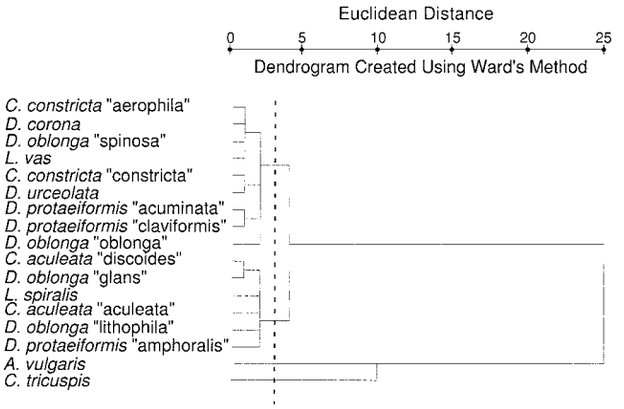

FIGURE 2. R-Mode Cluster Analysis results dividing species into groupings.

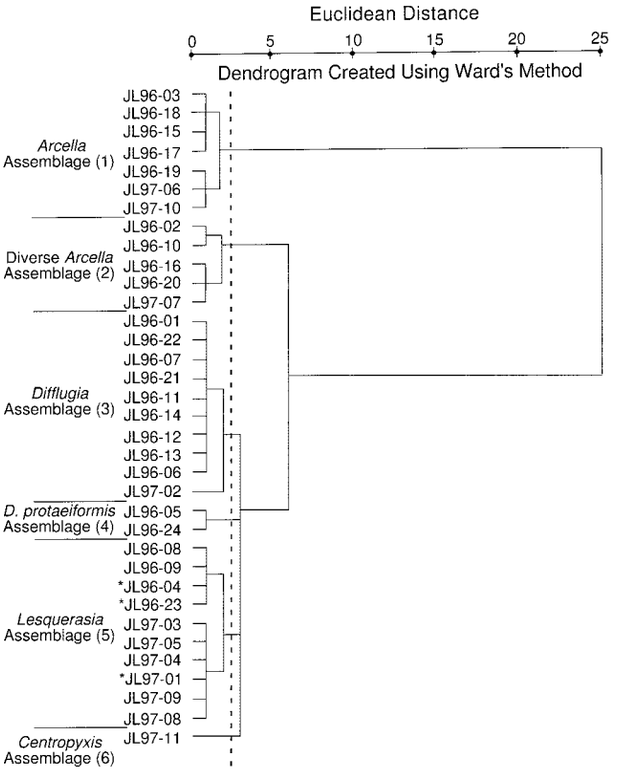

FIGURE 3. Q-Mode Cluster Analysis results dividing samples into 6 distinct groupings as indicated by the dashed line. Distinct clusters of samples with correlation coefficients greater than a subjectively selected level were considered biofacies.

paleontological analysis were first screened with a 1000 μm sieve to remove coarse organic materials, then with a 55 μm screen to retain arcellaceans and to remove silt and clay. All samples were treated with isopropyl alcohol and refrigerated after collection to avoid decay. Samples were subdivided into aliquots for quantitative analysis using a wet splitter (Scott and Hermelin, 1993). Wet aliquots were examined under a binocular microscope and, whenever possible, a statistically significant number of arcellaceans were counted (Patterson and Fishbein, 1989).

A 1 cm deep sediment sample was collected in 10 of the samples collected in 1997 and used for geochemical analysis of pore water (Table 1). The compounds and elements found in pore water are in forms that can be directly ingested and absorbed by most organisms and thus provide results that can be more directly compared to the observed fauna than those obtained from bulk geochemical analyses (Luoma, 1983; Campbell, 1995).

Quantitative Analytical Procedures

The nineteen observed arcellacean species and strain data (Table 2) were converted into fractional abundances, and standard errors were calculated according to the formula proposed by Patterson and Fishbein (1989):

$$SXi = [Xi(1 - Xi)/N]½ \quad (1)$$

where SXi is the standard error; Xi is the estimated fractional abundance for each i = 1,2,3. . ...; I species, where I = the total number of species in the sample; i is each species; and N is the total number of specimens counted in a sample. When making N counts, the actual fractional abundance f_i lies between,

$$X_i - 1.96S_{Xi} \leq fi \leq Xi + 1.96S_{Xi} \quad (2)$$

95% of the time. Therefore, the 95% confidence interval on the estimated fractional abundances is $X_i + 1.96S_{Xi}$. The standard error for samples having no specimens of a particular species was calculated using the standard error equation ((SXi); see Mosteller and others, 1970):

$$S_{Xi} = 1 - (0.051/N) \quad (3)$$

All samples contained statistically significant numbers of arcellaceans (Table 2; see Patterson and Fishbein, 1989). Statistically significant taxa were subjectively determined to be those with abundances equal to the standard error ±1% at the 95% confidence level in at least one sample. One arcellacean strain *Centropyxis constricta* 'spinosa' was present in statistically insignificant numbers and was therefore not utilized in cluster analysis (Figs. 2, 3). *Cucurbitella tricuspis* was very abundant in almost all samples. The presence of this species, known to have a planktic phase is not always indicative of lake bottom conditions (Schönborn, 1984; Patterson and others, 1985; Medioli and others, 1987; Collins and others, 1990). As the purpose of this research is to characterize benthic environments the Q-mode cluster analysis was carried out with *C. tricuspis* abundance data excluded (Fig. 3).

Q-mode cluster analysis was carried out on arcellacean data to group samples with similar species distributions. Samples grouped in this fashion are considered representative of a particular environment or biofacies.

Q-mode clustering of the reduced data sets was done on an Apple Macintosh computer using the SPSS v.5.2 statistical software package and Ward's minimum variance method. The results of the cluster analysis were reported as Euclidean distances and arranged in hierarchical dendrograms (Figs. 2, 3). The dendrograms were used to define sample and faunal associations. This methodology simulates a statistically based Error-Weighted Maximum Likelihood

TABLE 3. Mean fractional abundances and various parameters characterizing the six arcellacean assemblages identified in James Lake.

Species/Sample Assemblage	*Arcella* Assemblage (1)	Diverse *Arcella* Assemblage (2)	*Difflugia* Assemblage (3)	*Difflugia protaeiformis* Assemblage (4)	*Lesquerasia* Assemblage (5)	*Centropyxis* Assemblage (6)
Water Depth (m)	1.1	1.1	1.7	4.9	2.4	1.5
Sed/water Interface pH	4.5	3.0	6.7	6.8	6.8	6.4
Sed/water Interface O2	7.2	6.5	7.4	7.4	7.8	8
Sed/water Interface Temperature	22.0	21.5	21.1	19.7	18.6	18
Shannon Diversity Index	0.655	1.079	2.364	2.268	2.386	2.321
Arcella vulgaris	0.691	0.266	0.011	0.015	0.039	0.014
Centropyxis aculeata ''aculeata''	0.000	0.038	0.049	0.012	0.055	0.248
Centropyxis aculeata ''discoides''	0.001	0.017	0.078	0.035	0.069	0.149
Centropyxis constricta ''constricta''	0.000	0.000	0.073	0.047	0.051	0.041
Centropyxis constricta ''aerophila''	0.000	0.003	0.020	0.005	0.019	0.017
Cucurbitella triscuspis	0.294	0.583	0.152	0.179	0.269	0.132
Difflugia corona	0.002	0.008	0.025	0.015	0.028	0.003
Difflugia oblonga ''glans''	0.001	0.004	0.111	0.098	0.076	0.058
Difflugia oblonga ''bryophila''	0.001	0.000	0.139	0.060	0.032	0.014
Difflugia oblonga ''oblonga''	0.000	0.015	0.048	0.017	0.016	0.000
Difflugia oblonga ''spinosa''	0.000	0.000	0.014	0.014	0.009	0.008
Diffligia protaeiformis ''acuminata''	0.002	0.006	0.046	0.055	0.066	0.047
Difflugia protaeiformis ''amphoralis''	0.000	0.000	0.033	0.229	0.046	0.044
Difflugia protaeiformis ''claviformis''	0.000	0.002	0.027	0.086	0.034	0.028
Difflugia urceolata	0.000	0.003	0.052	0.017	0.045	0.036
Lagenodifflugia vas	0.000	0.004	0.004	0.000	0.034	0.094
Lesquerasia spiralis	0.002	0.045	0.072	0.091	0.100	0.058

(EWML) clustering method fully described by Fishbein and Patterson (1993).

R-Mode Analysis was performed on the 18 ''taxonomic units'' (species and selected strains) (Fig. 2) found in statistically significant numbers (see Patterson and Fishbein, 1989). The methodology employed is the same as for Q-Mode analysis but is performed on ''taxonomic units'' rather than samples. This dendrogram was used to determine which species and strains tend to co-occur, and is another useful method for identifying and assessing faunal associations.

SHANNON DIVERSITY INDEX

The overall diversity of the various assemblages recognized in this study was determined by using the Shannon Diversity Index, defined as $H(S) = -\Sigma p_i * \ln(p_i)$ where p_i is the proportion of the ith species (and/or strains) in the assemblage. The Shannon Diversity Index is a better measure of diversity than numbers of species because it also takes into account the relative proportions of species in the population (Sageman and Bina, 1997).

Healthy arcellacean faunas usually have Shannon Diversity Index values approaching 2.5 and abundances of near 500 specimens/cc. As in most stable climax communities, there is an equitable distribution of species in these healthy environments with none overwhelmingly dominating the fauna. Various strains of *Difflugia oblonga* typically characterize these assemblages.

RESULTS

The results of the R-mode cluster analysis revealed that morphologically defined strains are useful for environmental discrimination in the lake, as strains from the same species often did not cluster together (Fig. 2). Interpretation of the Q-mode cluster analysis resulted in recognition of the following six assemblages, each characterized by a distinct fauna (Fig. 3; Table 3), they are; (1) *Arcella* Assemblage, (2) Higher Diversity *Arcella* Assemblage, (3) *Difflugia* Assemblage, (4) *Difflugia protaeiformis* Assemblage, (5) *Lesquerasia* Assemblage, and (6) *Centropyxis* Assemblage.

DISCUSSION

The result of R-mode cluster analysis clearly demonstrates that morphologically defined strains are useful for environmental discrimination in the lake. If the distribution of strains was not affected by environmental parameters it would be expected that R-mode cluster analysis would have grouped all the strains of one species together. Reinhardt and others (1998) observed similar results in lakes from the nearby Cobalt area of Ontario. By using strains those researchers were able to resolve subenvironments and faunal relationships that were otherwise unrecognizable.

Two species, *C. tricuspis* and *A. vulgaris* clustered distinctly from all the others in the R-mode analysis (Fig. 2). As discussed earlier when tests of the seasonally planktic *C. tricuspis* finally sink they tend to be equitably distributed around lakes in an assortment of environments much different from where they actually lived (Schönborn, 1984; Patterson and others, 1985; Medioli and others, 1987; Collins and others, 1990). This species thus has no distinct association with any particular environment resulting in its isolated position in the R-mode cluster analysis.

Arcella vulgaris clustered distinctly from all other taxa because no other species can survive in appreciable numbers in the low-pH samples where it dominates. *Arcella vulgaris* and *C. tricuspis* form a weak association in the R-mode analysis only because transported planktic *C. tricuspis* specimens often co-occur with *Arcella vulgaris.*

Q-mode cluster analysis resulted in six distinct assemblages. The *Arcella* Assemblage (1), found in seven samples, is restricted to the area immediately adjacent to the mine waste rock pile in the Southern Basin (Tables 2, 3).

With the exception of a large proportion of allochthonous *C. tricuspis* the fauna is almost exclusively comprised of *A. vulgaris*. An extremely hostile habitat is indicated for the stations where this assemblage was identified because of the extremely low diversity faunas identified [mean Shannon Diversity Index value ($\bar{x}$SDI) = 0.655] and generally low abundances.

These samples were found in warm (up to 23.7° C at time of collection) well-oxygenated water (5.9–8.8 mg/l at the sediment water interface) because they were all restricted to relatively shallow water depths (0.9 and 1.4 m) in silt and/or clay environments. Levels of iron and aluminum were very high in samples collected in the vicinity of the waste rock pile (Table 1). However, the most serious ecological constraint at stations where these samples were collected was probably the extremely low pH that varied between 2.6 and 5.7.

The Higher Diversity *Arcella* Assemblage (2) was also overwhelmingly dominated by *A. vulgaris*, (Tables 2, 3). It is also found adjacent to the waste rock pile under conditions similar to those characterizing the *Arcella* Assemblage (1) and under pH conditions as low as 2.1. The only difference between this assemblage and the *Arcella* assemblage is the presence of a low proportion of a few additional taxa (xSDI = 1.079) most notably *Centropyxis aculeata* 'aculeata' and *Lesquerasia spiralis*. Because these assemblages are so similar they will be discussed together.

Arcella vulgaris dominates Assemblages 1 and 2 (90–100%) found in the most contaminated areas of the lake in areas where pH values of 2.1–5.7 were recorded (Table 2). A clue to the observed distribution of *A. vulgaris* can be provided by assessing its distribution in uncontaminated settings. The species is an important component of arcellacean faunas in boggy ponds in the Arctic and further south. The low pH values typical of these ponds has preadapted this species to dominate similar low pH environments. Other indications that pH may be the dominant controlling factor on arcellacean distribution in these assemblages, rather that elevated Al or Fe levels, is the greatly reduced presence of opportunistic centropyxid taxa. In higher pH environments in the Cobalt area strains of species such as *C. aculeata* dominate contaminated substrates (Patterson and others, 1996; Reinhardt and others, 1998).

Also notably missing from the lower pH environments of this lake are any strains of *Difflugia protaeiformis*, although the species is often abundant in portions of James Lake with pH of 6.5–7.5, and in higher pH and highly contaminated areas of Peterson and Crosswise lakes (Reinhardt and others, 1998).

The *Difflugia* Assemblage (3) characterizes 10 samples in relatively shallow water ($\bar{x}$ = 1.7 m) from higher pH areas ($\bar{x}$ = 6.7) of both the southern and northern basin of James Lake on a variety of muddy to silty substrates (Tables 2, 3). The fauna is very diverse and equitably distributed (xSDI = 2.364). Excluding *C. tricuspis* from consideration the fauna is dominated by various strains of *Difflugia oblonga*, most notably *D. oblonga* ''lithophila'' ($\bar{x}$ = 13.9) and *D. oblonga* ''glans'' ($\bar{x}$ = 11.1). Dominance of difflugids is generally associated with high levels of organic content in the substrate (Collins and others, 1990). The high diversity and great abundance of arcelleans found at these sites also indicate an abundant source of organics sufficient to maintain a habitat with high carrying capacity. Variants of this assemblage are common in eutrophic lakes throughout eastern North America (Patterson and others, 1985; Collins and others, 1990; Patterson and others, 1996). The occurrence of very high proportions of *C. tricuspis* in the lake associated with such algal species as *Spyrogyra* known to bloom under eutrophic conditions (Collins and others, 1990), corroborate this assessment.

The *Difflugia protaeiformis* Assemblage (4) was found only in two samples, 96JL5 and 96JL24, in close proximity to each other in the northern part of the lake (Tables 2, 3). The lake substrate consisted of clay at these sites, in the water depth varying between 4.2 and 5.5 m. The sites were well-oxygenated (7.2–7.7 mg/l) with near neutral pH conditions. The arcellacean fauna found in this assemblage was diverse ($\bar{x}$SDI = 2.268), with one strain *D. protaeiformis* ''amphoralis'' ($\bar{x}$ = 22.9%) being dominant, followed by *Lesquerasia spiralis* ($\bar{x}$ = 9.1%), *D. protaeiformis* ''claviformis'' (8.6%) and *D. protaeiformis* ''acuminata'' ($\bar{x}$ = 5.5%). Dominance of *D. protaeiformis* strains in an assemblage has generally been related to either polluted or stressed environments in northern Ontario and Italy (Asioli and others, 1996; Reinhardt and others, 1998). Reinhardt and others (1998) found that *D. protaeiformis* ''claviformis'' comprised nearly 60% of the fauna from highly contaminated raw tailing substrates in Peterson Lake near Cobalt, Ontario. However, water and substrate quality in the northern part of James Lake are very good. It is interesting to note that Reinhardt and others (1998) also reported relatively high proportions of *D. protaeiformis* ''amphoralis'' and *D. protaeiformis* ''acuminata'' (up to 10%) on muddy substrates, particularly those characterized by high numbers of pennate diatoms. The muds where these samples were collected in James Lake also had very high diatom abundances. These results seem to indicate that while high proportions of some strains of *D. protaeiformis* are key indicators of normal pH and highly contaminated conditions, other strains are more characteristic of other parameters. It is plausible that *D. protaeiformis* ''amphoralis'' and *D. protaeiformis* ''acuminata'' preferentially graze on pennate diatoms, and their abundance in this part of the lake is related to ample supplies of a preferred food source.

The *Lesquerasia* Assemblage (5) is quite similar to the *Difflugia* Assemblage in diversity ($\bar{x}$SDI = 2.386), preferred substrate, pH ($\bar{x}$ = 6.8), and distribution in both the southern and northern parts of James Lake (Tables 2, 3). As with the *Difflugia* Assemblage, the high diversity and high specimen counts in this assemblage reflect a high organic content in the substrate. However, the *Lesquerasia* Assemblage is found in slightly deeper water ($\bar{x}$ = 2.4 m) and unlike the *Difflugia* Assemblage no single species is overwhelmingly dominant. The most abundant species is *Lesquerasia spiralis* ($\bar{x}$ = 10.0). Substrate may be an important control over the distribution of this species as highest abundances were associated with sandier substrates. There has unfortunately been very little research done on the distribution of *L. spiralis* with the exception of results indicating that the species prefers temperate lakes and is generally not common in polar regions (Collins and others, 1990).

There were three sample cluster misclassifications asso-

ciated with this Assemblage. Samples 96JL-4, 96JL-23, and 97JL-1 were collected from between 9.8 and 14.1 m of water, well below the thermocline depth (5 m) under very low oxygen (1.4 mg/l) and temperature (7–9° C) conditions. This environment is not conducive to arcellaceans. Faunas examined in similar lakes from beneath the thermocline are invariably of low diversity and depauperate (Patterson and others, 1985; Patterson and others, 1996). The presence of a diverse fauna here probably indicates that some reworking of material from shallower water has occurred.

The *Centropyxis* Assemblage (6) was comprised of only a single sample (97JL-11) from near the narrows separating the northern and southern portions of James Lake in 1.5 m of water under high oxygenation levels (8.0) and near neutral pH (6.4; Tables 2, 3). Although diverse ($\bar{x}$SDI = 2.321) the fauna is overwhelmingly dominated by two strains of *C. aculeata* (*C. aculeata* ''aculeata'' and *C. aculeata* ''discoides''). Centropyxids are opportunistic species and faunas dominated by these species are typically stressed. For example, in the Cobalt region centropyxid-dominated faunas are typical of highly metal-contaminated lake environments under near neutral pH conditions. The presence of this fauna here is enigmatic. This portion of the lake is well away from the contaminated regions of the lake near the mine site and although near a commercial lodge the only potential source of pollutants from that site would be sewage. The influx of organics would have caused a spike in difflugids not centropyxids. Recovery of more than a single sample characterized by this fauna is required to ascertain the validity of this assemblage.

CONCLUSIONS

Morphologically defined strains are useful for environmental discrimination in the lake as shown by R-mode cluster analysis because strains from the same species did not cluster together. Q-mode cluster analysis of the samples resulted in six assemblages. The *Arcella* Assemblage (1) is restricted to the area close to the waste rock pile in the Southern Basin where levels of iron and aluminum were very high, and pH very low (between 2.6 and 5.7). Higher Diversity *Arcella* Assemblage (2) also occurs close to waste rock pile as does the *Arcella* Assemblage (1), but in the areas with pH as low as 2.1. *Arcella vulgaris* dominates Assemblages 1 and 2 (90–100%) found in the most contaminated areas close to the waste rock pile where both aluminum and iron levels were very high. *Difflugia* Assemblage (3) characterizes shallow-water ($\bar{x}$ = 1.7 m) higher-pH ($\bar{x}$ = 6.7) environments rich in organic matter and occurs both in the northern and southern basins of James Lake. *Difflugia protaeiformis* Assemblage (4) is found in areas of the northern basin with a clay substrate and abundant pennate diatoms. Although various strains of *Difflugia protaeiformis* are known to indicate chemically polluted environments, they also seem to graze on pennate diatoms. *Lesquerasia* Assemblage (5) is found in deeper waters ($\bar{x}$ = 2.4 m) and was associated with sandier substrates. *Centropyxis* Assemblage (6) is comprised of only one sample from the narrow region separating the northern and southern basins of the lake. Centropyxids are known to be opportunistic, and they dominate stressed environments. This part of the lake is away from the waste rock dump, but near a commercial lodge, the only potential source of pollutants from that would be sewage.

LIST OF ARCELLACEANS FOUND IN THIS STUDY

See Plates 1 and 2 for arcellaceans found in this study. ''Strain'' names are those designated by Reinhardt and others, 1998.

Arcella vulgaris Ehrenberg, 1830
Centropyxis aculeata ''aculeata'' (Ehrenberg 1832)
Centropyxis aculeata ''discoides'' (Ehrenberg 1832)
Centropyxis aculeata ''spinosa'' (Ehrenberg 1843)
Centropyxis constricta ''aerophila'' (Ehrenberg 1843)
Centropyxis constricta ''constricta'' (Ehrenberg 1843)
Cucurbitella tricuspis (Carter 1856) Medioli, Scott and Abbott, 1987
Difflugia corona Wallich, 1864
Difflugia oblonga ''bryophila'' (Ehrenberg 1832)
Difflugia oblonga ''glans'' (Ehrenberg 1832)
Difflugia oblonga ''oblonga'' (Ehrenberg 1832)
Difflugia oblonga ''spinosa'' (Ehrenberg 1832)
Difflugia oblonga ''linearis'' (Ehrenberg 1832)
Difflugia protaeiformis ''acuminata'' (Ehrenberg 1830)
Difflugia protaeiformis ''amphoralis'' (Lamarck 1816)
Difflugia protaeiformis ''claviformis'' (Lamarck 1816)
Difflugia urceolata ''urceolata'' (Carter 1864)
Difflugia urceolata ''elongata'' (Carter 1864)
Lagenodifflugia vas (Leidy 1874)
Lesquerasia spiralis (Ehrenberg 1840)
Pontigulasia compressa (Carter 1864)

ACKNOWLEDGMENTS

This research was supported by NSERC Research Grant OGP 0041665 to RTP. We also gratefully acknowledge the assistance of students in the Department of Earth Sciences Environmental Geology Field Camp (67.285) for their help in the field. We thank H. Elizabeth Anderson, David Scott, and Roland Gehrels for critically reviewing the manuscript and Patrick Lyons for helping us to finalize a few figures.

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Received 15 September 1999
Accepted 17 April 2000

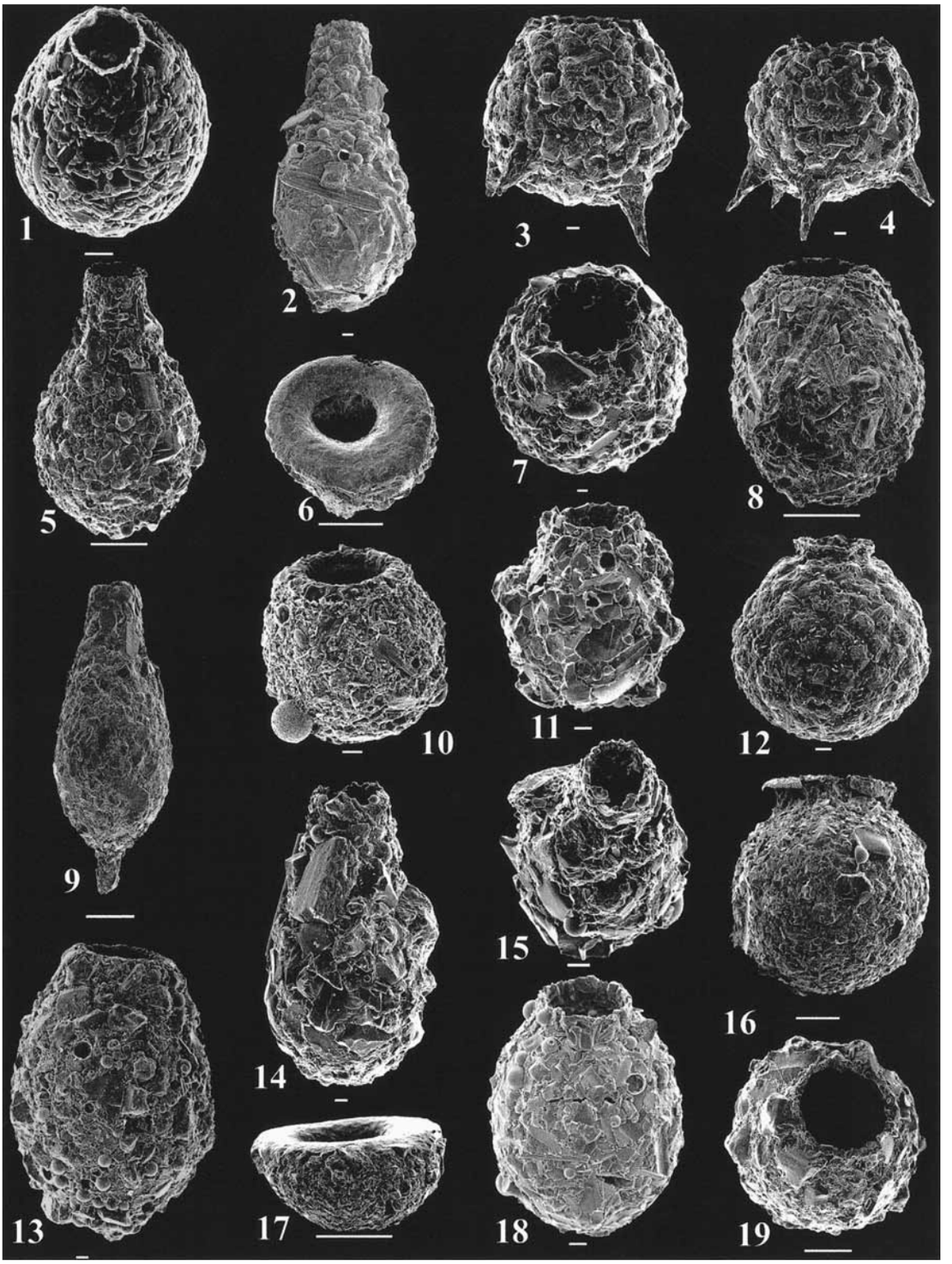

PLATE 1

''Strain'' names are those designated by Reinhardt and others, 1998. All bars are 10 μm unless stated otherwise. **1** *Cucurbitella tricuspis* (Carter, 1856). **2** *Difflugia oblonga* ''oblonga'' (Ehrenberg, 1832). **3** *Difflugia corona* Wallich, 1864. **4** *Difflugia corona* Wallich, 1864. **5** *Difflugia oblonga* ''oblonga'' (Ehrenberg, 1832) (bar length = 100 μm). **6** *Centropyxis aculeata* ''discoides'' (Ehrenberg, 1832) (bar length = 100 μm). **7** *Difflugia corona* Wallich, 1864. **8** *Difflugia oblonga* ''glans'' (Ehrenberg, 1832) (bar length = 100 μm). **9** *Difflugia protaeiformis* ''claviformis'' (Lamarck, 1816). **10** *Difflugia urceolata* ''urceolata'' (Carter, 1864). **11** *Difflugia oblonga* ''glans'' (Ehrenberg, 1832). **12** *Cucurbitella tricuspis* (Carter, 1856). **13** *Difflugia oblonga* ''glans'' (Ehrenberg, 1832). **14** *Difflugia oblonga* ''bryophila'' (Ehrenberg, 1832). **15** *Difflugia oblonga* ''linearis'' (Ehrenberg, 1832). **16** *Difflugia urceolata* ''urceolata'' (Carter, 1864). **17** *Centropyxis aculeata* ''discoides'' (Ehrenberg, 1832) (bar length = 100 μm). **18** *Difflugia urceolata* ''elongata'' (Carter, 1864). **19** *Difflugia oblonga* ''glans'' (Ehrenberg, 1832) (bar length = 100 μm).

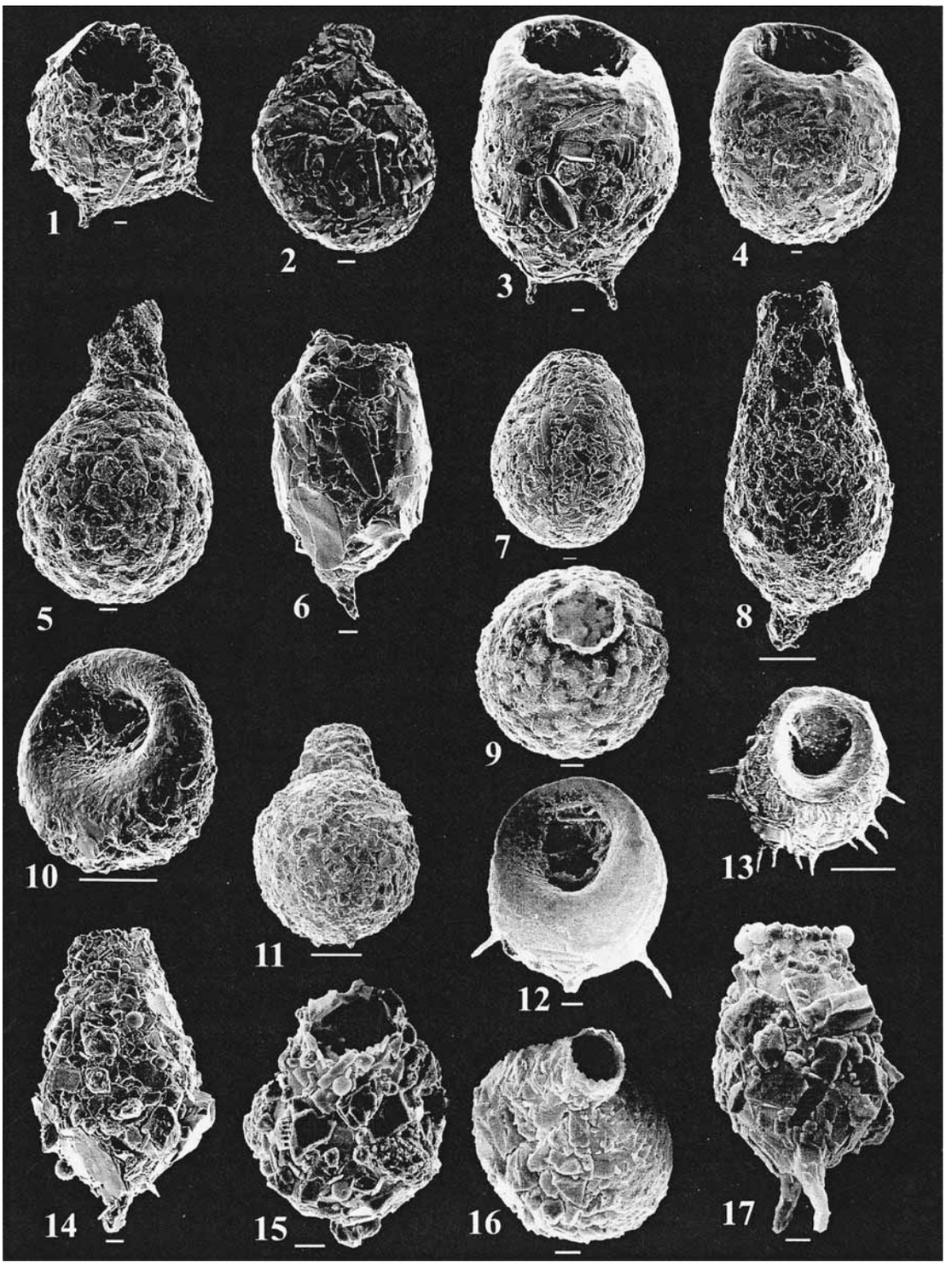

PLATE 2

''Strain'' names are those designated by Reinhardt and others, 1998. All bars are 10 μm length unless stated otherwise. **1** *Difflugia corona* Wallich, 1864. **2** *Lesquerasia spiralis* (Ehrenberg, 1840). **3** *Centropyxis constricta* ''constricta'' (Ehrenberg, 1843). **4** *Centropyxis constricta* ''aerophila'' (Ehrenberg, 1843). **5** *Diflugia oblonga "oblonga"* (Ehrenberg, 1832). **6** *Difflugia protaeiformis* ''claviformis'' (Lamarck, 1816) (bar length = 100 μm). **7** *Cucurbitella tricuspis* (Carter, 1856). **8** *Difflugia protaeiformis* ''claviformis'' (Lamarck, 1816) (bar length = 100 μm). **9** *Cucurbitella tricuspis* (Carter, 1856). **10** *Centropyxis aculeata* ''discoides'' (Ehrenberg, 1832) (bar length = 100 μm). **11** *Lagenodifflugia vas* (Leidy, 1874). **12** *Centropyxis aculeata* ''aculeata'' (Ehrenberg, 1832). **13** *Centropyxis aculeata* ''spinosa'' (Ehrenberg, 1843) (bar length = 100 μm). **14** *Difflugia protaeiformis* ''amphoralis'' (Lamarck, 1816). **15** *Difflugia protaeiformis* ''amphoralis'' (Lamarck, 1816). **16** *Lesquerasia spiralis* (Ehrenberg, 1840). **17** *Difflugia protaeiformis* ''amphoralis'' (Lamarck, 1816).