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 SO₄ 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 Diffugia 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 Lesquerella 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 unimpaired 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, SO₄, 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 Diffugia 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 45.3² 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
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 m³ 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 H₂S 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.

### 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-

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<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Al (mg/L)</th>
<th>Fe (mg/L)</th>
<th>Sulfate (mg/L)</th>
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<tr>
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<td>JL 97-15</td>
<td>3.46</td>
<td>1.13</td>
<td>32.4</td>
<td>396</td>
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</tbody>
</table>
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 | 1LD9 | 1LD8 | 1LD7 | 1LD6 | 1LD5 | 1LD4 | 1LD3 | 1LD2 | 1LD1 | 1LD10 | 1LD11 | 1LD12 | 1LD13 | 1LD14 | 1LD15 | 1LD16 | 1LD17 | 1LD18 | 1LD19 | 1LD20 | 1LD21 | 1LD22 | 1LD23 | 1LD24 | 1LD25 | 1LD26 | 1LD27 | 1LD28 | 1LD29 | 1LD30 | 1LD31 |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Specimens | 32 | 74 | 89 | 97 | 57 | 75 | 78 | 78 | 77 | 78 | 77 | 80 | 78 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 | 77 | 78 |
| Shannon diversity | 2.22 | 2.24 | 2.26 | 2.28 | 2.30 | 2.32 | 2.34 | 2.36 | 2.38 | 2.40 | 2.42 | 2.44 | 2.46 | 2.48 | 2.50 | 2.52 | 2.54 | 2.56 | 2.58 | 2.60 | 2.62 | 2.64 | 2.66 | 2.68 | 2.70 | 2.72 | 2.74 | 2.76 | 2.78 | 2.80 | 2.82 | 2.84 |
| Number of species | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Water depth (m) | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.4 | 3.6 | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.2 | 5.4 | 5.6 | 5.8 | 6.0 | 6.2 | 6.4 | 6.6 | 6.8 | 7.0 | 7.2 | 7.4 | 7.6 | 7.8 | 8.0 | 8.2 | 8.4 |
| Sediment/soil interface pH | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.7 | 8.8 |
| Sediment/soil interface O2 | 38.7 | 39.4 | 40.1 | 40.8 | 41.5 | 42.2 | 42.9 | 43.6 | 44.3 | 45.0 | 45.7 | 46.4 | 47.1 | 47.8 | 48.5 | 49.2 | 49.9 | 50.6 | 51.3 | 52.0 | 52.7 | 53.4 | 54.1 | 54.8 | 55.5 | 56.2 | 56.9 | 57.6 | 58.3 | 59.0 |
| Sediment/soil interface temperature | 7.0 | 7.2 | 7.4 | 7.6 | 7.8 | 8.0 | 8.2 | 8.4 | 8.6 | 8.8 | 9.0 | 9.2 | 9.4 | 9.6 | 9.8 | 10.0 | 10.2 | 10.4 | 10.6 | 10.8 | 11.0 | 11.2 | 11.4 | 11.6 | 11.8 | 12.0 | 12.2 | 12.4 | 12.6 | 12.8 | 13.0 |

**Table Legend:**
- **Arcellacean species:** As listed in the text.
- **Total counts:** Sum of individual species occurrences.
- **Shannon Diversity:** Measures the diversity of species.
- **Water depth:** Depth of the sample collection.
- **Sediment/soil interface pH:** pH of the sediment/soil interface.
- **Sediment/soil interface O2:** Oxygen concentration at the sediment/soil interface.
- **Sediment/soil interface temperature:** Temperature at the sediment/soil interface.
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):

\[
S_{Xi} = [X_i(1 - X_i)/N]^{1/2} \tag{1}
\]

where \(S_{Xi}\) is the standard error; \(X_i\) is the estimated fractional abundance for each \(i = 1,2,3,\ldots; I\) species, where \(I\) is 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,

\[
X_i - 1.96S_{X_i} \leq f_i \leq X_i + 1.96S_{X_i} \tag{2}
\]

95% of the time. Therefore, the 95% confidence interval on the estimated fractional abundances is \(X_i \pm 1.96S_{X_i}\). 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):

\[
S_{Xi} = 1 - (0.051/N) \tag{3}
\]

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 \(\pm 1\%\) 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
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) *Diffugia* Assemblage, (4) *Diffugia protoeformis* 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 associations that were otherwise recognizable.

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 (Schoonborn, 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 (xSDI) = 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 arellacean faunas in boggy ponds in the Arctic and further south. The arcellacean fauna found in this assemblage was diverse (xSDI = 2.268), with one strain *D. protaeiformis* “amphoralis” (x = 22.9%) being dominant, followed by *Lesquerasia spiralis* (x = 9.1%). *D. protaeiformis* “claviiformis” (8.6%) and *D. protaeiformis* “acuminata” (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 (Asoioli and others, 1996; Reinhardt and others, 1998). Reinhardt and others (1998) found that *D. protaeiformis* “claviiformis” 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 *Diffugia* Assemblage in diversity (xSDI = 2.386), preferred substrate, pH (x = 6.8), and distribution in both the southern and northern parts of James Lake (Tables 2, 3). As with the *Diffugia* 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 (x = 2.4 m) and unlike the *Diffugia* Assemblage no single species is overwhelmingly dominant. The most abundant species is *Lesquerasia spiralis* (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-
associated 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 (SDI = 2.321) the fauna is overwhelmingly dominated by two strains of C. acutea (C. acutea “acutea” and C. acutea “discoideis”). 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 diatomids 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. Diffugia Assemblage (3) characterizes shallow-water (x = 1.7 m) higher-pH (x = 6.7) environments rich in organic matter and occurs both in the northern and southern basins of James Lake. Diffugia protaeiformis Assemblage (4) is found in areas of the northern basin with a clay substrate and abundant pene-natal diatoms. Although various strains of Diffugia protaeiformis are known to indicate chemically polluted environments, they also seem to graze on pennate diatoms. Lesquerasia Assemblage (5) is found in deeper waters (x = 2.4 m) and was associated with sandier substrates. Centropyx 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 “acutea” (Ehrenberg 1832)

Centropyxis aculeata “discoideis” (Ehrenberg 1832)

Centropyxis aculeata “spinosa” (Ehrenberg 1843)

Centropyxis constricta “acrophila” (Ehrenberg 1843)

Centropyxis constricta “constricta” (Ehrenberg 1843)

Cucurbitella tricusps (Carter 1856) Medioli, Scott and Abbott, 1987

Diffugia corona Wallich, 1864

Diffugia oblonga “bryophila” (Ehrenberg 1832)

Diffugia oblonga “glans” (Ehrenberg 1832)

Diffugia oblonga “oblonga” (Ehrenberg 1832)

Diffugia oblonga “spinosa” (Ehrenberg 1832)

Diffugia oblonga “linearis” (Ehrenberg 1832)

Diffugia protaeiformis “acuminata” (Ehrenberg 1830)

Diffugia protaeiformis “amphoralis” (Lamarck 1816)

Diffugia protaeiformis “claviformis” (Lamarck 1816)

Diffugia urceolata “urceolata” (Carter 1864)

Diffugia urceolata “elongata” (Carter 1864)

Lagenodiffugia vas (Leidy 1874)

Lesquerasia spiralis (Ehrenberg 1840)

Pontigulasia compressa (Carter 1864)

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