FORAMINIFERA AND ARCELLACEANS

FROM NON-MARINE ENVIRONMENTS

IN NORTHERN LAKE WINNIPEGOSIS, MANITOBA

By

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A thesis submitted to the Graduate Studies and Research

in partial fulfilment of

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acceptance of the thesis.

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GENERAL ABSTRACT

This thesis is divided into two chapters. examining the environmental significance of arcellacean and foraminifera in northern Lake Winnipegosis. Manitoba, Canada. The northern most occurrence of a live marine foraminifer. *Cribroelphidium gunteri* (Cole. 1931). which has survived since the Holocene Hypsithermal in a high stress. non-marine environment in Point River Bay is discussed in Chapter One. The environmental aspects of arcellacean assemblages is studied in Chapter Two. to more tightly constrain their environments through the use of opportunistic species. Specific systems are studied. such as in German Lake where *Lagenodifflugia vas* dominates the assemblage in a low saline (2 - 3‰). high pH (8.0 - 8.3) environment.

DEDICATION

To my daughter Lindsay, who encouraged me to pursue paleontology through her youthful enthusiasm and interest in earth science.

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I would like to thank Tim Patterson for assisting me in my research. both in the lab and with the editing. and also Brian McKillop for his help and guidance in Northern Manitoba. I would also like to thank my field assistant. Andrew Dalby. and George Dix for the use of his microscope and photographic equipment.

Each paper (Chapter one and two) was compiled and written by R.E.A. Boudreau and submitted for comments to R.T. Patterson. The final drafts represented here. encompass style and content edits as suggested by the other contributing authors.

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INTRODUCTION

This thesis is divided into two chapters, each of which was written as a separate journal article for publication. All data were included in the individual papers with each containing a separate introduction and conclusion. The first chapter deals with an occurrence of the live foraminifer, *Cribroelphidium gunteri*, in a non-marine setting within Lake Winnipegosis, Manitoba, while the second chapter deals with the environmental aspects of freshwater arcellaceans in a site influenced by salt springs in the same area. Each chapter details the specific aspects of the study as a separate entity.

Lake Winnipegosis, Manitoba, is a small remnant of post-glacial Lake Agassiz. At its maximum extent 9000 years BP, this lake was 131 m above the present level (Nielsen and others, 1987). Dawson Bay in the northern part of the lake (Fig. 1) is characterized by extremely hard waters with high concentrations of Na^+ (up to 1300 mg/L), K^+ (up to 48 mg/L) and Cl^- (up to 2063 mg/L) and salinities up to 36‰ (Wadien, 1984; Nielsen and others, 1987).

The euryhaline marine foraminifera, *Cribroelphidium gunteri* (Cole), colonized Dawson Bay during the Holocene Hypsithermal via avian transport (Patterson, 1990; Patterson and others, 1997). After the Hypsithermal, because conditions became too cold , it was assumed that *C. gunteri* died out (Patterson and others, 1997), but current research as discussed in Chapter One, indicates that this foraminifera is alive and significant because it is living in an inland lake as opposed to its normal marine coastal environments.

Arcellaceans have been used as paleoenvironmental indicators in lacustrine settings (Scott and Medioli, 1983; Patterson and others, 1985; Medioli and Scott, 1988; McCarthy and others, 1995; Ellison, 1995; Patterson and Kumar, 1999 in publication); as bio-environmental indicators for paleoenvironmental reconstruction of late Quaternary-Holocene paleoenvironments (Medioli and Scott, 1983, 1988; Scott and Medioli, 1983; Medioli and others, 1985, 1987, 1990; Patterson and others, 1985; Honig and Scott, 1987; Collins and others, 1990; McCarthy and others, 1995; Asioli and others, 1996; Ellison, 1995); and as pollution level indicators (Collins and others, 1990; Reinhardt and others, 1998; Patterson and others, 1996). Chapter Two discusses The different environments, found in northern Lake Winnipegosis, are discussed in Chapter Two with emphasis on key assemblages and indicators in the modern setting.

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CHAPTER ONE

NON -MARINE OCCURRENCE OF THE FORAMINIFERA *CRIBROELPHIDIUM GUNTERI* IN LAKE WINNIPEGOSIS, MANITOBA

ABSTRACT

Analysis of sediment samples from the sediment-water interface of Point River Bay, northern Lake Winnipegosis, a very large lake in central Manitoba, indicates that Cribroelphidium gunteri, *a coastal marine foraminifera, is living and has adapted to this northern lake environment in salinities as low as 1 - 2 ‰. In Point River Bay, summer water temperatures reach 15.6 °C marginally above the minimum 14.5 °C required for reproduction by C. gunteri. It was known that this benthic foraminifera inhabited saline parts of the lake during the warm Holocene Hypsithermal (6000 - 3500 years BP), but previous analysis of stratigraphic data suggested that C. gunteri had died out in this area as conditions became cooler and more hostile. This hypothesis had been corroborated by the post Hypsithermal retreat of the marine range of C. gunteri from the Maritimes of Atlantic Canada to the south of Cape Cod, MA. The adaptation of the Holocene*

populations of this species that originally colonized Lake Winnipegosis, often to extremely low salinity values and progressively colder climate in this northern lake, is remarkable. The great abundance of C. gunteri found in sediments in Lake Winnipegosis, in some areas making up most of the sediment, also raises potential concerns about the interpretation of supposed marine sections based exclusively on the presence of foraminifera.

INTRODUCTION

Lake Winnipegosis, Manitoba, is a small remnant of post-glacial Lake Agassiz. At its maximum extent 9000 years BP, this lake was 131 m above the present level (Nielsen and others, 1987). Dawson Bay, in the northern part of the lake (Fig. 1-1), is characterized by extremely hard waters with high concentrations of Na^+ (up to 1300 mg/L), K^+ (up to 48 mg/L) and Cl^- (up to 2063 mg/L) and salinities up to 36‰ (Wadien, 1984; Nielsen and others, 1987). The area surrounding the bay is characterized by highly saline pools and marshes (Patterson and others, 1997) with salinities ranging from 8.3‰ to 61‰ (McKillop and others, 1992). These saline environments are the result of discharge of saline waters from the groundwater system (Downey, 1984) and are hypothesized to originate from either dissolution of Middle Devonian prairie evaporites (van Everdingen, 1971) or from dense brine pools in the Williston Basin in Alberta (Downey, 1984).

The climate of Dawson Bay is continental, with hot summers and cold winters in a semi-arid setting. The wind direction is generally from the west with peak precipitation occurring during the summer months (Patterson and others, 1997). Previous research on Lake Agassiz raised beach deposits, adjacent to Dawson Bay, indicated that conditions in the region were warmer during the Holocene Hypsithermal (6000 to 3500 years BP). The euryhaline marine foraminifera, *Cribroelphidium gunteri* (Cole, 1931), colonized Dawson Bay by 5430 years BP, early in the Hypsithermal (Patterson, 1990; Patterson and others, 1997). Colonization of *C. gunteri* was mediated by avian transport and occurred only after an influx of post-glacial brines raised the area salinity. As this foraminifera was not noted stratigraphically either before or after the Hypsithermal, Patterson and others (1997) concluded that conditions were too cold for *C. gunteri* to live in the area except during this warm episode. This hypothesis was corroborated by the previously observed retreat of Atlantic coastal populations of *C. gunteri* to the south of Cape Cod following termination of the Hypsithermal and subsequent development of cooler coastal waters in the Maritimes (Patterson and others, 1997; Scott and others, 1987).

Analysis of a set of sediment-water interface samples collected during the summer of 1997 in Point River Bay (Fig. 1-2) identified large populations of pristine *C. gunteri*. Up to 22.9% of the specimens in these samples stained positively with rose Bengal biological stain (Goldstein and Harben, 1993), suggesting that the species had not become extinct in this area, as first supposed. Further detailed sampling was carried out during the summer of 1998 to confirm the 1997 field season results and to confirm the observed distribution of *C. gunteri*.

The purpose of this paper is to document the live occurrence of *C. gunteri* and constraints on its distribution in this hostile non-marine environment.

METHODS

Twenty sediment-water interface samples were collected from stations in Dawson Bay (Fig. 1-2) during July 1997 and June 1998 using an Eckman Box Corer. The location of each station was determined using a Trimble Scout Global Positioning System unit and corroborated by triangulation. Water depth, pH, salinity and temperature were recorded at each station (Table. 1-1). To obtain a general idea of the lake conditions in the area, a complete geochemical analysis was carried out by Areco Canada in Nepean, Ontario on one sediment sample and one water sample, acidified with nitric acid, from Station 29. The presence of metals (Table 1-2) was determined by using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP - AES). Chloride was analyzed using Ion Chromatography, and arsenic and selenium levels were measured using Graphite Furnace Atomic Absorption (GFAAS).

The upper 2 - 3 mm of sediment from each Eckman grab were removed and treated with isopropyl alcohol and refrigerated to avoid decay. To detect specimens of foraminifera and arcellaceans living at the time of collection, samples were stained in the laboratory using Rose Bengal biological stain (Goldstein and Harben, 1993); and only those specimens that had one chamber full of stained protoplasm were counted as alive. This was checked by crushing numerous specimens to ensure that the chamber contained a glob of protoplasm as opposed to being coated on the inside by lightly stained organic material such as bacteria. After standing for 24 hours, the samples were rinsed to remove excess stain and then sieved using a 35-mesh Tyler (500 μm) screen to retain coarse organic material and a 230-mesh Tyler (63 μm) screen to retain foraminifera and arcellaceans. One cc of sample was then subdivided into aliquots for quantitative analysis using a wet splitter (Scott and Hermelin, 1993). The wet aliquots were analyzed under an Olympus SZH10 zoom stereo microscope. Scanning electron micrographs of foraminifera and arcellaceans were obtained using a JEOL 6400 Scanning Electron Microscope at the Carleton University Research Facility for Electron Microscopy (CURFEM). These digital images were compiled into plates using Adobe© Photoshop 4.0 (Plate 1-1). A transmitted light photo-micrograph of a stained foraminifera was obtained using a SLR camera mounted on a Leica WILD Macro420 binocular microscope (Plate 1-2).

RESULTS

For a week prior to and during the four days of collection in June of 1998, it rained almost continuously in the Dawson Bay area. The rain was also accompanied by high winds (20 - 30 knots). The high surf (3 - 4 m swells) resulted in considerable mixing of saline waters of the bay with fresh waters from areas of the lake. The resultant salinity values obtained in the bay were thus probably lower, and the oxygen content higher, than what normally prevails in this area.

Samples collected at all 20 stations examined yielded populations of foraminifera and arcellaceans in statistically significant numbers (Patterson and Fishbein, 1989). Twenty-four species of arcellaceans and one of foraminifera were identified in these samples, for which the relative fractional abundance (X_i) and the standard error (S_{xi}) associated with each taxonomic unit were calculated using the following equation:

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

Based on the results, five statistically insignificant species were removed from the database and not included in subsequent multivariate analysis (Table 1-3) (Patterson and Fishbein, 1989). The population diversity of each sample was calculated using the Shannon Diversity Index:

$$S.I. = -\sum_{i=1}^{S}\left(\frac{X_i}{N_i}\right) \times \ln\left(\frac{X_i}{N_i}\right)$$

where X_i ⇒ is the abundance of each taxon in a sample,

N_t ⇒ is the total abundance of the sample, and

S ⇒ is equal to the species richness of the sample.

High Shannon Diversity index values (2.5 - 3.5) usually indicate conditions of environmental stability, while lower values (0.1 - 1.5) often indicate environmental stress (Sageman and Bina, 1997). In these samples low diversity values were obtained when the fractional abundance of *C. gunteri* was high. Diversity values increased to a maximum of 2.0 with decreasing abundance of *C. gunteri* and increasing populations of centropyxid and difflugid arcellaceans (Fig. 1-3).

R-mode cluster analysis was used to determine species relationships (Scott and others, 1980). On the 19 species present in statistically significant populations, Q-mode cluster analysis was carried out using Ward's Minimum Variance method in order to determine the overall statistical similarity between samples. This resulted in a reduced data set recorded as Euclidean distances and arranged in a combined R-mode and Q-mode hierarchical diagram (Fig. 1-4) (see Fishbein and Patterson, 1993; and Westrop and Cuggy, 1999). Three assemblages were recognized based on the results:

(1) The **Cribroelphidium Assemblage** was found in Point River Bay at seven Stations. This assemblage is dominated almost entirely by *C. gunteri* ($X_i \geq 0.90$) (up to 9.3% live *C. gunteri*) and has a very low population diversity (Shannon Diversity Index 0.01 - 0.3). The sediment at these sites was a brown silt

containing a high proportion of shell fragments with evidence of pyritization. Water depths at these stations varied from two to four metres, with the pH ranging from 4.9 to 8.3 and oxygen content from 8.4 to 11.4 mg/L. Salinity readings were low (0.0 - 1.0 ‰).

(2) The **Diverse Assemblage** was found in Point River Bay at only Stations 18 and 19. It is dominated by centropyxid species ($X_i \geq 0.53$) with low fractional abundances of *C. gunteri* ($X_i < 0.15$) (no live *C. gunteri*) and a Shannon Diversity Index of 1.8 to 2.0. The sediment characterizing these sites was a fine sand at water depths varying from five to six metres. The pH ranged from 5.8 to 5.9, and oxygen content was high varying between 9.6 and 10.0 mg/L. No salinity readings were available for these stations (No salinity measurements were taken during the July 1997 field season).

(3) The **Mixed Assemblage** occurred in Point River Bay at ten stations. This assemblage, though dominated by *C. gunteri* ($0.45 < X_i < 0.83$) (2.5 - 22.9% live *C. gunteri*), also contained significant populations of centropyxids ($0.19 < X_i < 0.67$) and difflugids ($0.02 < X_i < 0.22$). The Shannon Diversity Index varied between 0.6 to 1.7. The sediments at these sites were comprised of dark brown gyttja with evidence of pyritization in some shell fragments. Water depths varied from 1.2 to 4.5 metres, with pH ranging from 4.6 to 7.9 and oxygen content from 9.3 to 10.1 mg/L. Salinity readings were negligible (0 ‰).

DISCUSSION

During the Hypsithermal, *C. gunteri* ranged as far north as the Northumberland Strait in Maritime Canada (Scott and others, 1987), but the eurythermal foraminifer had retreated to the south of Cape Cod during subsequent climate cooling (Patterson and others, 1997). Patterson and others (1997) linked the disappearance of *C. gunteri* from post Hypsithermal Lake Winnipegosis sediments to this cooling. The discovery of living *C. gunteri* during this study indicates that the species did not disappear from the lake. It now seems that isostatic uplift and tilting of post-glacial Lake Agassiz caused submergence of the shorelines in the south and a transition of the beaches around Dawson Bay from aquatic to marsh and finally to a terrestrial setting (Nielsen and others, 1987). This would account for the extinction horizon of *C. gunteri* in the cores reported by Patterson and others (1997).

The ability of foraminifera to survive in a particular area is closely linked to its reproductive cycle as many species require specific ranges of temperature to survive. Schafer (1973) investigated a stenothermal site at Chaleur Bay in the Gulf of St. Lawrence, where a power plant outlet provided a source of heat, and found that the proportion of living elphidids decreased with distance from the outfall heat source. Calcareous species, such as *C. excavatum*, tended to dominate the local populations near the outfall, while less heat tolerant agglutinated species, such as *Ammotium cassis* (Parker; Loeblich and Tappan, 1953), tended to become more abundant with distance

(Schafer, 1973). Thus the mechanism employed by temperate shallow water foraminifera to combat thermal stress seems to be avoidance (Seigle, 1975; Schafer and others, 1995), with populations quickly relocating to more ideal habitats. (N.B. The discovery of large numbers of living and dead *C. gunteri* in the Point River Bay, Lake Winnipegosis, modern lake bottom caused us to re-examine the results of Patterson and others, 1997.)

The minimum temperature tolerance for *C. gunteri* (Cole, 1931) has been determined to be 14.5°C (Boltovskoy and Lena, 1969). Mean summertime bottom water temperatures in Point River Bay, Lake Winnipegosis, average 15.6°C, marginally above the reproductive limits for *C. gunteri*, thus permitting reproduction during favorable intervals in an otherwise harsh environment (Bradshaw, 1961). Such favorable intervals occur during the summer in Point River Bay, where temperatures warm just enough to promote reproduction and ensure survival of *C. gunteri*.

Salinity is another important control over the distribution of many foraminiferal species. While conditions in Point River Bay are much less saline than in most marine environments, most elphidid species are euryhaline and able to adapt to a wide array of brackish to hypersaline conditions. For example, elphidid species such as *Cribroelphidium gerthi* (van Voorthuysen, 1957) are known to have adapted and survived in ephemeral lakes in Southern Australia, where seasonally extreme salinity variations prevail. These lakes are fed by winter rainfall and then dry out during the summer, resulting in salinities oscillating between 10‰ and 180‰ or more (Cann and De

Deckker. 1981). *Cribroelphidium excavatum* lives in freshwater zones of the Quequén Grande River. Argentina. in salinities as low as 0.48‰. These brackish conditions are derived from the occasional high tide penetrating far upriver (Boltovskoy and Boltovskoy. 1968; Wright. 1968: Boltovskoy and Wright. 1976). Similarly. *C. gunteri* presently inhabits low salinity marsh environments of the Fraser River Delta. British Columbia (Jonasson and Patterson. 1992: Patterson. 1990). and shallow brackish waters (< 10 ‰) on the Mississippi Delta (Poag, 1979). *Cribroelphidium* is extremely eurytopic as it has also been reported from lagoonal waters of coastal Brazil in salinities of up to 290‰ (Poag. 1978: Patterson and others. 1990. 1997).

Centropyxid arcellaceans. particularly *Centropyxis aculeata* (Ehrenberg 1832). are capable of withstanding low salinities (< 5‰: Decloître. 1953: Scott and Medioli. 1980: Patterson and others. 1985; Honig and Scott. 1987). These taxa occur abundantly with *C. gunteri* in Point River Bay. indicating that the normal salinity range at sites where *C. gunteri* are found are never above 5‰. As *C. gunteri* is also found in portions of Point River Bay with non-centropyxid arcellaceans that are intolerant of saline conditions, the presence of *C. gunteri* indicates that the species survives in portions of Point River Bay with barely detectable salinities.

Cribroelphidium gunteri has demonstrated a remarkable ability to adapt and survive in the hostile environments that have existed in the Point River Bay area of Lake Winnipegosis since the Holocene Hypsithermal. These results indicate that the species has not only survived but, based on the large numbers found, thrived in northern Lake Winnipegosis. This occurrence has pushed the known habitat of this species much farther north than the previously accepted limits of Cape Cod and the Fraser River Delta in North America, in addition to placing it in a lacustrine setting. This occurrence is also significant because it indicates, as has been reported previously (see Patterson 1987 for summary), that finding foraminifera in the fossil record does not necessarily indicate that true marine marsh conditions existed during deposition.

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SYNONYMY

Order FORAMINIFERIDA Eichwald 1830

Superfamily ROTALIACEA Ehrenberg 1839

Family ELPHIDIIDAE Galloway 1933

Subfamily ELPHIDIINAE Galloway 1933

Genus *Cribroelphidium* Cushman and Brönnimann 1948

Cribroelphidium gunteri (Cole)

Plate 1-1. figures 1 - 8; Plate 1-2

Cribroelphidium gunteri (Cole) PATTERSON 1990. pl. 2. figs. 1. 2

Elphidium gunteri (Cole) KNUDSEN in Feyling-Hanssen. Jrgensen. Knudsen and Anderson (eds.) 1971. p. 277. pl. 12. figs. 9. 10; pl. 21. figs. 4 - 7. (not *Elphidium gunteri* Cole 1931)

Numerous arcellacean species have been separated and defined through the years (Medioli and Scott. 1983. 1988). The systematic approaches utilized range 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 almost every variety recognized (Deflandre. 1928). Both approaches may be partially right as several distinct morphological populations can be observed within many arcellacean species. These strains develop in response to different environmental stresses and can be considered ecomorphs. An abbreviated taxonomy as well as photomicrographs of the species discriminated (based on Medioli and Scott 1983) are provided along with diagnoses for infrasubspecific strains. Parentheses have been used to demarcate strains and to emphasize their infrasubspecific designation (Reinhardt and others. 1998).

Order ARCELLINIDA Kent 1880

Superfamily ARCELLACEA Ehrenberg 1830

Family **ARCELLIDAE** Ehrenberg 1830

Genus ***Arcella*** Ehrenberg 1830

Arcella vulgaris Ehrenberg 1830

Plate 1-1, figure 9

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

Arcella vulgaris Ehrenberg 1830 REINHARDT and others 1998, pl. 1, fig. 3

Diagnosis: Test without spines, hyaline and transparent, aperture sub-terminal or occasionally central, circular or oval, invaginated.

Family **CENTROPYXIDIDAE** Deflandre 1953

Genus *Centropyxis* Stein 1859

Centropyxis aculeata (Ehrenberg 1832) strain "aculeata"

Plate 1-1, figure 10

Arcella aculeata EHRENBERG 1832, p.91

Centropyxis aculeata "aculeata" REINHARDT and others 1998, pl. 1, fig. 1

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

Centropyxis aculeata (Ehrenberg 1832) strain "discoides"

Plate 1-1. figure 11

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.151. pl. 5. figs. 38 - 41

Centropyxis discoides Penard [sic], OGDEN and HEDLEY 1980. p.54. pl. 16. figs. A - e

Centropyxis aculeata "discoides" REINHARDT and others 1998. pl. 1. fig. 2

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

Centropyxis constricta (Ehrenberg 1843) strain "aerophila"

Plate 1-1. figure 12

Centropyxis aerophila DEFLANDRE 1929

Centropyxis aerophila Deflandre OGDEN and HEDLEY 1980. p. 48 - 49

Cucurbitella [sic.] *constricta* REINHARDT and others 1998. pl. 1. fig. 6

Centropyxis constricta "aerophila" KUMAR and DALBY 1998. pl.   fig.

Diagnosis: Test varies from spherical, subspherical to elongated with thick aperural lip at an angle of 45° to 60° with respect to the test. Spines absent.

Centropyxis constricta (Ehrenberg 1843) strain "constricta"

Plate 1-1, figure 13

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

Centropyxis constricta "constricta" REINHARDT and others 1998, pl. 1, fig. 4

Diagnosis: Test flattened with three or less spines on the fundus.

Centropyxis constricta (Ehrenberg 1843) strain "spinosa"

Plate 1-1, figure 14

Centropyxis spinosa CASH in CASH and HOPKINSON 1905, p. 62, pl. 20, figs. a - d

Centropyxis spinosa Cash, OGDEN and HEDLEY 1980, p. 62, pl. 20, figs. a - d

Centropyxis constricta "spinosa" REINHARDT and others 1998, pl. 1, fig. 5

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

Family **DIFFLUGIDAE** Stein 1859

Genus *Difflugia* Leclerc in Lamarck 1816

Difflugia bidens Penard 1902

Plate 1-1, figure 16

Difflugia bidens PENARD 1902, p. 264, figs. 1 - 8

Difflugia bidens Penard MEDIOLI and SCOTT 1983, p. 21 - 22, pl. 1, figs. 1 - 5

Diagnosis: Test laterally compressed with two to three short spines. Aperture round and simple.

Difflugia corona Wallich 1864

Plate 1-1, figure 17

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 corona Wallich REINHARDT and others 1998, pl. 2, fig. 1

Diagnosis: Fundus with one to ten short spines, aperture circular, crenulated by six to 20 indentations forming a thin collar.

Difflugia oblonga Ehrenberg 1832 strain "bryophila"

Plate 1-1, figure 18

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

Difflugia oblonga "bryophila" REINHARDT and others 1998, pl. 2, fig. 9

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

Difflugia oblonga Penard 1902 strain "glans"

Plate 1-1. figure 19

Difflugia oblonga "glans" PENARD 1902

Difflugia oblonga "glans" REINHARDT and others 1998. pl. 2. fig. 7

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

Difflugia oblonga Ehrenberg 1832 strain "oblonga"

Plate 1-1. figure 20

Difflugia oblonga EHRENBERG 1832. p. 90

Difflugia oblonga Ehrenberg 1832. OGDEN and HEDLEY 1980. p. 148. pl. 63. figs. a - c

Difflugia oblonga Ehrenberg 1832. HAMAN 1982. p. 367. pl. 3. figs. 19 - 25

Difflugia oblonga Ehrenberg 1832. SCOTT and MEDIOLI 1983. p. 818. figs. 9a - b

Difflugia oblonga "oblonga" REINHARDT and others 1998. pl. 2. fig. 10

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

Difflugia oblonga Ehrenberg 1832 strain "spinosa"

Plate 1-1. figure 21

Difflugia oblonga var. *spinosa* REINHARDT 1998, p. 140, pl. 2, figs. 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

Difflugia oblonga Ehrenberg 1832 "tenuis"

Plate 1-1, figure 22

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

Difflugia oblonga "tenuis" REINHARDT and others 1998, pl. 2, fig. 12

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 strain "acuminata"

Plate 1-1, figure 23

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

Difflugia acuminata EHRENBERG 1830, p. 95

Difflugia acuminata Ehrenberg 1830, OGDEN and HEDLEY 1980, p. 118, pl. 4, figs. a - c

Difflugia acuminata Ehrenberg 1830, SCOTT and MEDIOLI 1983, p. 818, fig. 9d

Difflugia protaeiformis "acuminata" REINHARDT and others 1998, pl. 2, fig. 5

Diagnosis: Distinguished from *Difflugia protaeiformis "claviformis"* by having a thinner wall which appears transparent under a light microscope.

Difflugia protaeiformis Lamark 1816 strain "claviformis"

Plate 1-1, figure 24

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

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 and others, 1996, p. 250, pl. 2, fig. 1, a - b

Difflugia protaeiformis "claviformis" REINHARDT and others 1998, pl. 2, fig. 3

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

Difflugia urceolata Carter 1864 strain "elongata"

Plate 1-1, figure 25

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

Difflugia urceolata Carter 1864 REINHARDT and others 1998, pl. 2, fig. 2a

Diagnosis: Test elongate; aperture a distinct hanging collar.

Difflugia urceolata Carter 1864 strain "urceolata"

Plate 1-1, figure 26

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

Difflugia urceolata Carter 1864 REINHARDT and others 1998, pl. 2, fig. 2b

Diagnosis: Test spheroidal to ovoidal; aperture a distinct hanging collar.

Family **HYALOSPHENIIDAE** Schultze 1877

Genus *Cucurbitella* Penard 1902

Cucurbitella tricuspis (Carter 1856)

Plate 1-1, figure 15

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

Cucurbitella tricuspis (Carter 1856) REINHARDT and others 1998, pl. 1, fig. 7

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

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Figure 1-1. Map showing location of Point River Bay in northern Lake Winnipegosis. Manitoba.

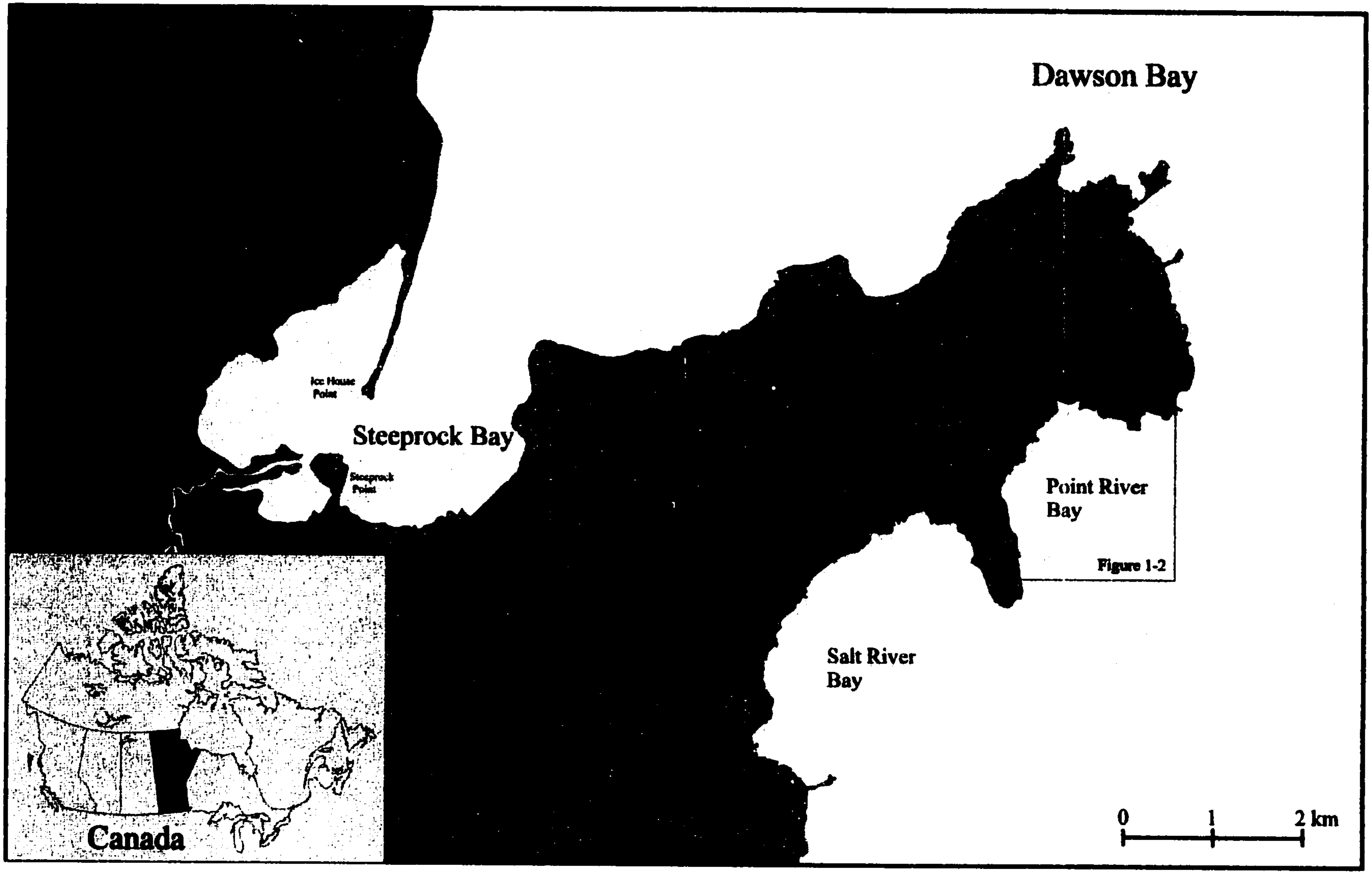

Dawson Bay
Ice House Point
Steeprock Bay
Steeprock Point
Point River Bay
Figure 1-2
Salt River Bay
0
1
2 km
Canada

Figure 1-2. Map showing locations of sample stations in Point River Bay.

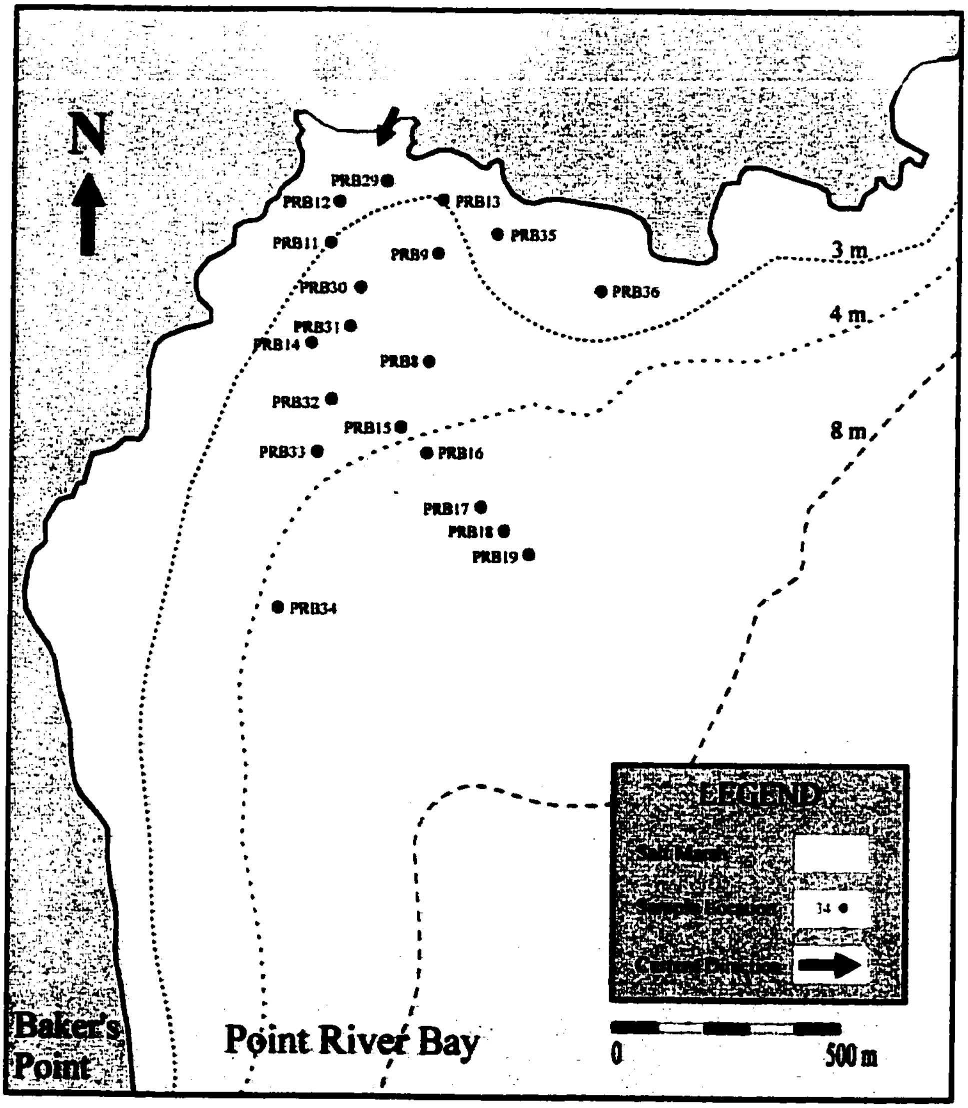
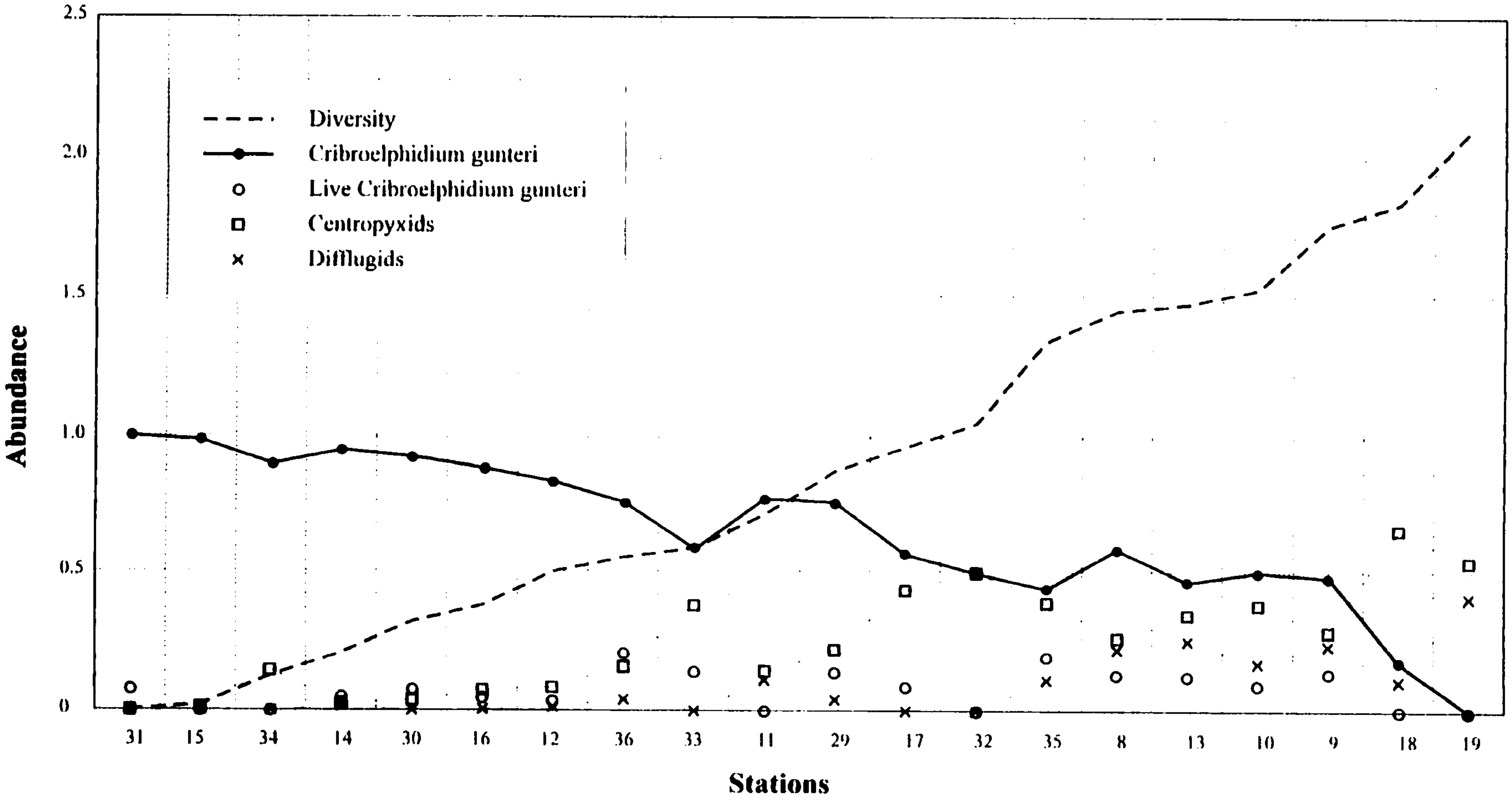

N
PRB29
PRB12
PRB13
PRB11
PRB35
PRB9
3 m
PRB30
PRB36
4 m
PRB31
PRB14
PRB8
PRB32
PRB15
8 m
PRB33
PRB16
PRB17
PRB18
PRB19
PRB34
34
0
500 m
Baker's Point
Point River Bay

Figure 1-3. Shannon Diversity Index vs. abundance of arcellaceans and the foraminifera *Cribroelphidium gunteri* (Cole) in Point River Bay.



Diversity
Cribroelphidium gunteri
Live Cribroelphidium gunteri
Centropyxids
Difflugids
Abundance
2.5
2.0
1.5
1.0
0.5
0
31
15
34
14
30
16
12
36
33
11
29
17
32
35
8
13
10
9
18
19
Stations

Figure 1-4. R-mode vs. Q-mode cluster diagram showing abundances of arcellaceans and the foraminifera *Cribroelphidium gunteri* (Cole), and their assemblage relationships in Point River Bay (after Westrop and Cuggy, 1999).

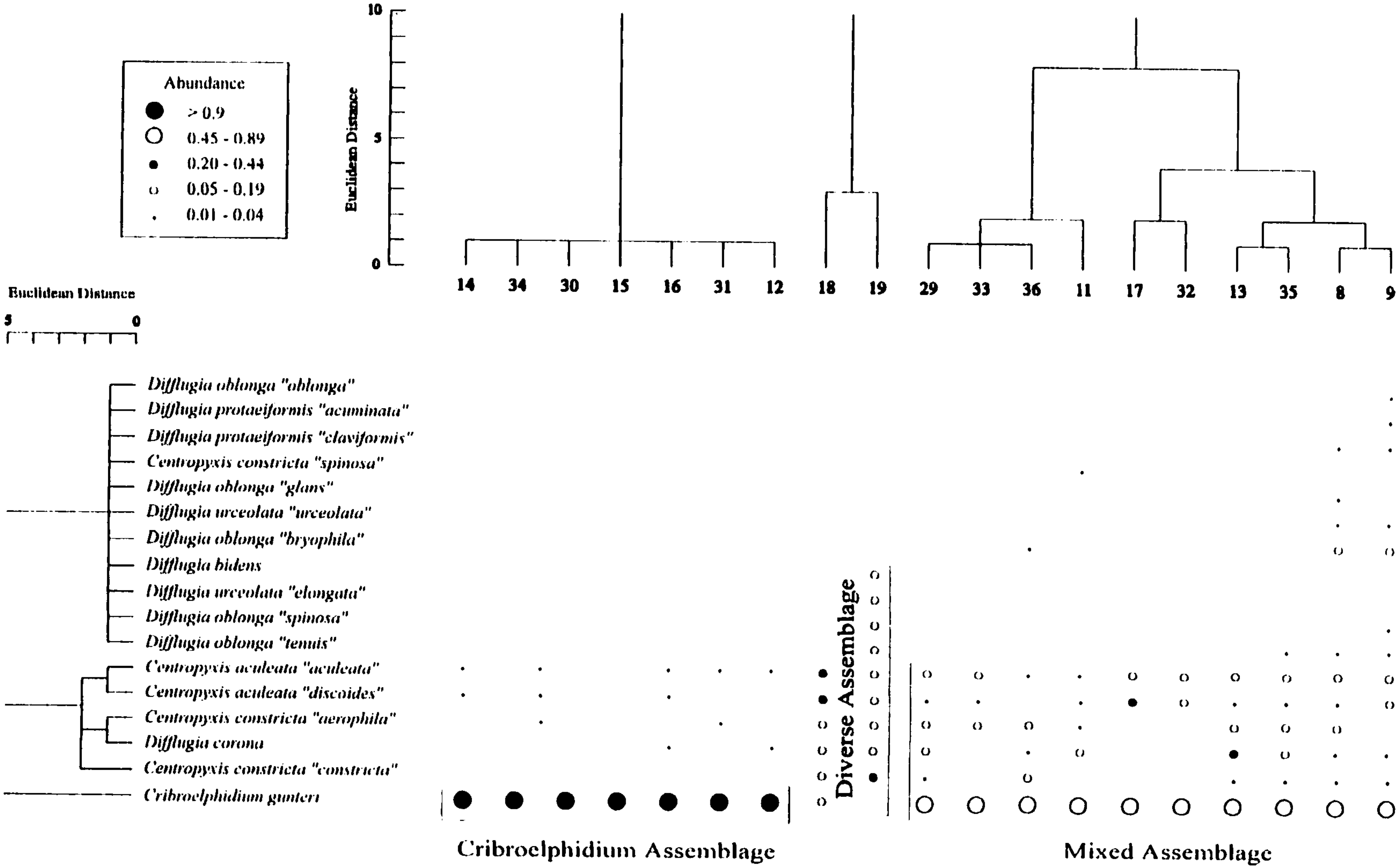

Abundance
> 0.9
0.45 - 0.89
0.20 - 0.44
0.05 - 0.19
0.01 - 0.04
Euclidean Distance
10
5
0
14
34
30
15
16
31
12
18
19
29
33
36
11
17
32
13
35
8
9
Euclidean Distance
5
0
Difflugia oblonga "oblonga"
Difflugia protaeiformis "acuminata"
Difflugia protaeiformis "claviformis"
Centropyxis constricta "spinosa"
Difflugia oblonga "glans"
Difflugia urceolata "urceolata"
Difflugia oblonga "bryophila"
Difflugia bidens
Difflugia urceolata "elongata"
Difflugia oblonga "spinosa"
Difflugia oblonga "tenuis"
Centropyxis aculeata "aculeata"
Centropyxis aculeata "discoides"
Centropyxis constricta "aerophila"
Difflugia corona
Centropyxis constricta "constricta"
Cribroelphidium gunteri
Diverse Assemblage
Cribroelphidium Assemblage
Mixed Assemblage

Table 1-1. Physical data at sample stations in Point River Bay indicating water depth. pH. oxygen content. salinity and temperature (readings indicated by a "-" were from the July 1997 field season. and the values were not available).

Station		Depth (metres)	pH	Oxygen (mg/L)	Salinity (‰)	Temperature (°C)
1997	8	3.0	-	-	-	-
	9	2.0	-	-	-	-
	11	3.0	8.6	9.6	-	13.3
	12	2.0	6.1	11.5	-	12.6
	13	3.0	4.6	9.6	-	13.6
	14	4.0	5.1	9.4	-	13.4
	15	4.0	4.9	8.4	-	13.6
	16	4.0	6.3	9.1	-	13.8
	17	4.5	5.9	10.1	-	13.9
	18	5.0	5.8	10.0	-	13.9
	19	6.0	5.9	9.6	-	14.1
	29	1.2	7.9	9.3	2	15.3
1998	30	2.8	8.3	9.4	1	15.0
	31	3.4	8.3	9.3	0	15.2
	32	4.0	7.0	9.3	0	15.2
	33	3.4	6.9	9.4	0	15.1
	34	4.3	7.0	9.3	0	15.3
	35	1.8	7.0	9.4	0	15.0
	36	2.1	7.0	5.6	0	15.6

Table 1-2. Chemical data from one acidified bottom water sample, and one sediment sample from the sediment-water interface (top 2 - 3 mm), at Station 29 in Point River Bay.

Chemical Species	*Bottom water (mg/L)*	*mean detection limit*	*Sediment (µg/g)*	*mean detection limit*
Aluminum	0.14	0.05	1240	1
Ammonia (N)	0.07	0.01		
Arsenic			1.4	1
Barium	0.04	0.01	60	1
Boron	0.06	0.01	1.45	0.02
Calcium	56.3	1.0		
Chloride	211	1.0	2962	4
Chromium			9	1
Copper			6	1
Iron	0.12	0.01	6770	2
Manganese	0.034	0.005	374	1
Magnesium	21.1	1.0		
Phosphorous			728	20
Potassium	9.5	1.0		
Sodium	143	1.0		
Strontium	0.24	0.01	740	1
Sulphate	48.7	1.0		
Zinc	0.04	0.02	2	2

Table 1-3. Taxonomic unit counts. Shannon Diversity. Abundances and Standard Error for sample stations in Point River Bay.

Station Taxonomic Counts Diversity	PRB8 516 1.453	PRB9 497 1.752	PRB11 316 0.640	PRB12 286 0.298	PRB13 438 1.461	PRB14 693 0.159	PRB15 636 0.006	PRB16 432 0.302	PRB17 107 0.945	PRB18 69 1.778
Arcella vulgaris	0.002	0.002	0.009	0.000	0.002	0.000	0.000	0.000	0.000	0.014
standard error =	0.004	0.004	0.011	0.000	0.004	0.000	0.000	0.000	0.000	0.028
Centropyxis aculeata "aculeata"	0.095	0.123	0.038	0.031	0.151	0.022	0.000	0.03	0.187	0.232
standard error =	0.025	0.029	0.021	0.02	0.034	0.011	0.000	0.016	0.074	0.1
Centropyxis aculeata "discoides"	0.033	0.068	0.022	0.007	0.046	0.009	0.005	0.016	0.196	0.203
standard error =	0.015	0.022	0.016	0.01	0.02	0.007	0.005	0.012	0.075	0.095
Centropyxis constricta "aerophila"	0.052	0.046	0.013	0.01	0.087	0.000	0.000	0.000	0.019	0.145
standard error =	0.019	0.018	0.012	0.012	0.026	0.000	0.000	0.000	0.026	0.083
Centropyxis constricta "constricta"	0.037	0.036	0.000	0.000	0.018	0.001	0.000	0.000	0.000	0.087
standard error =	0.016	0.016	0.000	0.000	0.013	0.003	0.000	0.000	0.000	0.066
Centropyxis constricta "spinosa"	0.004	0.002	0.013	0.003	0.005	0.000	0.000	0.000	0.000	0.000
standard error =	0.005	0.004	0.012	0.007	0.006	0.000	0.000	0.000	0.000	0.000
Cribroelphidium gunteri	0.591	0.495	0.826	0.916	0.457	0.964	0.994	0.935	0.589	0.159
standard error =	0.042	0.044	0.042	0.032	0.047	0.014	0.006	0.023	0.093	0.086
Curcurbitella tricuspis	0.006	0.002	0.003	0.000	0.016	0.000	0.000	0.000	0.009	0.058
standard error =	0.007	0.004	0.006	0.000	0.012	0.000	0.000	0.000	0.018	0.055
Difflugia bidens	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.014
standard error =	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.028
Difflugia corona	0.017	0.04	0.057	0.031	0.205	0.003	0.002	0.016	0.000	0.058
standard error =	0.011	0.017	0.026	0.02	0.038	0.004	0.003	0.012	0.000	0.055
Difflugia fragosa	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
Difflugia globulus	0.000	0.006	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.000	0.007	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "bryophila"	0.079	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014
standard error =	0.023	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028
Difflugia oblonga "glans"	0.01	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.008	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "lanceolata"	0.002	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error =	0.004	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "oblonga"	0.006	0.012	0.000	[illegible]	0.002	0.000	0.000	0.000	0.000	0.014
standard error =	0.007	0.01	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.028
Difflugia oblonga "spinosa"	0.002	0.012	0.03	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.004	0.01	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "tenuis"	0.017	0.022	0.003	0.000	0.000	0.001	0.000	0.000	0.000	0.000
standard error =	0.011	0.013	0.006	0.000	0.000	0.003	0.000	0.000	0.000	0.000
Difflugia protaeiformis "acuminata"	0.006	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.007	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "amphoralis"	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "claviformis"	0.01	0.018	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error =	0.008	0.012	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Difflugia urceolata "elongata"	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia urceolata "urceolata"	0.027	0.014	0.009	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error =	0.014	0.01	0.011	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Lagenodifflugai vas	0.002	0.002	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000
standard error =	0.004	0.004	0.000	0.000	0.004	0.000	0.000	0.005	0.000	0.000

Station Taxonomic Counts Diversity	PRB19 132 2.018	PRB29 443 0.962	PRB30 606 0.162	PRB31 343 0.224	PRB32 65 1.070	PRB33 83 0.797	PRB34 161 0.128	PRB35 401 1.465	PRB36 435 0.848
Arcella vulgaris	0.000	0.002	0.002	0.000	0.000	0.012	0.025	0.002	0.000
standard error =	0.000	0.004	0.003	0.000	0.000	0.023	0.024	0.005	0.000
Centropyxis aculeata "aculeata"	0.136	0.077	0.012	0.029	0.108	0.120	0.006	0.120	0.044
standard error =	0.059	0.025	0.009	0.018	0.075	0.070	0.012	0.032	0.019
Centropyxis aculeata "discoides"	0.053	0.032	0.008	0.009	0.138	0.048	0.006	0.035	0.000
standard error =	0.038	0.016	0.007	0.010	0.084	0.046	0.012	0.018	0.000
Centropyxis constricta "aerophila"	0.091	0.065	0.008	0.015	0.123	0.060	0.000	0.117	0.087
standard error =	0.049	0.023	0.007	0.013	0.080	0.051	0.000	0.031	0.027
Centropyxis constricta "constricta"	0.258	0.014	0.002	0.000	0.000	0.000	0.000	0.047	0.060
standard error =	0.075	0.011	0.003	0.000	0.000	0.000	0.000	0.021	0.022
Centropyxis constricta "spinosa"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000
Cribroelphidium gunteri	0.008	0.731	0.969	0.939	0.615	0.735	0.963	0.489	0.763
standard error =	0.015	0.041	0.014	0.025	0.118	0.095	0.029	0.049	0.040
Curcurbitella tricuspis	0.045	0.002	0.000	0.000	0.000	0.012	0.000	0.007	0.002
standard error =	0.036	0.004	0.000	0.000	0.000	0.023	0.000	0.008	0.005
Difflugia bidens	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia corona	0.114	0.072	0.000	0.009	0.015	0.012	0.000	0.142	0.009
standard error =	0.054	0.024	0.000	0.010	0.030	0.023	0.000	0.034	0.009
Difflugia fragosa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
Difflugia globulus	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
Difflugia oblonga "bryophila"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.021
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.013
Difflugia oblonga "glans"	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "lanceolata"	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "oblonga"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005
Difflugia oblonga "spinosa"	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005
standard error =	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
Difflugia oblonga "tenuis"	0.053	0.002	0.000	0.000	0.000	0.000	0.000	0.017	0.000
standard error =	0.038	0.004	0.000	0.000	0.000	0.000	0.000	0.013	0.000
Difflugia protaeiformis "acuminata"	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "amphoralis"	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
Difflugia protaeiformis "claviformis"	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia urceolata "elongata"	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
standard error =	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008
Difflugia urceolata "urceolata"	0.023	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.025	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lagenodifflugai vas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000

Plate 1-1. **1 - 8** *Cribroelphidium gunteri* (Cole, 1931). 1. Side view of an eight chambered specimen showing sutures; x114. 2. Apertural view; x85. 3. A large convoluted nine chambered specimen; x60. 4. Side view of a ten chambered specimen; x88. 5. Side view of a slightly corroded specimen; x95. 6. Dorsal view; x91. 7. Side view of a seven chambered specimen; x112. 8. Specimen with exploded chamber; x111. **9**. *Arcella vulgaris* Ehrenberg, 1830; x131. **10**. *Centropyxis aculeata* (Ehrenberg, 1832) strain "aculeata"; x186. **11**. *Centropyxis aculeata* (Ehrenberg, 1832) strain "discoides"; x153. **12**. *Centropyxis constricta* (Ehrenberg, 1843) strain "aerophila"; x156. **13**. *Centropyxis constricta* (Ehrenberg, 1843) strain "constricta"; x162. **14**. *Centropyxis constricta* (Ehrenberg, 1843) strain "spinosa"; x158. **15**. *Cucurbitella tricuspis* (Carter, 1856); x103. **16**. *Difflugia bidens* Penard, 1902; x166. **17**. *Difflugia corona* Wallich, 1864; x200. **18**. *Difflugia oblonga* (Ehrenberg, 1832) strain "bryophila"; x97. **19**. *Difflugia oblonga* (Penard, 1902) strain "glans"; x154. **20**. *Difflugia oblonga* (Ehrenberg, 1832) strain "oblonga"; x114. **21**. *Difflugia oblonga* (Ehrenberg, 1832) strain "spinosa"; x90. **22**. *Difflugia oblonga* (Ehrenberg, 1832) strain "tenuis"; x93. **23**. *Difflugia protaeiformis* (Lamarck, 1816) strain "acuminata"; x117. **24**. *Difflugia protaeiformis* (Lamarck, 1816) strain "claviformis"; x146. **25**. *Difflugia urceolata* (Carter, 1864) strain "elongata"; x92. **26**. *Difflugia urceolata* (Carter, 1864) strain "urceolata"; x114.

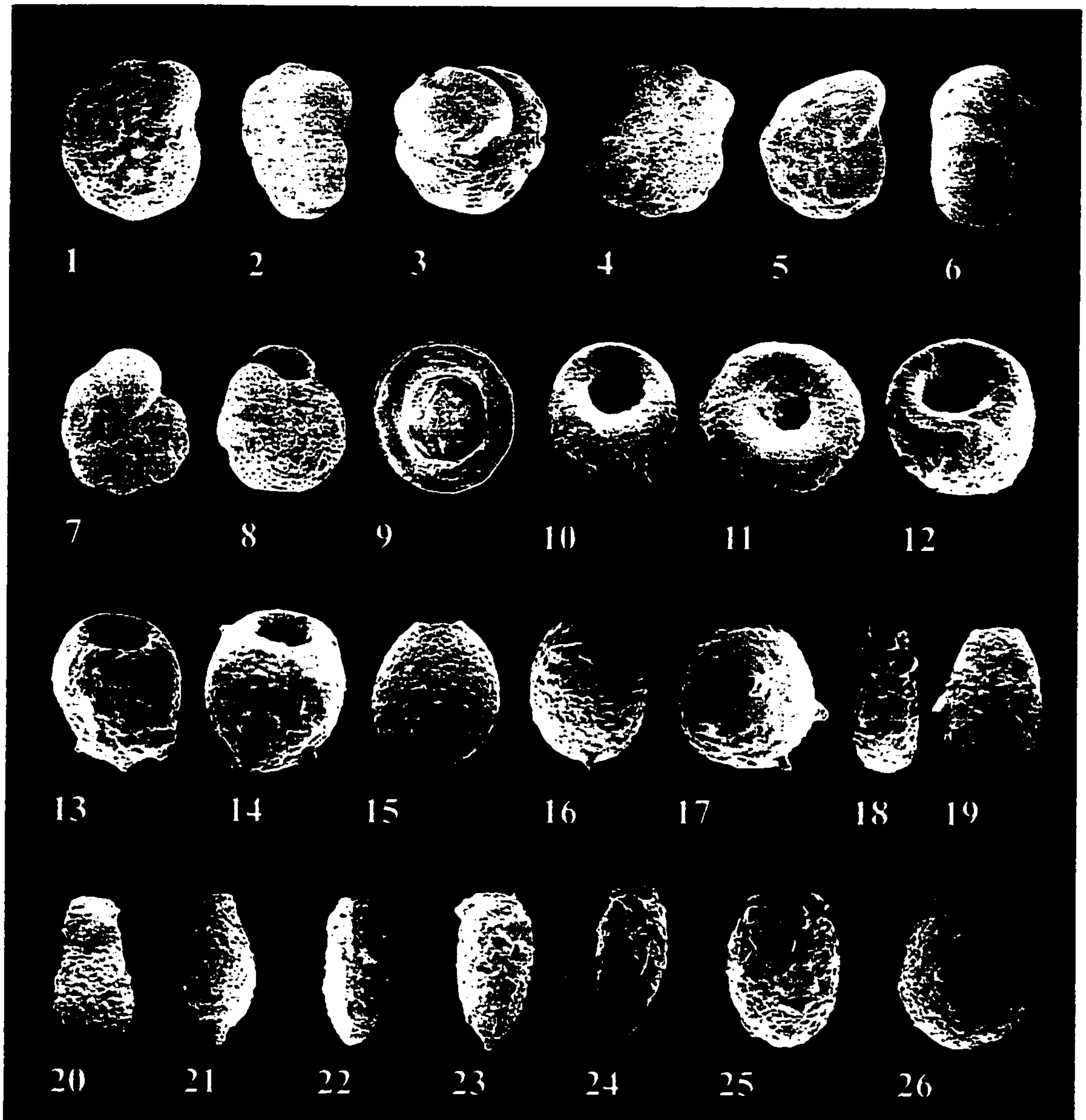


Plate 1-1

Plate 1-2. *Cribroelphidium gunteri* (Cole, 1931) specimen stained with Rose Bengal biological stain. Arrow indicates glob of stained protoplasm.

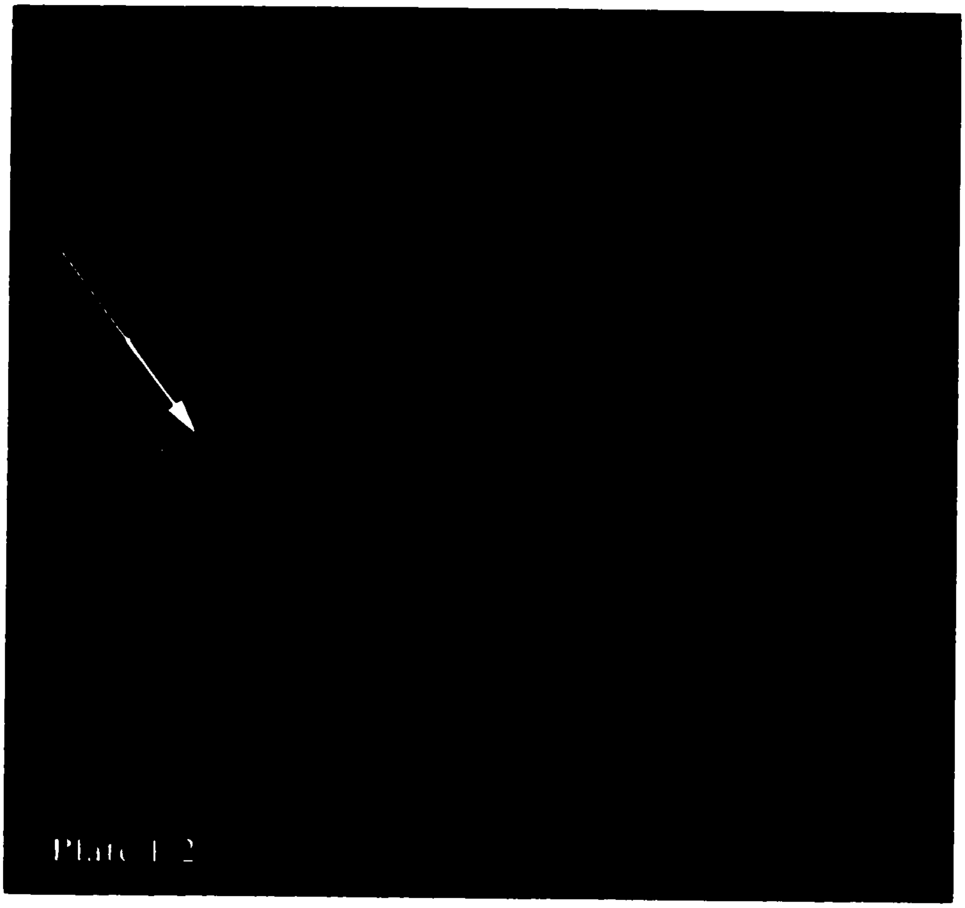


Plate I-2

CHAPTER 2

THE ENVIRONMENTAL SIGNIFICANCE OF ARCELLACEANS AND FORAMINIFERA, AT A SITE POLLUTED BY NATURAL SALT SPRINGS, IN NORTHERN LAKE WINNIPEGOSIS, MANITOBA

ABSTRACT

Analysis of sediment-water interface sediment samples collected in June 1998 from northern Lake Winnipegosis, a very large lake in central Manitoba, indicate that arcellaceans and marine foraminifera are living in this northern lake environment in proximity to salt springs which inject waters with salinities up to 60‰ and whose sediments contain chemicals which in some cases exceed the Canadian Guidelines (toxicity tolerances for aquatic life; from Moore, 1991) such as for Arsenic (66.7 µg/g), chloride (6054 µg/g), copper (15 µg/g), phosphorus (1815 µg/g), manganese (129 µg/g) and strontium (403 µg/g). When mixed with the fresh waters of the lake, salinities of 1.0 to 7.0‰, and pH ranging from 4.9 to 8.3 have been noted with high amounts of chloride (2063 mg/L), iron (0.59 mg/L), manganese (0.09 mg/L), sodium (1300 mg/L) and sulfate (161 mg/L). In this naturally stressed environment, the euryhaline foraminifera Cribroelphidium gunteri and the opportunistic arcellaceans <u>*Centropyxis aculeata*</u>*,* <u>*Difflugia corona*</u> *and* <u>*Lagenodifflugia vas*</u> *are thriving in low diversity populations.*

INTRODUCTION

Arcellaceans have been used as paleoenvironmental indicators in lacustrine settings (Scott and Medioli. 1983: Patterson and others. 1985; Medioli and Scott. 1988: McCarthy and others. 1995: Ellison. 1995; Patterson and Kumar. 1999 in press). as bio-environmental indicators for paleoenvironmental reconstruction of late Quaternary-Holocene paleoenvironments (Medioli and Scott. 1983. 1988: Scott and Medioli. 1983; Medioli and others. 1985. 1987. 1990; Patterson and others. 1985; Honig and Scott. 1987: Collins and others. 1990: McCarthy and others. 1995; Asioli and others. 1996; Ellison. 1995). and as pollution level indicators (Collins and others. 1990; Reinhardt and others. 1998; Patterson and others. 1996).

Numerous papers have also been written discussing the salinity tolerance of arcellaceans and foraminifera. Some arcellaceans can live in brackish waters (Todd and Brönniman. 1957: Haman. 1982: Hayward and others. 1996). and foraminifera have been used as salinity indicators in combined estuarine and river systems (Dyer. 1973; Scott and others. 1980). and as environmental classification tools in estuaries (Nichols. 1974: Scott and others. 1980). For example, in the Upper Estuarine Zone in Miramichi Bay, New Brunswick. it was noted in the area where river and marine processes met that salinities were less than 20 ‰ (Scott and others. 1980). Here, populations of foraminifera. such as *Cribroelphidium excavatum incertum* were found living in close proximity to arcellacean populations that included *Centropyxis aculeata* (Ehrenberg, 1832), *Centropyxis* *constricta* (Ehrenberg, 1843). *Difflugia oblonga* (Penard, 1902) and *Difflugia urceolata* (Carter, 1864); (Scott and others, 1980). Previous research in Dawson Bay, Lake Winnipegosis, Manitoba indicated that four foraminifera and nine arcellacean taxa were found living in close proximity to inland salt springs in marshy areas (Patterson and others, 1990).

Physical Setting

Lake Winnipegosis is a small remnant of post-glacial Lake Agassiz, which at its maximum extent 9000 years BP was 131 m above the present level of the lake (Nielsen and others, 1987). Dawson Bay in northern Lake Winnipegosis, Manitoba (Fig. 2-1) is characterized by extremely hard waters with high concentrations of Na^{+} (up to 1300 mg/L), K^{+} (up to 48 mg/L) and Cl^{-} (up to 2063 mg/L) and salinities up to 36‰ (Wadien, 1984; Nielsen and others, 1987). The area surrounding the bay is characterized by highly saline pools and marshes (Patterson and others, 1997) with salinities ranging from 8.3‰ to 61‰ (McKillop and others, 1992). These saline environments are the result of discharge of saline waters from the groundwater system (Downey, 1984) and are hypothesized to originate from either dissolution of Middle Devonian halites from prairie evaporites (van Everdingen, 1971), or from dense pools of brine in the Williston Basin in Alberta (Downey, 1984).

The climate of Dawson Bay is continental with hot summers and cold winters, in a semi-arid setting. The wind direction is generally from the west with peak precipitation occurring during the summer months (Patterson and others. 1997). Previous research on Lake Agassiz raised beach deposits. adjacent to Dawson Bay. indicated that conditions in the region were warmer during the Holocene Hypsithermal (6000 to 3500 years BP). Early in the Hypsithermal (by 5430 years BP). the euryhaline marine foraminifera. *Cribroelphidium gunteri* (Cole, 1931) colonized Dawson Bay (Patterson. 1990; Patterson and others. 1997), and has recently been found alive in great abundance in Dawson Bay (see Chapter 1). Another live foraminiferal species. *Annectina viriosa* PATTERSON and MCKILLOP. 1991. and the arcellacean *C. aculeata* were noted in salt marshes in southern Lake Winnipegosis. while other arcellacean species have been found in freshwater parts of the lake (McKillop and others. 1992).

Due to their high abundance and resistance to dissolution in low pH environments (Thibaudeau and others. 1987; McCarthy and others. 1995), and because of agglutination (Scott and Medioli. 1983). arcellaceans make excellent paleoenvironmental indicators (Scott and Medioli. 1983. Medioli and Scott. 1988; Patterson and others. 1985; McCarthy and others. 1995; Ellison. 1995). Research in Canada and Italy has demonstrated the use of arcellaceans as pollution indicators (Asioli and others. 1996; Reinhardt and others. 1998; Patterson and others. 1996).

Agglutinated arcellaceans are primarily benthic and reflect bottom conditions (Schönborn. 1962; Scott and Medioli, 1983), have a generation time of only a few days, and ultimately develop distinct morphologies in response to environmental stress

(Patterson and Kumar, in press). Most of these lacustrine taxa prefer oligotrophic lakes with mildly acidic waters and are found in reduced numbers in eutrophic lakes (Medioli and others, 1990). Large populations of arcellaceans are present in a wide variety of freshwater habitats including moss, soil, peat, standing waters and sewage treatment systems and are seen in settings from tropical to polar regions (Ogden and Hedley, 1980). A healthy assemblage will be characterized by a Shannon Diversity Index greater than 2.5 with abundances greater than 500 specimens per cc and is usually characterized by various strains of *D. oblonga* (Scott and others, 1998).

Immediately following the retreat of the ice sheets of the Wisconsinan glaciation, the Centropyxid arcellaceans *C. aculeata* and *C. constricta*, and the Difflugid arcellaceans *D. oblonga*, *D. urceolata* and *Difflugia corona* (Wallich, 1864) were found to be common in lakes in Canada (McCarthy and others, 1995). During the late Pleistocene to early Holocene cold water conditions were recorded by low diversity assemblages dominated by *D. oblonga* with common *C. aculeata*, which is similar to assemblages seen today in Arctic lakes. As lake assemblages matured during the Holocene, they became more diverse (Collins and others, 1990) as is seen today within parts of Dawson Bay. More recently, when the environment stabilized, biological relationships such as preditor-prey, competition or clumping became more important with increasing variability (Scott and Medioli, 1980). In a modern high diversity assemblage can also be found *Lesquereusia spiralis* (Ehrenberg, 1840), *Cucurbitella tricuspis* (Carter, 1856), *Lagenodifflugia vas* (Leidy, 1874) and *Nebella collaris* (Ehrenberg, 1848) which could reflect conditions of paludification and eutrophication (Scott and others. 1998).

Environment

In a marine setting, foraminifera will secrete a $CaCO_3$ test depending on whether the environment is conducive to carbonate preservation (McCrone and Schafer. 1966: Greiner. 1970). Environments where carbonate preservation does not occur tend to happen in areas with low salinity or colder waters. either of which make precipitation of carbonate difficult. Carbonate preservation can also be restricted when the pH is lowered. by the occurrence of high organic carbon or when low oxygen conditions are present in some polluted environments (Schafer. 1973; Schafer and others. 1975; Vilks and others. 1975).

Arcellaceans. like foraminifera. can secrete an autogenous test or form a xenogenous test. For example, *Difflugia* spp. use xenogenous material like silt grains and tend to dominate lacustrine environments where a sediment supply is readily available (Scott and others. 1998). Thecamoebans on the whole eat mostly diatoms and bacteria or in some cases can be cannibalistic (Medioli and Scott, 1983). Some like *C. tricuspis* feed on algal mats during the summer and form autogenous tests. while in the fall they become benthic and form a xenogenous test (Schönborn. 1962: Medioli and others. 1987). *C. tricuspis* which has been associated with eutrophic conditions is often seen in conjunction with the floating algae *spyrogyra* (Medioli and Scott. 1988). and probably reflects nutrient loading associated with human occupation. Although organic loading is not usually toxic. it can often create low oxygen conditions which are toxic to many organisms (Schafer and Cole, 1974).

If an environment is stressed, then the assemblage tends to have low diversity and can be dominated by an "opportunistic species" (Schafer and others, 1991), such as the infrasubspecies *Difflugia protaeiformis* (Lamarck, 1816) strain "claviformis" which can survive in areas where high levels of pollutants such as As, Cd, Cr and Cu would prevent most species from living (Asioli and others, 1996). These infrasubspecies have discriminated their environment better than individual species would (Patterson and others, 1996; Reinhardt and others, 1998). In German Lake, *L. vas* discriminates the environment, occurring in a low diversity assemblage within a high pH setting (pH 8.0 - 8.3). Increasing marine influence, such as that which occurs near the upper limit of tidal activity, decreases species diversity as shown when the only survivors are *Centropyxis* spp. (Scott and others, 1998). Marshes can represent the extreme of the marine environment with large variations of temperature, salinity and pH (Phleger and Bradshaw, 1966), and these marginal marine environments are characterized by assemblages containing relatively euryhaline foraminifera and arcellaceans in a low diversity setting. In a coastal environment, such as estuaries, these assemblages tend to be dominated by foraminifera such as *Elphidium excavatum* that is restricted to shallow waters with low salinities (Loeblich and Tappan, 1953), and can be found with species of the arcellacean genus *Centropyxis* (Decloître, 1953; Scott and others, 1977, 1980; Collins, 1996). This type of assemblage was noted in Point River Bay and in Salt River Bay where *C. gunteri* and *A.viriosa* are seen with species of Centropyxids and Difflugids in low diversity settings. A high percentage of *C. aculeata* suggests brackish conditions, while *D. oblonga* dominated assemblages can indicate a freshwater setting (Scott, 1977; Scott and others, 1980b; Collins, 1996). Live *C. gunteri* was found in abundance in the presence of *D. oblonga* and *C. aculeata*, indicating that it can survive in waters of little or no salinity.

Chemistry

Dawson Bay in northern Lake Winnipegosis is a unique environment that is naturally polluted via salt springs that penetrate Devonian dolomites in the area of Dawson Bay. Water flow through the substrate leaches sulfates from the sulfide minerals in the country rock, causing an interaction between the sulfate ions in the leachate and the hydrogen ions in the water, forming sulfuric acid and lowering the pH of the water (Gale, 1990). When these acidic, metal laden waters mix with neutral lake waters the result can be the precipitation of Fe, Mn and Al in the form of hydroxides (Fortin and others, 1993; Tessier and others, 1996). The result of this oxidation is seen in the vicinity of the salt springs where red limonite-stained gravelly sinter was reported by McKillop and others (1992).

In waters contaminated with Fe and Al, where the pH ranges from 2.0 to 5.5, the Shannon Diversity Index tends to be less than 1.0 with less than six species per sample. In this setting, Al can mobilize into biologically useable forms (Burrows, 1977), such as gibbsite, and Fe^{2+} can form oxyhydroxides such as goethite (Morel and others, 1993). In environments where the pH ranges from 6.5 to 7.5 and the Shannon Diversity Index ranges from 1.5 to 2.5. Al complexes into relatively stable compounds (Plankey and Patterson, 1987, 1988). Fe^{2+} is prevalent in solution when in the presence of sulfides and carbonates. Fe^{2+} oxidizes to Fe^{3+} (Morel and others, 1993). Due to a lower ΔG° of reaction, Mn^{2+} oxidizes at a higher pH (pH $\geq$ 7 - 8) than does Fe^{2+}, not concentrating as much as does Fe^{2+} , allowing more advective mixing before and during formation of particulate material. As the pH becomes more alkaline (pH > 7.0) in the presence of carbonates, more $MnCO_3$ will precipitate out (Tipping and others, 1984).

Indications are that *Arcella vulgaris* (Ehrenberg, 1830) can dominate with abundances in excess of 90% in polluted waters where the pH is less than 5.5 and forms less than 5% of the assemblage when the pH increases to 7.5. This means that *A. vulgaris* can act as an indicator for a low pH chemically contaminated environment (Patterson and Kumar, in press). *C. aculeata* tends to dominate environments when pH ranges from 5.5 to 7.5 as in the vicinity of Cobalt Ontario (Patterson and others, 1996; Reinhardt and others, 1998). In general, in a lacustrine environment, as the pH rises *D. oblonga* dominates with 25 to 50% of the species in an assemblage and *D. corona, L. spiralis, D. urceolata* and *Difflugia protaeiformis* (Lamarck, 1816) can occur in significant numbers (Scott and others, 1998).

This paper will investigate assemblages of arcellaceans and foraminifera in order to constrain the various environments in Dawson Bay.

METHODS

Analysis of sediment-water interface samples was carried out on samples collected during July 1997 and June 1998 from the following sites within Dawson Bay:

- Steeprock Bay, Steeprock Lagoon (Fig. 2-2), German Lake and Sausage Lake (Fig. 2-3),
- Salt River Bay (Fig. 2-4), and
- Point River Bay (Fig. 2-5).

The week previous and during the four days of collection in June of 1998, it was raining in Dawson Bay accompanied by high winds (20 - 30 knots). This resulted in a high surf (3 - 4 m swells) and ultimately a high level of mixing within the waters of the bay giving salinity readings lower than expected for this area. At some of these sites, large populations of pristine *C. gunteri* were found in proximity to large populations of arcellaceans.

Fifty-two sediment-water interface samples were collected from various bays and lakes in the vicinity of Dawson Bay were obtained using an Eckman Box Corer, and the exact location of each station was determined using a Trimble Scout Global Positioning System unit, and corroborated by triangulation. Water depth, pH, salinity and temperature were recorded at 52 stations in Dawson Bay (Table 2-1).

A complete geochemical analysis was carried out by Areco Canada in Nepean, Ontario, on five sediment-water interface sediment samples; and, five bottom-water samples, acidified with nitric acid, from one station in each of German Lake (GL23), Sausage Lake (SL25), Steeprock Lagoon (STL27), Point River Bay (PRB29) and Salt River Bay (SRB37). In addition, one sediment sample was analyzed from within a salt spring located on Salt Point (STR49). Placed in acid washed jars, the samples were refrigerated for transportation, and analyzed immediately upon return. A variety of metals (Table 2-2) were analyzed using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP - AES), chloride was analyzed using Ion Chromatography, and arsenic and selenium levels were measured using Graphite Furnace Atomic Absorption (GFAAS).

The upper 2 - 3 mm of sediment from each Eckman grab was removed and treated with isopropyl alcohol and refrigerated to avoid decay. To detect specimens of arcellaceans and foraminifera living at the time of collection, samples were stained in the laboratory using Rose Bengal biological stain (Goldstein and Harben, 1993). After standing over night, the samples were rinsed to remove excess stain, and then sieved using a 35-mesh Tyler (500 μm) screen to retain coarse organic material and a 230-mesh Tyler (63 μm) screen to retain foraminifera and arcellaceans. One cc of sample was then subdivided into aliquots for quantitative analysis using a wet splitter (Scott and Hermelin, 1993). The wet aliquots were analyzed under an Olympus SZH10 zoom stereo microscope. Only those specimens that had one chamber full of stained protoplasm were counted as alive. Numerous stained specimens were also crushed to ensure that chamber contained protoplasm, as opposed to being coated on the inside by lightly stained organic material, such as bacteria. Scanning electron micrographs of picked foraminifera and arcellaceans were obtained using a JEOL 6400 Scanning Electron Microscope at the Carleton University Research Facility for Electron Microscopy (CURFEM). These digital images were compiled into plates using Adobe© Photoshop 4.0 (Plates 2-1 & 2-2). Transmitted light photo-micrographs of stained foraminifera and arcellaceans were obtained using a SLR camera mounted on a Leica WILD Macro420 binocular microscope (Plate 2-3).

RESULTS

One cc samples collected from the sediment-water interface at 52 stations examined yielded 50 stations with populations of foraminifera and arcellaceans large enough for statistical analysis (Table 2-3; Patterson and Fishbein, 1989). Arcellaceans were not counted with respect to living populations, because with their rapid regeneration time of only a few days, total populations provide better estimates of standing crops (Scott and Medioli, 1980a), living species were noted throughout the Bay.

Twenty-seven species of arcellaceans and two of foraminifera were identified in these samples, from which the relative fractional abundance (X_i) and the standard error (S_{xi}) associated with each taxonomic unit were calculated using the following equation:

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

Based on the results, three statistically insignificant species, *Difflugia globulus* (Ehrenberg, 1848), *Difflugia oblonga* (Leidy, 1879) strain "triangularis", and *N. collaris*; and Stations SRB43 and SRB49, were removed from the database and not included in subsequent multivariate analysis (Table 2-4; Patterson and Fishbein, 1989). The population diversity of each sample was calculated using the Shannon Diversity Index:

$$S.I. = -\sum_{i=1}^{S}\left(\frac{X_i}{N_i}\right) \times \ln\left(\frac{X_i}{N_i}\right)$$

where X_i	⇒	is the abundance of each taxon in a sample,
N_i	⇒	is the total abundance of the sample, and
S	⇒	is equal to the species richness of the sample.

High Shannon Diversity index values (2.5 - 3.5) usually indicates conditions of environmental stability, while lower values (0.1 - 1.5) often indicate environmental stress (Sageman and Bina, 1997). In Point River Bay, low diversity values were obtained when the fractional abundance of *C. gunteri* was high, and likewise in German Lake where the fractional abundance of *L. vas* was high. Diversity increased to a maximum of 2.4 (moderate diversity 1.6 - 2.4) with decreasing abundance of *C. gunteri* or *L. vas*, and increasing populations of Centropyxid and Difflugid arcellaceans (Table 2-5).

R-mode and Q-mode cluster analysis were carried out on the 29 species present. R-mode analysis was used to determine which species best characterized an assemblage (Scott and others, 1980a), and Q-mode cluster analysis was carried out to determine the statistically significant populations using Ward's Minimum Variance method. This resulted in a reduced data set recorded as Euclidean distances and arranged in a combined R-mode and Q-mode hierarchical diagram (Fig. 2-6). Also, the six sediment and five water samples analyzed geochemically were clustered using R-mode and Q-mode multivariate analysis and their results arranged in a combined hierarchical diagram (Fig. 2-7; see Fishbein and Patterson, 1993; and Westrop and Cuggy, 1999). Six assemblages were recognized based on the results (Table 2-6):

(1) The **Cribroelphidium Assemblage** was found in Point River Bay at eleven Stations and in Salt River Bay at two Stations. This assemblage is dominated almost entirely by *C. gunteri* ($0.73 \leq X_i \leq 0.99$) and has a very low population diversity (Shannon Diversity Index 0.01 - 1.0). Live *C. gunteri*, *A. viriosa* and *C. constricta* were found in a brown silt containing a high proportion of shell fragments with evidence of pyritization. Water depths at these stations varied from two to four metres, with the pH ranging from 4.9 to 8.3, and oxygen content from 8.4 to 11.4 mg/L. Salinity readings were low (0.0 - 1.0 ‰). Chemical analysis of the sediments at Station SRB37 indicated moderate levels of Ba (0.04 mg/g), Mn (0.46 mg/g), Sr (0.33 mg/g) and Cl (0.19 mg/g), while analysis of the bottom waters indicated 0.04 mg/L of Ba. In addition, the Canadian Guidelines

with respect to toxic levels (toxicity tolerances for aquatic life; from Moore, 1991) were exceeded with 0.04 mg/L Zn in the bottom waters (maximum 0.03 mg/L) (Moore, 1991).

(2) The **Centropyxid Assemblage** occurred in Steeprock Bay at two Stations, Salt River Bay at one Station and in Point River Bay at six stations. This assemblage was dominated by *C. gunteri* ($0.35 < X_i < 0.53$), but also contained significant populations of Centropyxids ($0.22 < X_i < 0.42$) and Difflugids ($0.00 \leq X_i < 0.46$). The Shannon Diversity Index varied between 0.9 to 1.7. Here, *C. gunteri*, *D. corona*, *C. aculeata*, and *Difflugia oblonga* (Penard, 1902) strain "bryophila" were found living in sediments comprised of dark brown gyttja with evidence of pyritization in some shell fragments. Water depths varied from 1.2 to 4.5 metres, with pH ranging from 4.6 to 7.9, and oxygen content from 9.3 - 10.1 mg/L. Salinity readings were negligible (0 ‰).

(3) The **Lagenodifflugia Assemblage** occurred in German Lake at two Stations. This assemblage is dominated by *L. vas* ($0.69 < X_i < 0.76$) and has a low Shannon Diversity Index between 0.6 and 1.0. *L. vas* and *D. corona* were found living in a sediment that consisted of a brown gyttja and occurred in 1.8 metres of water. The pH in this lake was high and ranged between 8.3 and 8.6, and the oxygen content was steady at 8.6 mg/L. The salinity was 3‰. Chemical analysis of the sediments at Station SB23 in German Lake indicated levels of Al (9.93 mg/g), Cr

(0.02 mg/g). Fe (17.2 mg/g). V (0.04 mg/g). Cu (0.02 mg/g) and Zn (0.05 mg/g). while analysis of the bottom waters indicated amounts of Ba (0.04 mg/L) and Zn (0.04 mg/L).

(4) The **Moderate Diversity Assemblage** was found in Steeprock Bay at six Stations. Steeprock Lagoon at two Stations. Salt River Bay at five Stations. German Lake at one Station and in Point River Bay at one Station. It is dominated by Centropyxids ($0.27 \leq X_i \leq 0.67$) and Difflugids ($0.00 \leq X_i \leq 0.49$), with low fractional abundances of *C. gunteri* ($X_i < 0.16$), and a Shannon Diversity Index of 0.18 to 2.3. In this assemblage, live *D. corona*, *C. aculeata*, *L. vas*, and *A. vulgaris* were found living in a fine sand at water depths varying from five to six metres. The pH ranged from 5.8 to 5.9, and oxygen content was high varying between 9.6 and 10.0 mg/L. No salinity readings were available for these stations. Chemical analysis of the sediments at Station SB27 in Steeprock Lagoon indicated levels of Al (9.93 mg/g). Cr (0.02 mg/g). Fe (17.2 mg/g). V (0.04 mg/g). Cu (0.02 mg/g) and Zn (0.05 mg/g). while analysis of the bottom waters indicated amounts of Al (0.6 mg/L). Fe (0.59 mg/L) and Mn (0.097 mg/L).

(5) The ***Difflugia corona*** **Assemblage** occurred in Sausage Lake at three Stations and in Steeprock Bay at one Station. This assemblage was dominated by *D. corona* ($0.43 < X_i < 0.79$) and has a low Shannon Diversity Index between 0.09 and 1.7. Live *D. oblonga* were found in a brown gyttja in water depths that varied

between 0.2 and 1.5 metres. The pH ranged between 7.2 and 8.0, the oxygen content varied between 5.9 and 9.0 mg/L and the salinity varied from 1.0 to 7.0‰. Chemical analysis of the sediments at Station SL25 in Sausage Lake indicated moderate levels of Ba (0.04 mg/g), Mn (0.46 mg/g), Sr (0.33 mg/g) and Cl (0.19 mg/g), while analysis of the bottom waters indicated amounts of Cl (2063 mg/L), Na (1300 mg/L), B (0.34 mg/L), K (48 mg/L), Sr (1.02 mg/L), NH_3 - N (0.31 mg/L), SO_4 (161 mg/L) and Mg (53.1 mg/L).

(6) The **Difflugia Assemblage** occurred in Steeprock Bay at three Stations, Point River Bay at one and Salt River Bay at one Station. This assemblage is dominated by populations of Difflugids ($0.32 < X_i < 0.60$) and Centropyxids ($0.25 < X_i < 0.52$). The Shannon Diversity Index varied between 1.2 and 2.4. *C. aculeata* strain "aculeata" and *D. protaeiformis* strain "claviformis" were found living in sediments comprised of a brown gyttja and occurred in water depths that varied between 3.7 to 6.0 metres deep. pH varied from 5.8 to 7.0, while salinity was negligible (0.00‰). The oxygen content varied from 9.6 mg/L at station PRB19 to 3.0 mg/L at station SRB48.

The salt spring at SRB49 on Salt Point near Steeprock Bay indicated high levels of B (0.0047 mg/g), P (1.82 mg/g) and As (0.067 mg/g) and a salinity of 54 ‰. The sediments in the vicinity of the spring were heavily coated with limonite as reported earlier by McKillop and others (1992). After mixing with the waters of the lake, the major ion concentrations fall between what is observed for aquatic freshwater and marine systems (Table 2-7; Morel and others, 1993).

DISCUSSION

The arcellacean and foraminiferal assemblages found in Dawson Bay cover a range of environments that could be found from marine settings to inland lakes polluted by mine tailings. The **Cribroelphidium Assemblage** is dominated by *C. gunteri* (0.73 - 0.99) and is similar to the type of assemblage that could be found in an estuary in a coastal marine intertidal setting (Nichols, 1974; Scott and others, 1980). The **Centropyxid Assemblage** is also dominated by *C. gunteri* (0.35 - 0.59), but contains abundant *C. aculeata* (0.22 - 0.42) and can contain significant Difflugids (0.00 - 0.42), and is similar to the type of assemblage that could be found in an upper estuary where river and marine processes meet (Scott and others, 1980). The **Lagenodifflugia Assemblage** is dominated by *L. vas* (0.69 - 0.76) and is found in a high pH (8.3 - 8.6) chemically polluted, brackish (3‰) lake. The **Moderate Diversity Assemblage** (Shannon Diversity Index 1.7 - 2.3) is dominated by *C. aculeata* strain "aculeata" (0.38 - 0.76) with abundant *D. corona* (0.20 - 0.43) and is similar to the more diverse assemblages that matured after the Holocene Hypsithermal (Collins and others, 1990). The ***Difflugia corona*** **Assemblage** is dominated by *D. corona* (0.43 - 0.79) and occurs in a low diversity setting (Shannon Diversity Index 0.07 - 1.7) as an opportunistic species in the salt spring polluted Sausage

Lake. *D. corona* discriminates its environment similar to what has been reported for polluted lakes elsewhere (Asioli and others. 1996: Patterson and others, 1996; Reinhardt and others. 1998). The **Difflugia Assemblage** is the most diverse assemblage in the area of Dawson Bay (Shannon Diversity Index 2.1 - 2.4) with many Centropyxid and Difflugid species represented. This assemblage is similar to modern mature assemblages which can be found in many Canadian lakes consisting of *C. aculeata*. *C. constricta*. *D. oblonga*. *D. urceolata* and *D. corona* (McCarthy and others, 1995). No assemblage was found in the samples obtained from the salt spring. These springs, however, bring a marine component into the surrounding bays and lakes, by injecting brines and metals into the waters. This has made the area a good natural laboratory within which to study the range of conditions from marine to marsh to freshwater, polluted or non-polluted. The environments in Steeprock Bay. Point River Bay, Salt River Bay, German Lake and Sausage Lake will be discussed with respect to the assemblages found in Dawson Bay.

Steeprock Bay

Previous research in Dawson Bay indicated that Steeprock Bay has numerous salt springs in and around (McKillop and others, 1992) it that provide brines (up to 60‰ at STR54) to the freshwater mix. Within this system, a range of environments exist that indicate Shannon Diversity indices from zero to 2.4. Not counting the toxic waters found at the salt springs, four assemblages were found in this bay, the Centropyxid, Moderate Diversity, Difflugia Corona and Difflugia assemblages. Salinities in the bay were close to zero except with the Moderate Diversity Assemblage in Steeprock Lagoon where it ranged up to 4‰. pH ranged from 6.8 at STR54 to 7.8 in Steeprock Lagoon and the oxygen content within the bay ranged from 4.5 in Steeprock Lagoon to 8.6 at STR54. all within the Moderate Diversity Assemblage which encompassed the greatest part of Steeprock Bay. Here. *C. aculeata* and *D. corona* were abundant with common *C. constricta*. *C. tricuspis* and *D. oblonga*. High levels of Fe and Mn are present. and high abundances of Centropyxids suggest conditions ranging from brackish (Scott. 1977: Scott and others. 1980b; Collins. 1996) to those chemically stressed (Patterson and others. 1996; Reinhardt and others. 1998). The Centropyxid domination of the Moderate Diversity Assemblage ties into what is expected with respect to pH ranges from 5.5 to 7.5.

Point River Bay

The environment in Point River Bay is similar to what can be found in estuaries (Scott and others. 1980) in a coastal or marine setting and is almost entirely dominated by the Cribroelphidium and Centropyxid Assemblages which show low diversity (0.01 - 1.75) and high abundances of *C. gunteri*. Live *C. gunteri* and *A. viriosa* were found with live Centropyxids in both assemblages. and also with live *D. oblonga* within the Centropyxid Assemblage. Here is a low salinity environment (0 - 2‰) with a large range of pH (5.1 - 8.3) and a wide range of oxygen (5.6 - 11.5 mg/L).

Salt River Bay

Salt River Bay indicates low populations of arcellaceans and foraminifera in a low diversity setting (0.07 - 1.83). The bay is dominated by the Moderate Diversity Assemblage with stable pH (6.9 - 7.0), low salinity (0.0 - 1.0‰) and variable oxygen content (2.7 to 9.6 mg/L). Under near anaerobic conditions, assemblages tended to be small with low diversity such as at SRB44 and SRB47 and were dominated by *C. aculeata*. Although the populations of Centropyxids, Difflugids and foraminifera are variable, the only live occurrence in Salt River Bay was *C. gunteri*.

German Lake

The major assemblage in German Lake, the *Lagenodifflugia* Assemblage, is dominated almost entirely by the opportunistic species *L. vas* (0.69 - 0.76) in a low diversity high pH environment (8.3 - 8.6). Found in waters 1.8 m deep, with a constant salinity of 3‰, this shallow lake, found among salt pans, showed higher temperatures (17.0 °C) which combined with the high pH to create a unique niche. *L. vas* has monopolized this environment similar to the way *A. vulgaris* has dominated and indicates a low pH environment (Patterson and Kumar, in press).

Sausage Lake

Sausage Lake is a chemical mix consisting of abundant amounts of dissolved Cl, Na, B, K, SO_4, Sr, NO_3 - N and Mg in solution, and is dominated by *D. corona* (0.43 - 0.79) in a low diversity setting (0.09 - 0.80). No live arcellaceans were found within the *D. corona* Assemblage, and counts of Centropyxids were low (0.00 - 0.15). Environmental stress caused by pollutants in lacustrine ecosystems can cause eutrophication and acidification of lake waters and sediments as was observed in Peterson and Crosswise lakes in northern Ontario (Patterson and others. 1996). As opposed to this. in Sausage Lake where the low diversity *D. corona* Assemblage exists in high pH. brackish waters. with low oxygen conditions.

Salt Spring STB49

C. aculeata. can withstand a variety of hostile conditions such as salinities up to 5‰ (Decloître. 1953; Scott and Medioli. 1980b; Patterson and others. 1985; Honig and Scott. 1987), cold temperatures (Decloître. 1956). low nutrient levels and oligotrophic conditions (Schönborn. 1984) and sites heavily contaminated with metals such as As (Patterson and others. 1996). In polluted oxic waters. arsenate is most common. while under anoxic conditions arsenite is common. Arsenic is often adsorbed onto iron and manganese oxyhydroxides present in oxic sediments (Cullen and Reimer. 1989). Most arcellaceans are benthic organisms which live at the sediment-water interface and tend to be good indicators of arsenic contamination (Patterson and others. 1996: Reinhardt and others. 1998). This is seen in the sediments of the salt spring located within Salt Point at Station 49. where As is in excess of current guidelines as indicated in Table 2-2. but unlike what was noted in the above studies. the environment at this site is hostile to benthic organisms. and the samples investigated were barren.

The overall aquatic environment at the sediment-water interface in Dawson Bay ranges from quite stressed. showing no live arcellaceans in the vicinity of the salt springs. to chemically stressed sites where few species are living, such as in Sausage Lake, to less stressed sites like German Lake, which has assemblages dominated by the opportunistic species *L. vas*, to brackish sites in Salt River Bay and Point River Bay which are dominated by the foraminifera *C. gunteri* and finally after mixing, to moderate diversity sites in Steeprock Bay which are dominated by Centropyxids and Difflugids.

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SYNONYMY

Numerous arcellacean species have been separated and defined through the years (Medioli and Scott, 1983, 1988). The systematic approaches utilized range 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 almost every variety recognized (Deflandre, 1928). Both approaches may be partially right as several distinct morphological populations can be observed within many arcellacean species. These strains develop in response to different environmental stresses, and can be considered ecomorphs. An abbreviated taxonomy as well as photomicrographs of the species discriminated (based on Medioli and Scott 1983) is provided along with diagnoses for infrasubspecific strains. Parentheses have been used to demarcate strains and to emphasize their infrasubspecific designation (Reinhardt and others, 1998).

Order ARCELLINIDA Kent 1880

Superfamily ARCELLACEA Ehrenberg 1830

Family **ARCELLIDAE** Ehrenberg 1830

Genus ***Arcella*** Ehrenberg 1830

Arcella vulgaris Ehrenberg 1830

Plate 2-1, figure 1; Plate 2-3, figure 3

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

Arcella vulgaris Ehrenberg 1830 REINHARDT and others 1998, pl. 1, fig. 3

Diagnosis: Test without spines, hyaline and transparent, aperture sub-terminal or occasionally central, circular or oval, invaginated.

Family **CENTROPYXIDIDAE** Deflandre 1953

Genus *Centropyxis* Stein 1859

Centropyxis aculeata (Ehrenberg 1832) strain "aculeata"

Plate 2-1, figures 2 - 3

Arcella aculeata EHRENBERG 1832, p.91

Centropyxis aculeata "aculeata" REINHARDT and others 1998, pl. 1, fig. 1

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

Centropyxis aculeata (Ehrenberg 1832) strain "discoides"

Plate 2-1, figure 4

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.151. pl. 5. figs. 38 - 41

Centropyxis discoides Penard [sic], OGDEN and HEDLEY 1980. p.54. pl. 16. figs. A - e

Centropyxis aculeata "discoides" REINHARDT and OTHERS 1998. pl. 1. fig. 2

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

Centropyxis constricta (Ehrenberg 1843) strain "aerophila"

Plate 2-1. figures 5 - 7

Centropyxis aerophila DEFLANDRE 1929

Centropyxis aerophila Deflandre OGDEN and HEDLEY 1980. p. 48 - 49

Cucurbitella [sic.] *constricta* REINHARDT and others 1998. pl. 1. fig. 6

Centropyxis constricta "aerophila" KUMAR and DALBY 1998. Issue 1. fig. 5-1

Diagnosis: Test varies from spherical. subspherical to elongated with thick aperural lip at an angle of 45° to 60° with respect to the test. Spines absent.

Centropyxis constricta (Ehrenberg 1843) strain "constricta"

Plate 2-1. figure 8

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

Centropyxis constricta "constricta" REINHARDT and others 1998, pl. 1, fig. 4

Diagnosis: Test flattened with three or less spines on the fundus.

Centropyxis constricta (Ehrenberg 1843) strain "spinosa"

Plate 2-1, figure 9

Centropyxis spinosa CASH in CASH and HOPKINSON 1905, p. 62, pl. 20, figs. a - d

Centropyxis spinosa Cash. OGDEN and HEDLEY 1980, p. 62, pl. 20, figs. a - d

Centropyxis constricta "spinosa" REINHARDT and others 1998, pl. 1, fig. 5

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

Family **DIFFLUGIDAE** Stein 1859

Genus *Difflugia* Leclerc in Lamarck 1816

Difflugia bidens Penard 1902

Plate 2-1, figure 10

Difflugia bidens PENARD 1902, p. 264, figs. 1 - 8

Difflugia bidens Penard MEDIOLI and SCOTT 1983, p. 21 - 22, pl. 1, figs. 1 - 5

Diagnosis: Test laterally compressed with two to three short spines. Aperture round and simple.

Difflugia corona Wallich 1864

Plate 2-1, figures 11 - 12

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 corona Wallich REINHARDT and others 1998. pl. 2. fig. 1

Diagnosis: Fundus with one to ten short spines. aperture circular. crenulated by six to 20 indentations forming a thin collar.

Difflugia fragosa HEMPEL 1898

Plate 2-1. figure 13

Difflugia fragosa HEMPEL 1898. p. 320. text-figs. 1-2

Difflugia fragosa Penard 1902. p. 573. fig. 2

Difflugia fragosa Averintsev 1906. p. 216

Difflugia fragrosa Schoutenden 1906. p. 344

Difflugia fragosa Harnisch 1958. p. 40. pl. 8. fig. 21 (after Penard. 1902)

Difflugia fragosa Scott and Medioli. 1983. p. 818. fig. 9o

Difflugia oblonga Ehrenberg 1832 strain "bryophila"

Plate 2-1. figures 14 - 15

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

Difflugia oblonga "bryophila" REINHARDT and others 1998, pl. 2, fig. 9

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

Difflugia oblonga Penard 1902 strain "glans"

Plate 2-1, figures 16 - 18

Difflugia oblonga "glans" PENARD 1902

Difflugia oblonga "glans" REINHARDT and others 1998, pl. 2, fig. 7

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

Difflugia oblonga Penard 1890 strain "lanceolata"

Plate 2-1, figure 19

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

Difflugia oblonga "lanceolata" REINHARDT and others 1998, pl. 2, fig. 6

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

Difflugia oblonga Ehrenberg 1832 strain "oblonga"

Plate 2-1. figures 20 - 21

Difflugia oblonga EHRENBERG 1832. p. 90

Difflugia oblonga Ehrenberg 1832. OGDEN and HEDLEY 1980. p. 148. pl. 63. figs. a - c

Difflugia oblonga Ehrenberg 1832. HAMAN 1982. p. 367. pl. 3. figs. 19 - 25

Difflugia oblonga Ehrenberg 1832. SCOTT and MEDIOLI 1983. p. 818. figs. 9a - b

Difflugia oblonga "oblonga" REINHARDT and others 1998. pl. 2. fig. 10

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

Difflugia oblonga Ehrenberg 1832 strain "spinosa"

Plate 2-1. figures 22 - 23

Difflugia oblonga var. *spinosa* REINHARDT 1998. p. 140. pl. 2. figs. 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

Difflugia oblonga Ehrenberg 1832 "tenuis"

Plate 2-1. figures 24 - 25

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

Difflugia oblonga "tenuis" REINHARDT and others 1998, pl. 2, fig. 12

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 strain "acuminata"

Plate 2-1, figure 26

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

Difflugia acuminata EHRENBERG 1830, p. 95

Difflugia acuminata Ehrenberg 1830, OGDEN and HEDLEY 1980, p. 118, pl. 4, figs. a - c

Difflugia acuminata Ehrenberg 1830, SCOTT and MEDIOLI 1983, p. 818, fig. 9d

Difflugia protaeiformis "acuminata" REINHARDT and others 1998, pl. 2, fig. 5

Diagnosis: Distinguished from *Difflugia protaeiformis "claviformis"* by having a thinner wall which appears transparent under a light microscope.

Difflugia protaeiformis REINHARDT and others 1998 strain "amphoralis"

Plate 2-1, figure 27

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 without lip. test smooth almost hyaline and small.

Difflugia protaeiformis Lamark 1816 strain "claviformis"

Plate 2-1. figures 28 - 29

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

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 and others. 1996. p. 250. pl. 2. fig. 1. a - b

Difflugia protaeiformis "*claviformis*" REINHARDT and others 1998. pl. 2. fig. 3

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

Difflugia urceolata Carter 1864 strain "elongata"

Plate 2-2. figure 1

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

Difflugia urceolata Carter 1864 REINHARDT and others 1998, pl. 2, fig. 2a

Diagnosis: Test elongate; aperture a distinct hanging collar.

Difflugia urceolata Carter 1864 strain "urceolata"

Plate 2-2, figures 2 - 3

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

Difflugia urceolata Carter 1864 REINHARDT and others 1998, pl. 2, fig. 2b

Diagnosis: Test spheroidal to ovoidal; aperture a distinct hanging collar.

Genus *Lagenodifflugia* MEDIOLI and SCOTT 1983

Lagenodifflugia vas (Leidy 1874)

Plate 2-2, figures 4 - 7

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

Family **HYALOSPHENIIDAE** Schultze 1877

Genus *Cucurbitella* Penard 1902

Cucurbitella tricuspis (Carter 1856)

Plate 2-2, figures 8 - 10

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

Cucurbitella tricuspis (Carter 1856) REINHARDT and others 1998, pl. 1, fig. 7

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

Order FORAMINIFERIDA Eichwald 1830

Superfamily ROTALIACEA Ehrenberg 1839

Family ELPHIDIIDAE Galloway 1933

Subfamily ELPHIDIINAE Galloway 1933

Genus *Cribroelphidium* Cushman and Brönnimann 1948

Cribroelphidium gunteri (Cole, 1931)

Plate 2-2, figures 11 - 15; Plate 2-3, figure 1

Cribroelphidium gunteri (Cole) PATTERSON 1990, pl. 2, figs. 1, 2

Elphidium gunteri (Cole) KNUDSEN in Feyling-Hanssen, Jrgensen, Knudsen and Anderson (eds.) 1971, p. 277, pl. 12, figs, 9, 10; pl. 21, figs. 4 - 7. (not *Elphidium gunteri* Cole, 1931)

Family AMMODISCIDAE Reuss, 1862

Subfamily AMMOVERTELLININAE Saidova. 1981

Genus *Annectina* Suleymanov. 1963

Annectina viriosa PATTERSON and MCKILLOP. 1991

Plate 2-2. figures 16 - 17; Plate 2-3. figure 2

Annectina viriosa PATTERSON and MCKILLOP. 1991. p. 36. fig. 3. 1 - 7

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Figure 2-1. Map showing the location of Dawson Bay in northern Lake Winnipegosis, Manitoba.

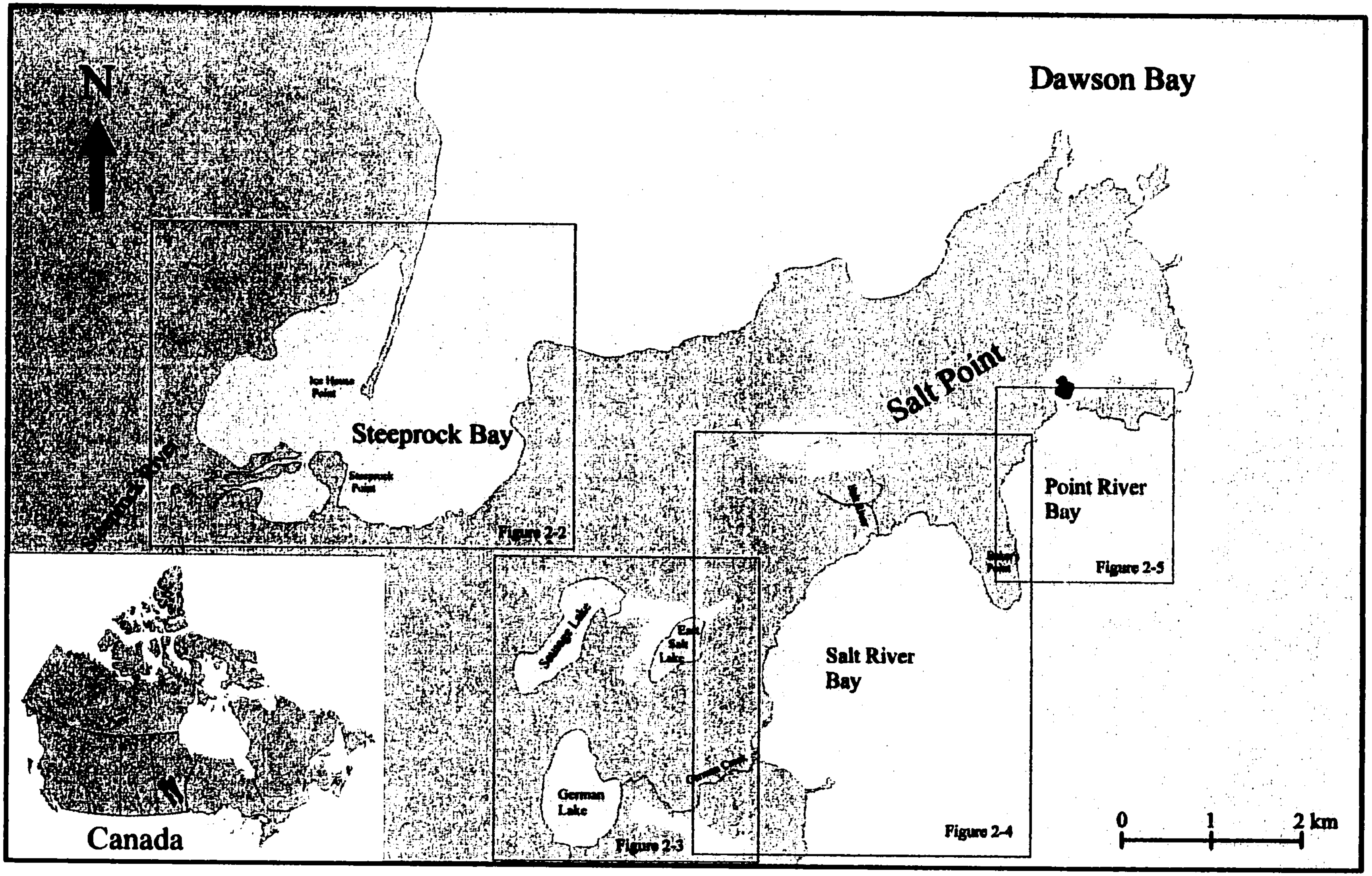
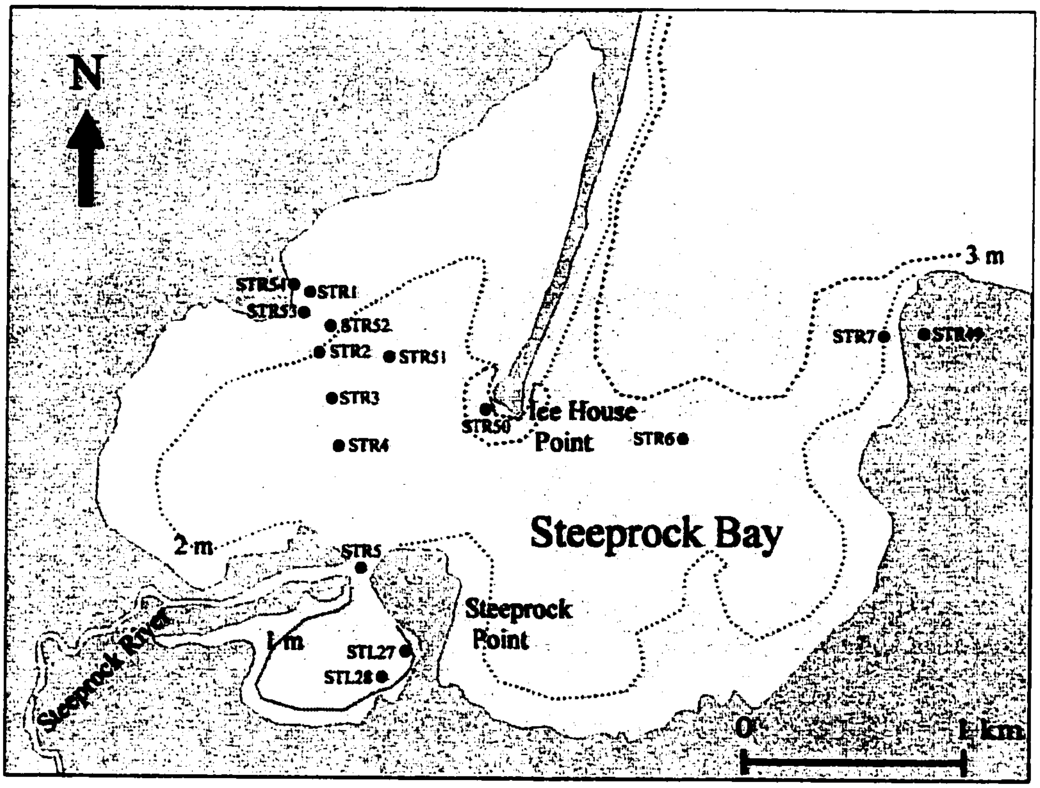

Dawson Bay
N
Salt Point
Steeprock Bay
Ice House Point
Steeprock Point
Figure 2-2
Point River Bay
Figure 2-5
Salt River Bay
Figure 2-4
East Salt Lake
German Lake
Figure 2-3
Canada
0
1
2 km

Figure 2-2. Map showing the locations of sample Stations in Steeprock Bay and Steeprock Lagoon.



N
STR54
STR1
STR53
STR52
STR2
STR51
STR3
STR4
STR50
Ice House
Point
STR6
3 m
STR7
2 m
STR5
Steeprock Bay
Steeprock
Point
1 m
STL27
STL28
Steeprock River
0
1 km

Figure 2-3. Map showing the locations of sample Stations in German Lake and Sausage Lake.

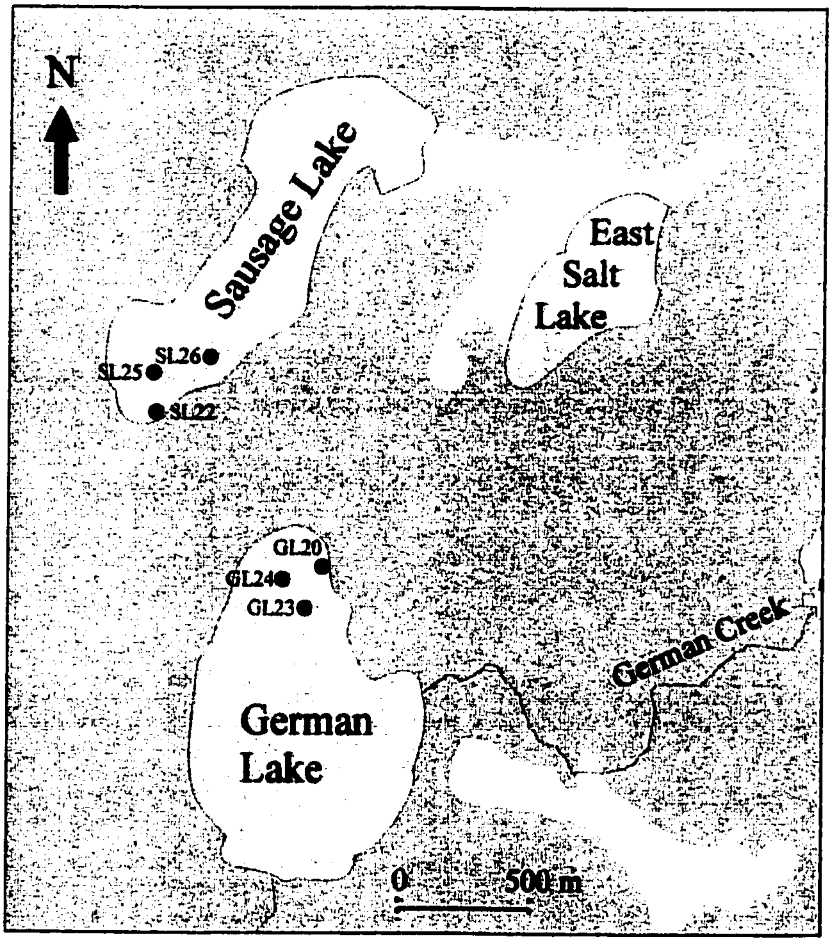

N
Sausage Lake
East
Salt
Lake
SL26
SL25
SL22
GL20
GL24
GL23
German
Lake
German Creek
0
500 m

Figure 2-4. Map showing the locations of sample Stations in Salt River Bay.

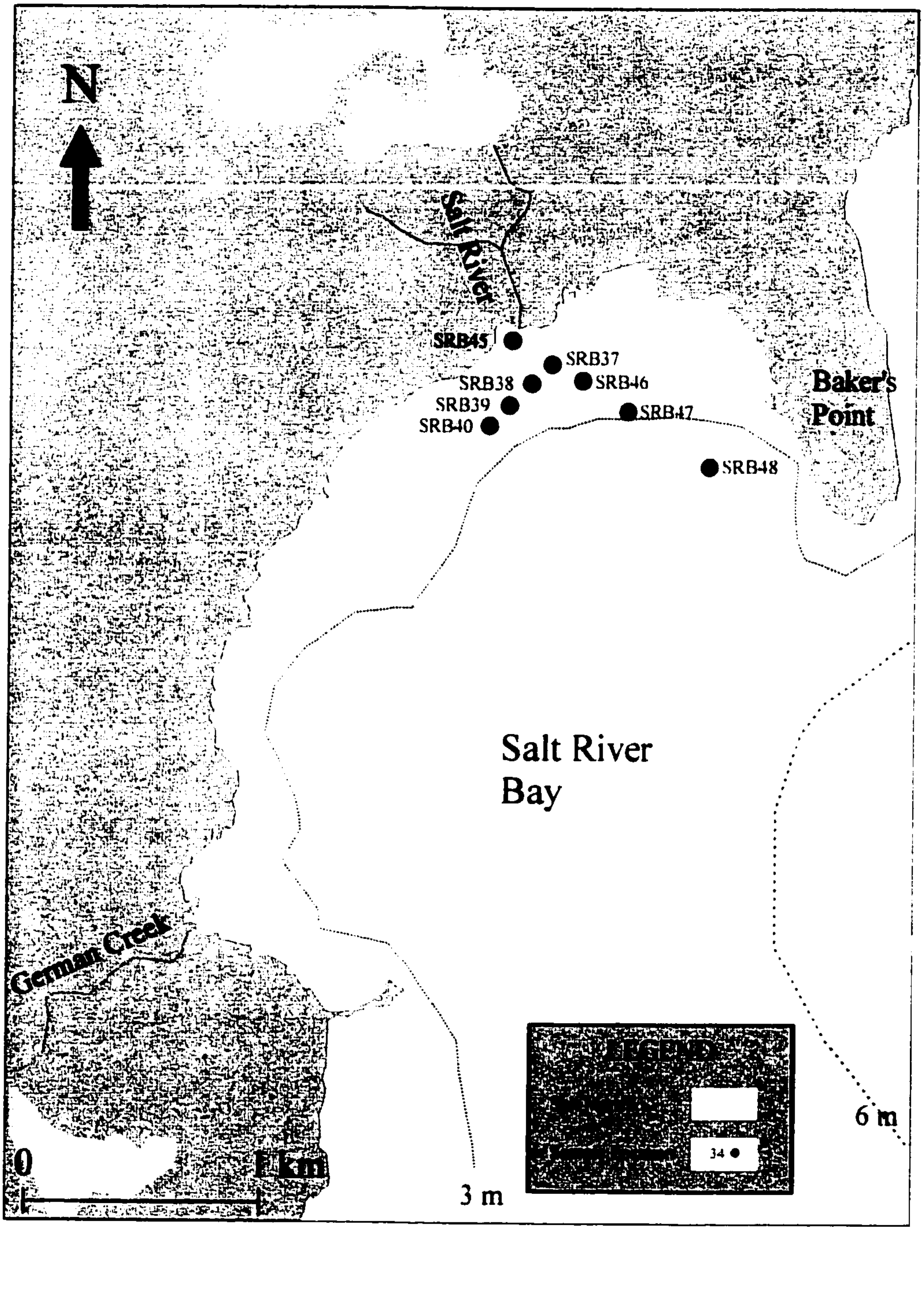

N
Salt River
SRB45
SRB37
SRB38
SRB46
SRB39
SRB47
SRB40
SRB48
Baker's Point
Salt River Bay
German Creek
6 m
3 m
0
1 km

Figure 2-5. Map showing the locations of sample Stations in Point River Bay.

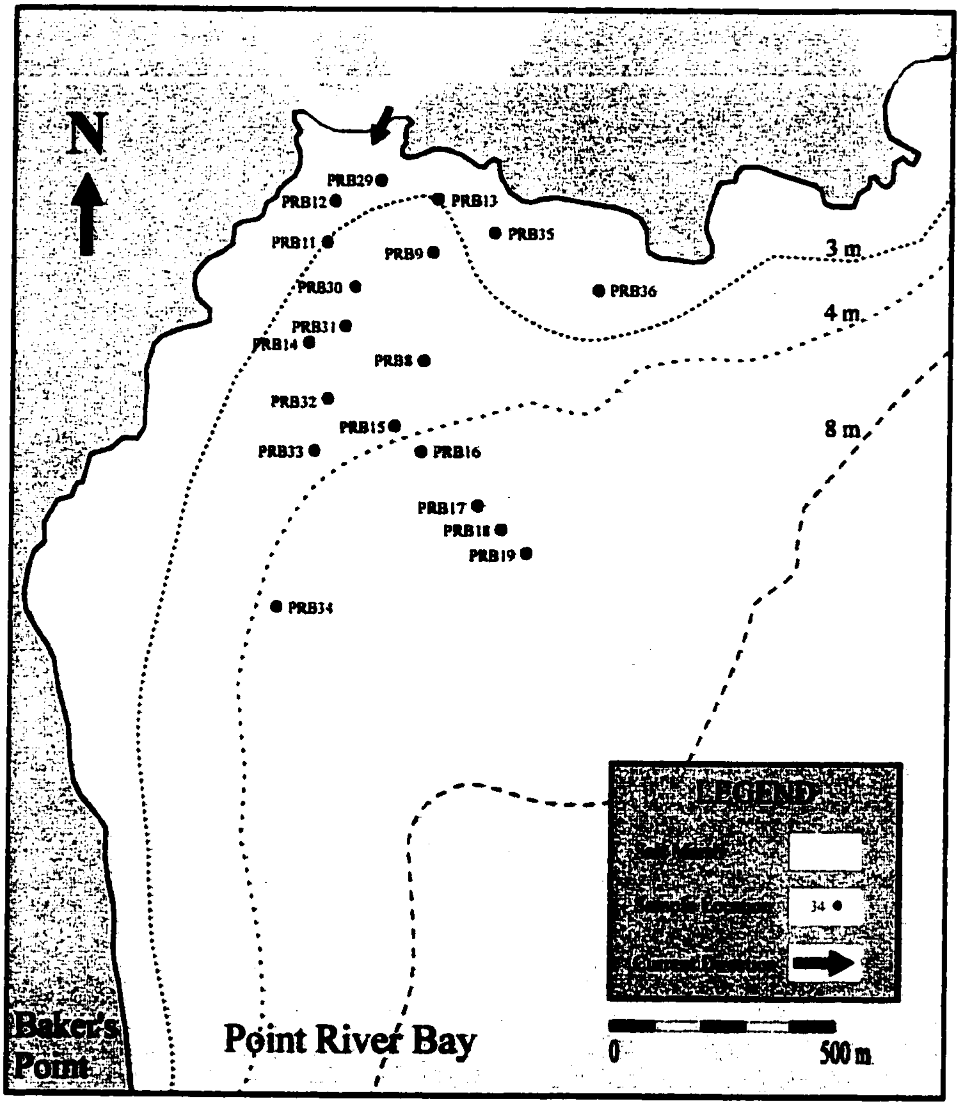
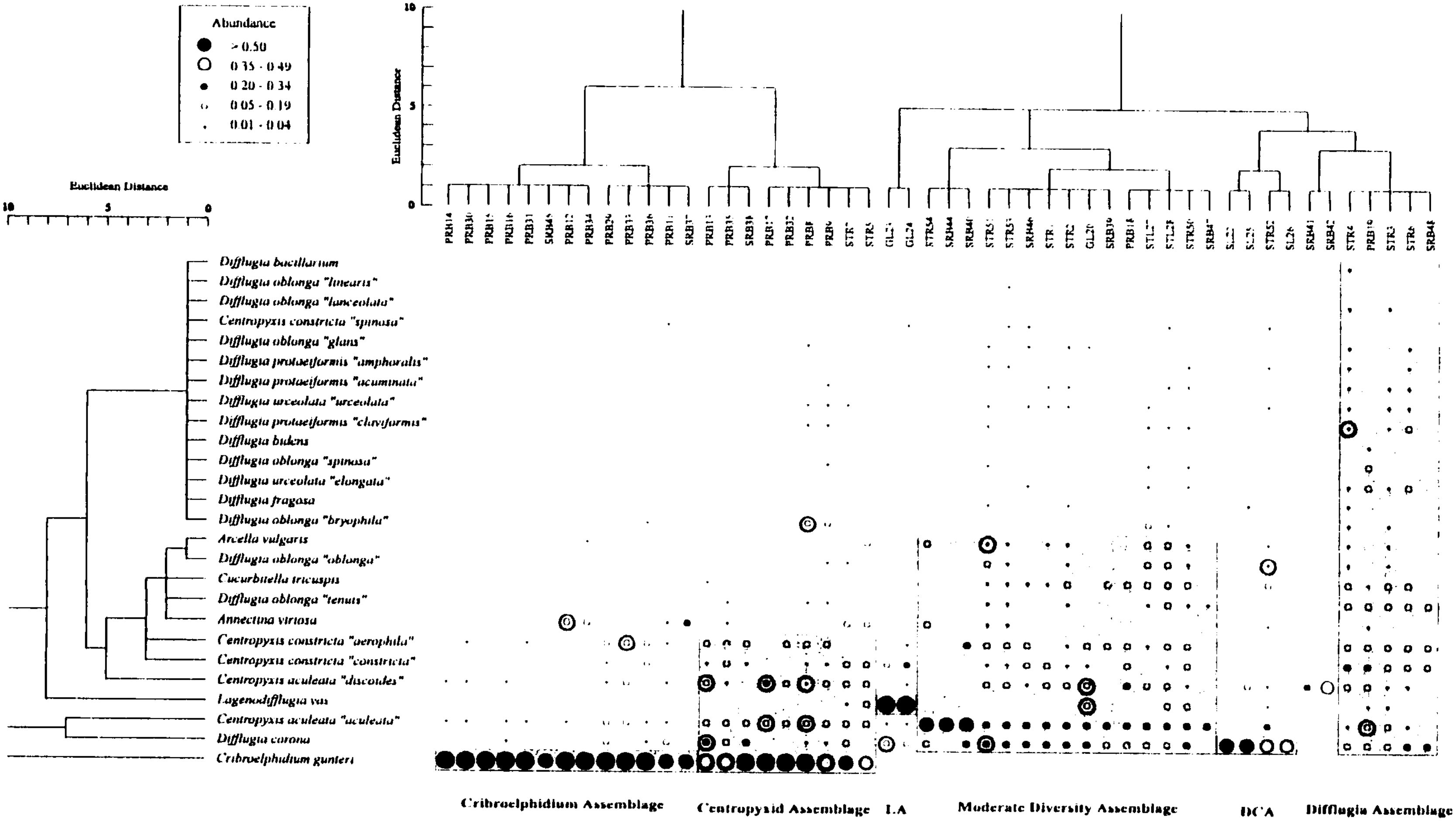

N
PRB29
PRB12
PRB13
PRB11
PRB9
PRB35
PRB30
PRB36
PRB31
PRB14
PRB8
PRB32
PRB15
PRB33
PRB16
PRB17
PRB18
PRB19
PRB34
3 m.
4 m.
8 m.
LEGEND
34
Baker's Point
Point River Bay
0
500 m

Figure 2-6. R-mode vs. Q-mode cluster diagram showing abundances for arcellaceans and foraminifera with assemblage relationships in Dawson Bay. Red circle indicates live arcellaceans or foraminifera within the population abundance (after Westrop and Cuggy, 1999).



Abundance
> 0.50
0.35 - 0.49
0.20 - 0.34
0.05 - 0.19
0.01 - 0.04
Euclidean Distance
Euclidean Distance
Difflugia bacillarium
Difflugia oblonga "linearis"
Difflugia oblonga "lanceolata"
Centropyxis constricta "spinosa"
Difflugia oblonga "glans"
Difflugia protaeiformis "amphoralis"
Difflugia protaeiformis "acuminata"
Difflugia urceolata "urceolata"
Difflugia protaeiformis "claviformis"
Difflugia bidens
Difflugia oblonga "spinosa"
Difflugia urceolata "elongata"
Difflugia fragosa
Difflugia oblonga "bryophila"
Arcella vulgaris
Difflugia oblonga "oblonga"
Cucurbitella tricuspis
Difflugia oblonga "tenuis"
Annectina viriosa
Centropyxis constricta "aerophila"
Centropyxis constricta "constricta"
Centropyxis aculeata "discoides"
Lagenodifflugia vas
Centropyxis aculeata "aculeata"
Difflugia corona
Cribroelphidium gunteri
Cribroelphidium Assemblage
Centropyxid Assemblage
LA
Moderate Diversity Assemblage
DCA
Difflugia Assemblage

Figure 2-7. Combined Q-mode and R-mode hierarchical diagram for chemical species in Dawson Bay, for both bottom waters and sediment at the sediment-water interface (after Westrop and Cuggy, 1999).

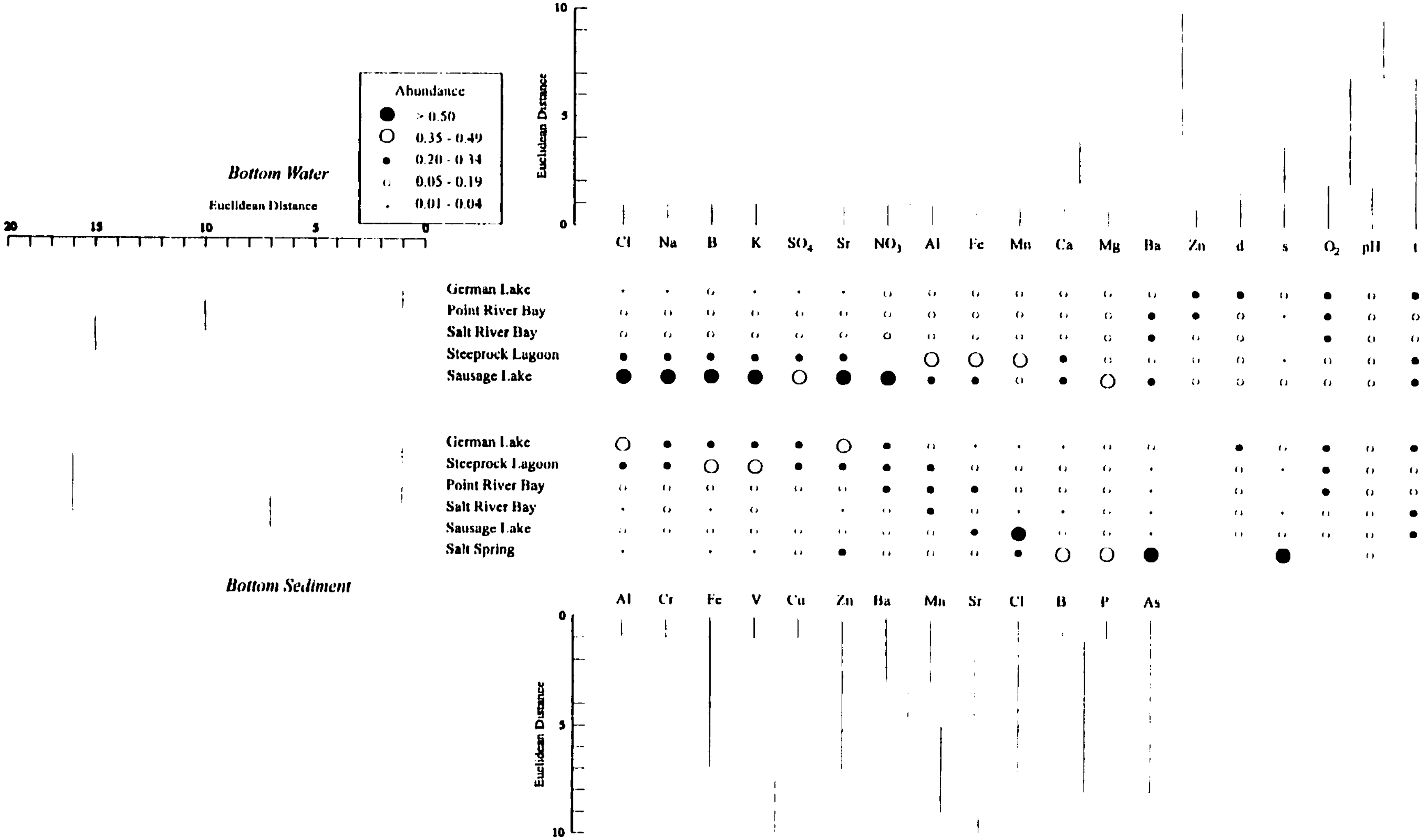

Bottom Water
Euclidean Distance
20
15
10
5
0
Abundance
> 0.50
0.35 - 0.49
0.20 - 0.34
0.05 - 0.19
0.01 - 0.04
Euclidean Distance
10
5
0
Cl
Na
B
K
SO_4
Sr
NO_3
Al
Fe
Mn
Ca
Mg
Ba
Zn
d
s
O_2
pH
t
German Lake
Point River Bay
Salt River Bay
Steeprock Lagoon
Sausage Lake
German Lake
Steeprock Lagoon
Point River Bay
Salt River Bay
Sausage Lake
Salt Spring
Bottom Sediment
Al
Cr
Fe
V
Cu
Zn
Ba
Mn
Sr
Cl
B
P
As
Euclidean Distance
0
5
10

Table 2-1. Physical data at sample Stations in Dawson Bay including depth, pH, oxygen content, salinity and temperature. No data was available for variables indicated by "-".

Station		Depth (metres)	pH	Oxygen (mg/L)	Salinity (‰)	Temperature (°C)
	STR1	1.0	-	-	-	-
	STR2	2.0	-	-	-	-
	STR3	3.0	-	-	-	-
	STR4	3.0	-	-	-	-
	STR5	1.5	-	-	-	-
	STR6	5.0	-	-	-	-
	STR7	2.0	-	-	-	-
	PRB8	3.0	-	-	-	-
1997	PRB9	2.0	-	-	-	-
	PRB11	3.0	8.6	9.6	-	13.3
	PRB12	2.0	6.1	11.5	-	12.6
	PRB13	3.0	4.6	9.6	-	13.6
	PRB14	4.0	5.1	9.4	-	13.4
	PRB15	4.0	4.9	8.4	-	13.6
	PRB16	4.0	6.3	9.1	-	13.8
	PRB17	4.5	5.9	10.1	-	13.9
	PRB18	5.0	5.8	10.0	-	13.9
	PRB19	6.0	5.9	9.6	-	14.1
	GL20	0.2	8.2	8.5	1	17.0
	GL23	1.8	8.6	8.6	3	17.0
	GL24	1.8	8.3	8.6	3	17.0
	SL22	0.2	8.0	9.0	6	17.0
	SL25	1.2	7.7	7.2	7	16.6
	SL26	1.2	7.8	7.2	6	16.6
	STL27	1.2	7.8	5.3	2	16.5
	STL28	2.7	7.7	6.9	4	16.7
	PRB29	1.2	7.9	9.3	2	15.3
	PRB30	2.8	8.3	9.4	1	15.0
	PRB31	3.4	8.3	9.3	0	15.2
	PRB32	4.0	7.0	9.3	0	15.2
	PRB33	3.4	6.9	9.4	0	15.1
	PRB34	4.3	7.0	9.3	0	15.3
	PRB35	1.8	7.0	9.4	0	15.0
	PRB36	2.1	7.0	5.6	0	15.6
1998	SRB37	0.9	7.0	9.6	0	14.0
	SRB38	1.2	6.9	9.2	0	15.1
	SRB39	2.0	6.9	9.3	1	15.2
	SRB40	2.4	6.9	9.4	0	15.7
	SRB41	3.0	7.0	9.2	0	15.6
	SRB42	3.7	6.9	9.5	0	15.7
	SRB43	3.7	6.9	9.2	0	15.8
	SRB44	4.3	6.9	2.7	0	15.8
	SRB45	1.2	6.9	6.5	0	12.8
	SRB46	2.4	6.9	6.5	2	12.9
	SRB47	3.0	7.0	3.0	1	14.5
	SRB48	3.7	7.0	3.0	0	14.5
	STR49	0.0	6.8	-	57	-
	STR50	2.7	7.3	4.5	3	14.5
	STR51	1.5	7.2	7.5	1	14.5
	STR52	1.5	7.2	5.9	1	15.4
	STR53	1.2	7.2	6.6	0	14.9
	STR54	0.9	6.8	8.6	60	13.6

Table 2-2. Chemical analysis of sediment and water samples from selected Stations in Dawson Bay (after Moore, 1991)

Chemical Species	*Bottom water (mg/L)*					*MDL*	*CG (mg/L)*	*Sediment (µg/g)*						*MDL*	*CG (µg/g)*
Stations	*23*	*25*	*27*	*29*	*37*			*23*	*25*	*27*	*29*	*37*	*49*		
Aluminum	0.06	0.34	0.6	0.14	0.1	0.05		11100	4360	9930	3430	1240	245	1	
Ammonia (N)					0.07	0.01	2.5								
Arsenic							0.05	4.9	0.8	2.8	1.4	0.3	66.7	1	50
Barium	0.01	0.04	0.03	0.04	0.04	0.01	1000	77	40	66	60	41	16	1	1000
Boron	0.03	0.34	0.13	0.06	0.06	0.01	5	0.41	1.42	1.43	1.45	0.47	4.68	0.02	5000
Calcium	26.5	97.3	66.7	56.3	56.5	1.0									
Chloride	19.9	2063	679	211	221	1.0		46	16860	3852	2962	193	6054	4	
Chromium							0.002	23	10	21	9	6		1	2
Copper							0.0002	14	8	15	6		2	1	0.2 - 0.4
Iron	0.11	0.27	0.59	0.12	0.2	0.01	0.3	15500	5320	17200	6770	1805	24	2	3000 - 1000
Manganese	0.031	0.026	0.097	0.034	0.022	0.005	0.05	121	163	480	374	465	129	1	
Magnesium	12.5	53.1	21.8	21.1	21.4	1.0									
Phosphorous								408	286	630	728	207	1815	20	
Potassium	1.3	48	16.5	9.5	9.9	1.0									
Sodium	13.7	1300	448	143	153	1.0									
Strontium	0.04	1.02	0.48	0.24	0.25	0.01		37	535	175	740	331	403	1	
Sulphate	3.2	161	67.5	48.7	49.3	1.0	400								
Zinc	0.03	0.02	0.02	0.04	0.02	0.02	0.03	93	27	54	22	2	64	2	30

Table 2-3. Total Stations and Species investigated in Dawson Bay.

Site	Stations	Insignificant Stations	Total Species	Insignificant Species	Diversity
Steeprock Bay	13	1	29	3	1.27 - 2.36
Steeprock Lagoon	2	-	25	2	2.06 - 2.18
German Lake	3	-	17	-	0.59 - 1.79
Sausage Lake	3	-	9	1	0.21 - 0.80
Salt River Bay	12	1	20	1	0.00 - 1.84
Point River Bay	19	-	24	1	0.01 - 2.02
Dawson Bay	***52***	***1***	***29***	***3***	***0.56***

Table 2-4. Taxonomic unit counts, Shannon Diversity, Abundances and Standard Error for sample stations in Dawson Bay.

Station	SB1	SB2	SB3	SB4	SB5	SB6	SB7
Taxonomic Counts	**199**	**535**	**595**	**523**	**59**	**539**	**210**
Diversity	**1.701**	**1.783**	**2.181**	**2.254**	**1.274**	**2.365**	**1.344**
Arcella vulgaris	0.111	0.022	0.010	0.011	0.068	0.002	0.000
standard error ±	0.044	0.013	0.008	0.009	0.064	0.004	0.000
Centropyxis aculeata "aculeata"	0.342	0.292	0.091	0.042	0.085	0.030	0.124
standard error ±	0.066	0.039	0.023	0.017	0.071	0.014	0.045
Centropyxis aculeata "discoides"	0.126	0.090	0.020	0.002	0.119	0.020	0.057
standard error ±	0.046	0.024	0.011	0.004	0.083	0.012	0.031
Centropyxis constricta "aerophila"	0.000	0.021	0.047	0.050	0.017	0.061	0.014
standard error ±	0.000	0.012	0.017	0.019	0.033	0.020	0.016
Centropyxis constricta "constricta"	0.070	0.034	0.131	0.331	0.136	0.130	0.062
standard error ±	0.036	0.015	0.027	0.040	0.087	0.028	0.033
Centropyxis constricta "spinosa"	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
Cribroelpnidium gunteri	0.010	0.002	0.003	0.000	0.288	0.000	0.510
standard error ±	0.014	0.004	0.005	0.000	0.116	0.000	0.068
Curcurbitella tricuspis	0.040	0.123	0.111	0.050	0.017	0.139	0.005
standard error ±	0.027	0.028	0.025	0.019	0.033	0.029	0.009
Difflugia bacillariarum	0.000	0.006	0.000	0.013	0.000	0.002	0.000
standard error ±	0.000	0.006	0.000	0.010	0.000	0.004	0.000
Difflugia bidens	0.000	0.004	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.005	0.000	0.000	0.000	0.000	0.000
Difflugia corona	0.241	0.241	0.129	0.107	0.000	0.020	0.081
standard error ±	0.059	0.036	0.027	0.027	0.000	0.034	0.037
Difflugia fragosa	0.005	0.007	0.003	0.008	0.000	0.000	0.000
standard error ±	0.010	0.007	0.005	0.007	0.000	0.000	0.000
Difflugia globulus	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "bryophila"	0.000	0.000	0.010	0.017	0.000	0.006	0.000
standard error ±	0.000	0.000	0.008	0.011	0.000	0.006	0.000
Difflugia oblonga "glans"	0.000	0.009	0.005	0.008	0.000	0.007	0.000
standard error ±	0.000	0.008	0.006	0.007	0.000	0.007	0.000
Difflugia oblonga "lanceolata"	0.000	0.002	0.013	0.008	0.000	0.002	0.000
standard error ±	0.000	0.004	0.009	0.007	0.000	0.004	0.000
Difflugia oblonga "linearis"	0.005	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "oblonga"	0.005	0.007	0.034	0.034	0.000	0.045	0.000
standard error ±	0.010	0.007	0.014	0.016	0.000	0.017	0.000
Difflugia oblonga "spinosa"	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
Difflugia oblonga "tenuis"	0.000	0.024	0.165	0.185	0.017	0.078	0.014
standard error ±	0.000	0.013	0.030	0.033	0.033	0.023	0.016
Difflugia oblonga "triangularis"	0.000	0.000	0.000	0.002	0.000	0.000	0.000
standard error ±	0.000	0.000	0.000	0.004	0.000	0.000	0.000
Difflugia protaeiformis "acuminata"	0.025	0.013	0.027	0.010	0.000	0.022	0.000
standard error ±	0.022	0.010	0.013	0.008	0.000	0.012	0.000
Difflugia protaeiformis "amphoralis"	0.000	0.002	0.003	0.023	0.000	0.011	0.000
standard error ±	0.000	0.004	0.005	0.013	0.000	0.009	0.000
Difflugia protaeiformis "claviformis"	0.000	0.000	0.025	0.025	0.000	0.048	0.000
standard error ±	0.000	0.000	0.013	0.013	0.000	0.018	0.000
Difflugia urceolata "elongata"	0.000	0.000	0.020	0.027	0.000	0.048	0.000
standard error ±	0.000	0.000	0.011	0.014	0.000	0.018	0.000
Difflugia urceolata "urceolata"	0.020	0.015	0.029	0.025	0.000	0.043	0.024
standard error ±	0.019	0.010	0.013	0.013	0.000	0.017	0.021
Lagenodifflugai vas	0.000	0.000	0.007	0.023	0.000	0.087	0.033
standard error ±	0.000	0.000	0.007	0.013	0.000	0.024	0.024
Nebella collaris	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.004	0.000	0.000	0.000	0.000	0.000

Station Taxonomic Counts Diversity	SB50 523 2.337	SB51 537 2.056	SB52 612 1.604	SB53 539 1.559	SB27 540 2.061	SB28 556 2.176	SB49 0 0
Arcella vulgaris	0.042	0.022	0.031	0.035	0.089	0.074	0.000
standard error ±	0.017	0.013	0.014	0.016	0.024	0.022	0.000
Centropyxis aculeata "aculeata"	0.216	0.276	0.222	0.299	0.278	0.318	0.000
standard error ±	0.035	0.038	0.033	0.039	0.038	0.039	0.000
Centropyxis aculeata "discoides"	0.031	0.056	0.034	0.056	0.094	0.049	0.000
standard error ±	0.015	0.019	0.014	0.019	0.025	0.018	0.000
Centropyxis constricta "aerophila"	0.054	0.069	0.039	0.069	0.026	0.047	0.000
standard error ±	0.019	0.021	0.015	0.021	0.013	0.018	0.000
Centropyxis constricta "constricta"	0.090	0.037	0.041	0.007	0.006	0.050	0.000
standard error ±	0.025	0.016	0.016	0.007	0.006	0.012	0.000
Centropyxis constricta "spinosa"	0.004	0.000	0.013	0.013	0.000	0.020	0.000
standard error ±	0.005	0.000	0.009	0.010	0.000	0.009	0.000
Cribroelphidium gunteri	0.000	0.002	0.000	0.000	0.007	0.011	0.000
standard error ±	0.000	0.004	0.000	0.000	0.007	0.009	0.000
Curcurbitella tricuspis	0.103	0.030	0.056	0.030	0.065	0.011	0.000
standard error ±	0.026	0.014	0.018	0.014	0.021	0.018	0.000
Difflugia bacillariarum	0.000	0.000	0.000	0.002	0.004	0.000	0.000
standard error ±	0.000	0.000	0.000	0.004	0.005	0.000	0.000
Difflugia bidens	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
Difflugia corona	0.201	0.268	0.431	0.295	0.174	0.088	0.000
standard error ±	0.034	0.037	0.039	0.039	0.032	0.024	0.000
Difflugia fragosa	0.002	0.017	0.000	0.002	0.000	0.000	0.000
standard error ±	0.004	0.011	0.000	0.004	0.000	0.000	0.000
Difflugia globulus	0.000	0.002	0.003	0.006	0.004	0.002	0.000
standard error ±	0.000	0.004	0.005	0.006	0.005	0.004	0.000
Difflugia oblonga "bryophila"	0.000	0.000	0.000	0.000	0.046	0.014	0.000
standard error ±	0.000	0.000	0.000	0.000	0.018	0.010	0.000
Difflugia oblonga "glans"	0.002	0.015	0.000	0.000	0.000	0.000	0.000
standard error ±	0.004	0.010	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "lanceolata"	0.000	0.000	0.000	0.000	0.000	0.002	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.004	0.000
Difflugia oblonga "linearis"	0.000	0.000	0.000	0.007	0.002	0.000	0.000
standard error ±	0.000	0.000	0.000	0.007	0.004	0.000	0.000
Difflugia oblonga "oblonga"	0.033	0.069	0.010	0.009	0.012	0.076	0.000
standard error ±	0.015	0.021	0.008	0.008	0.027	0.022	0.000
Difflugia oblonga "spinosa"	0.023	0.019	0.002	0.000	0.011	0.002	0.000
standard error ±	0.013	0.011	0.003	0.000	0.009	0.004	0.000
Difflugia oblonga "tenuis"	0.023	0.032	0.003	0.007	0.007	0.038	0.000
standard error ±	0.013	0.015	0.005	0.007	0.007	0.020	0.000
Difflugia oblonga "triangularis"	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
Difflugia protaeiformis "acuminata"	0.023	0.004	0.002	0.000	0.004	0.020	0.000
standard error ±	0.013	0.005	0.003	0.000	0.005	0.012	0.000
Difflugia protaeiformis "amphoralis"	0.034	0.009	0.016	0.015	0.000	0.002	0.000
standard error ±	0.016	0.008	0.010	0.010	0.000	0.004	0.000
Difflugia protaeiformis "claviformis"	0.044	0.019	0.000	0.002	0.022	0.038	0.000
standard error ±	0.018	0.011	0.000	0.004	0.012	0.016	0.000
Difflugia urceolata "elongata"	0.000	0.000	0.020	0.000	0.007	0.005	0.000
standard error ±	0.000	0.000	0.011	0.000	0.007	0.006	0.000
Difflugia urceolata "urceolata"	0.020	0.015	0.029	0.006	0.011	0.000	0.000
standard error ±	0.019	0.010	0.013	0.006	0.009	0.000	0.000
Lagenodifflugai vas	0.000	0.000	0.007	0.000	0.000	0.050	0.000
standard error ±	0.000	0.000	0.007	0.000	0.000	0.018	0.000
Nebella colllaris	0.000	0.002	0.000	0.000	0.002	0.000	0.000
standard error ±	0.000	0.004	0.000	0.000	0.004	0.000	0.000

Station Taxonomic Counts Diversity	SB54 180 2.061	SB20 217 1.788	SB23 135 0.587	SB24 240 1.039	SB22 25 0.208	SB25 91 0.801	SB26 28 0
Arcella vulgaris	0.033	0.000	0.007	0.000	0.000	0.000	0.036
standard error ±	0.026	0.000	0.014	0.000	0.000	0.000	0.069
Centropyxis aculeata "aculeata"	0.256	0.253	0.037	0.021	0.040	0.022	0.036
standard error ±	0.064	0.058	0.032	0.018	0.077	0.030	0.069
Centropyxis aculeata "discoides"	0.006	0.101	0.022	0.021	0.080	0.011	0.000
standard error ±	0.011	0.040	0.025	0.018	0.106	0.064	0.000
Centropyxis constricta "aerophila"	0.000	0.161	0.007	0.033	0.000	0.000	0.000
standard error ±	0.000	0.049	0.014	0.023	0.000	0.000	0.000
Centropyxis constricta "constricta"	0.000	0.041	0.022	0.050	0.040	0.011	0.036
standard error ±	0.000	0.027	0.025	0.028	0.077	0.021	0.069
Centropyxis constricta "spinosa"	0.000	0.014	0.000	0.017	0.000	0.000	0.000
standard error ±	0.000	0.016	0.000	0.016	0.000	0.000	0.000
Cribroelphidium gunteri	0.000	0.023	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.020	0.000	0.000	0.000	0.000	0.000
Curcurbitella tricuspis	0.006	0.000	0.007	0.004	0.040	0.000	0.000
standard error ±	0.011	0.000	0.014	0.008	0.077	0.000	0.000
Difflugia bacillariarum	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia bidens	0.000	0.009	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.013	0.000	0.000	0.000	0.000	0.000
Difflugia corona	0.028	0.203	0.119	0.158	0.076	0.505	0.107
standard error ±	0.024	0.053	0.055	0.046	0.167	0.103	0.115
Difflugia fragosa	0.000	0.005	0.000	0.000	0.000	0.088	0.000
standard error ±	0.000	0.009	0.000	0.000	0.000	0.058	0.000
Difflugia globulus	0.000	0.000	0.000	0.000	0.000	0.011	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.021	0.000
Difflugia oblonga "bryophila"	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
Difflugia oblonga "glans"	0.000	0.018	0.000	0.004	0.000	0.000	0.000
standard error ±	0.000	0.018	0.000	0.008	0.000	0.000	0.000
Difflugia oblonga "lanceolata"	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
Difflugia oblonga "linearis"	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
Difflugia oblonga "oblonga"	0.000	0.000	0.007	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.014	0.000	0.000	0.000	0.000
Difflugia oblonga "spinosa"	0.000	0.000	0.007	0.000	0.000	0.000	0.036
standard error ±	0.000	0.000	0.014	0.000	0.000	0.000	0.069
Difflugia oblonga "tenuis"	0.006	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "triangularis"	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
Difflugia protaeiformis "acuminata"	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
Difflugia protaeiformis "amphoralis"	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
Difflugia protaeiformis "claviformis"	0.000	0.000	0.007	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.014	0.000	0.000	0.000	0.000
Difflugia urceolata "elongata"	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
Difflugia urceolata "urceolata"	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
Lagenodifflugai vas	0.000	0.166	0.756	0.692	0.000	0.000	0.000
standard error ±	0.000	0.049	0.072	0.058	0.000	0.000	0.000
Nebella colllaris	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

Station Taxonomic Counts Diversity	SRB37 20 0.95	SRB38 136 0.963	SRB39 66 0.864	SRB40 50 0.96	SRB41 9 0.333	SRB42 4 0.5	SRB44 5 0.6	SRB45 26 0.962	SRB46 494 0.979	SRB47 12 0.583	SRB48 28 0.643
Arcella vulgaris	0.000	0.000	0.030	0.000	0.222	0.250	0.200	0.000	0.002	0.000	0.000
standard error =	0.000	0.000	0.041	0.000	0.272	0.424	0.351	0.000	0.004	0.000	0.000
Centropyxis aculeata "aculeata"	0.000	0.103	0.303	0.540	0.111	0.250	0.600	0.038	0.328	0.333	0.107
standard error =	0.000	0.051	0.111	0.138	0.205	0.424	0.429	0.074	0.041	0.267	0.115
Centropyxis aculeata "discoides"	0.000	0.007	0.015	0.040	0.333	0.500	0.200	0.000	0.028	0.083	0.071
standard error =	0.000	0.014	0.029	0.054	0.308	0.490	0.351	0.000	0.015	0.156	0.095
Centropyxis constricta "aerophila"	0.000	0.088	0.165	0.222	0.000	0.000	0.000	0.000	0.140	0.167	0.143
standard error =	0.000	0.048	0.090	0.115	0.000	0.000	0.000	0.000	0.031	0.211	0.130
Centropyxis constricta "constricta"	0.000	0.029	0.045	0.000	0.000	0.000	0.000	0.000	0.051	0.167	0.143
standard error =	0.000	0.028	0.050	0.000	0.000	0.000	0.000	0.000	0.019	0.211	0.130
Centropyxis constricta "spinosa"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000
Cribroelphidium gunteri	0.950	0.529	0.152	0.000	0.000	0.000	0.000	0.962	0.038	0.000	0.000
standard error =	0.096	0.084	0.087	0.000	0.000	0.000	0.000	0.074	0.017	0.000	0.000
Curcurbitella tricuspis	0.000	0.007	0.076	0.000	0.222	0.000	0.000	0.000	0.045	0.000	0.071
standard error =	0.000	0.014	0.064	0.000	0.272	0.000	0.000	0.000	0.018	0.000	0.095
Difflugia bacillariarum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Difflugia corona	0.000	0.213	0.165	0.200	0.111	0.000	0.000	0.000	0.269	0.250	0.214
standard error =	0.000	0.069	0.090	0.111	0.205	0.000	0.000	0.000	0.039	0.245	0.152
Difflugia fragosa	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
standard error =	0.096	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000
Difflugia globulus	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.036
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.069
Difflugia oblonga "bryophila"	0.000	0.007	0.045	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000
standard error =	0.000	0.014	0.050	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
Difflugia oblonga "glans"	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.000	0.000
standard error =	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000
Difflugia oblonga "oblonga"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Difflugia oblonga "tenuis"	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.000	0.143
standard error =	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.130
Difflugia protaeiformis "claviformis"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.071
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.095
Difflugia urceolata "elongata"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000
Difflugia urceolata "urceolata"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000
Lagenodifflugai vas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000

Station **Taxonomic Counts** **Diversity**	**PRB8** **516** **1.453**	**PRB9** **497** **1.752**	**PRB11** **316** **0.640**	**PRB12** **286** **0.298**	**PRB13** **438** **1.461**	**PRB14** **693** **0.159**	**PRB15** **636** **0.006**	**PRB16** **432** **0.302**	**PRB17** **107** **0.945**	**PRB18** **69** **1.778**
Arcella vulgaris	0.002	0.002	0.009	0.000	0.002	0.000	0.000	0.000	0.000	0.014
standard error =	0.004	0.004	0.011	0.000	0.004	0.000	0.000	0.000	0.000	0.028
Centropyxis aculeata "aculeata"	0.095	0.123	0.038	0.031	0.151	0.022	0.000	0.03	0.187	0.232
standard error =	0.025	0.029	0.021	0.02	0.034	0.011	0.000	0.016	0.074	0.1
Centropyxis aculeata "discoides"	0.033	0.068	0.022	0.007	0.046	0.009	0.005	0.016	0.196	0.203
standard error =	0.015	0.022	0.016	0.01	0.02	0.007	0.005	0.012	0.075	0.095
Centropyxis constricta "aerophila"	0.052	0.046	0.013	0.01	0.087	0.000	0.000	0.000	0.019	0.145
standard error =	0.019	0.018	0.012	0.012	0.026	0.000	0.000	0.000	0.026	0.083
Centropyxis constricta "constricta"	0.037	0.036	0.000	0.000	0.018	0.001	0.000	0.000	0.000	0.087
standard error =	0.016	0.016	0.000	0.000	0.013	0.003	0.000	0.000	0.000	0.066
Centropyxis constricta "spinosa"	0.004	0.002	0.013	0.003	0.005	0.000	0.000	0.000	0.000	0.000
standard error =	0.005	0.004	0.012	0.007	0.006	0.000	0.000	0.000	0.000	0.000
Cribroelphidium gunteri	0.591	0.495	0.826	0.916	0.457	0.964	0.994	0.935	0.589	0.159
standard error =	0.042	0.044	0.042	0.032	0.047	0.014	0.006	0.023	0.093	0.086
Cucurbitella tricuspis	0.006	0.002	0.003	0.000	0.016	0.000	0.000	0.000	0.009	0.058
standard error =	0.007	0.004	0.006	0.000	0.012	0.000	0.000	0.000	0.018	0.055
Difflugia bidens	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.014
standard error =	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.028
Difflugia corona	0.017	0.04	0.057	0.031	0.205	0.003	0.002	0.016	0.000	0.058
standard error =	0.011	0.017	0.026	0.02	0.038	0.004	0.003	0.012	0.000	0.055
Difflugia fragosa	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
Difflugia globulus	0.000	0.006	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.000	0.007	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "bryophila"	0.079	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014
standard error =	0.023	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028
Difflugia oblonga "glans"	0.01	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.008	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "lanceolata"	0.002	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error ±	0.004	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "oblonga"	0.006	0.012	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.014
standard error ±	0.007	0.01	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.028
Difflugia oblonga "spinosa"	0.002	0.012	0.03	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.004	0.01	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "tenuis"	0.017	0.022	0.003	0.000	0.000	0.001	0.000	0.000	0.000	0.000
standard error ±	0.011	0.013	0.006	0.000	0.000	0.003	0.000	0.000	0.000	0.000
Difflugia protaeiformis "acuminata"	0.006	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.007	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "amphoralis"	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "claviformis"	0.01	0.018	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error ±	0.008	0.012	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Difflugia urceolata "elongata"	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia urceolata "urceolata"	0.027	0.014	0.009	0.000	0.002	0.000	0.000	0.000	0.000	0.000
standard error =	0.014	0.01	0.011	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Lagenodifflugai vas	0.002	0.002	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000
standard error =	0.004	0.004	0.000	0.000	0.004	0.000	0.000	0.005	0.000	0.000

Station Taxonomic Counts Diversity	PRB19 132 2.018	PRB29 443 0.962	PRB30 606 0.162	PRB31 343 0.224	PRB32 65 1.070	PRB33 83 0.797	PRB34 161 0.128	PRB35 401 1.465	PRB36 435 0.848
Arcella vulgaris	0.000	0.002	0.002	0.000	0.000	0.012	0.025	0.002	0.000
standard error =	0.000	0.004	0.003	0.000	0.000	0.023	0.024	0.005	0.000
Centropyxis aculeata "aculeata"	0.136	0.077	0.012	0.029	0.108	0.120	0.006	0.120	0.044
standard error =	0.059	0.025	0.009	0.018	0.075	0.070	0.012	0.032	0.019
Centropyxis aculeata "discoides"	0.053	0.032	0.008	0.009	0.138	0.048	0.006	0.035	0.000
standard error =	0.038	0.016	0.007	0.010	0.084	0.046	0.012	0.018	0.000
Centropyxis constricta "aerophila"	0.091	0.065	0.008	0.015	0.123	0.060	0.000	0.117	0.087
standard error =	0.049	0.023	0.007	0.013	0.080	0.051	0.000	0.031	0.027
Centropyxis constricta "constricta"	0.258	0.014	0.002	0.000	0.000	0.000	0.000	0.047	0.060
standard error =	0.075	0.011	0.003	0.000	0.000	0.000	0.000	0.021	0.022
Centropyxis constricta "spinosa"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000
Cribroelphidium gunteri	0.008	0.731	0.969	0.939	0.615	0.735	0.963	0.489	0.763
standard error =	0.015	0.041	0.014	0.025	0.118	0.095	0.029	0.049	0.040
Curcurbitella tricuspis	0.045	0.002	0.000	0.000	0.000	0.012	0.000	0.007	0.002
standard error =	0.036	0.004	0.000	0.000	0.000	0.023	0.000	0.008	0.005
Difflugia bidens	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia corona	0.114	0.072	0.000	0.009	0.015	0.012	0.000	0.142	0.009
standard error =	0.054	0.024	0.000	0.010	0.030	0.023	0.000	0.034	0.009
Difflugia fragosa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
Difflugia globulus	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
Difflugia oblonga "bryophila"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.021
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.013
Difflugia oblonga "glans"	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "lanceolata"	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "oblonga"	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
standard error =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005
Difflugia oblonga "spinosa"	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005
standard error =	0.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
Difflugia oblonga "tenuis"	0.053	0.002	0.000	0.000	0.000	0.000	0.000	0.017	0.000
standard error =	0.038	0.004	0.000	0.000	0.000	0.000	0.000	0.013	0.000
Difflugia protaeiformis "acuminata"	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "amphoralis"	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
Difflugia protaeiformis "claviformis"	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia urceolata "elongata"	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
standard error ±	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008
Difflugia urceolata "urceolata"	0.023	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error =	0.025	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lagenodifflugai vas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000

Table 2-5. Population abundances of arcellaceans and foraminifera with respect to diversity in Dawson Bay.

Site	Diversity	*Cribroelphidium gunteri*	Centropyxids	Difflugids	*Lagenodifflugia vas*
Steeprock Bay	low	0.39 - 0.55	0.26 - 0.77	0.00 - 0.11	0.04
	moderate	0.00 - 0.02	0.25 - 0.56	0.22 - 0.51	0.01 - 0.08
German Lake	low	0.00	0.04 - 0.14	0.12 - 0.15	0.69 - 0.76
	moderate	0.00 - 0.02	0.56	0.22	0.17
Sausage Lake	low	0.00	0.00 - 0.15	0.43 - 0.79	0.00
	moderate	0.00	0.00	0.00	0.00
Salt River Bay	low	0.15 - 0.96	0.00 - 0.47	0.00 - 0.36	0.00
	moderate	0.04	0.56	0.34	0.00
Point River Bay	low	0.46 - 0.99	0.00 - 0.40	0.00 - 0.22	0.00
	moderate	0.01 - 0.50	0.28 - 0.67	0.10 - 0.41	0.00
SS23	low	0.00	0.77	0.08	0.00
	moderate	-	-	-	-

Table 2-6. Assemblages in Dawson Bay, based on the results of multivariate analysis.

Site	Assemblage	Diversity	% Cribroelphidium gunteri	% Centropyxids	% Difflugids	% Lagenodifflugia vas
Point River Bay	**Cribroelphidium**	0.01 - 1.0	0.73 - 0.99	0.00 - 0.18	0.00 - 0.07	0.00
	Centropyxid	0.95 - 1.75	0.46 - 0.59	0.22 - 0.38	0.00 - 0.41	0.00
	Moderate Diversity	1.8	0.16	0.67	0.06	0.00
	Difflugia	2.1	0.00	0.52	0.32	0.00
Steeprock Bay	**Centropyxid**	1.5 - 1.6	0.35 - 0.51	0.24 - 0.42	0.00 - 0.46	0.09
	Moderate Diversity	1.7 - 2.3	0.00 - 0.02	0.38 - 0.61	0.07 - 0.49	0.00 - 0.06
	Difflugia corona	1.7	0.00	0.37	0.49	0.01
	Difflugia	2.3 - 2.4	0.00	0.25 - 0.42	0.51 - 0.60	0.01 - 0.09
German Lake	**Lagenodifflugia**	0.6 - 1.0	0.00	0.04 - 0.14	0.12 - 0.16	0.69 - 0.76
	Moderate Diversity	0.18	0.02	0.56	0.22	0.17
Sausage Lake	**Difflugia corona**	0.09 - 0.80	0.00	0.00 - 0.15	0.43 - 0.79	0.00
Salt River Bay	**Cribroelphidium**	0.07 - 0.57	0.73 - 0.93	0.00	0.00	0.00
	Centropyxid	1.2	0.53	0.21	0.21	0.00
	Moderate Diversity	0.31 - 1.83	0.00 - 0.15	0.27 - 0.76	0.00 - 0.34	0.00
	Difflugia	1.2	0.00	0.29	0.36	0.00

Table 2-7. Major ion concentrations in Dawson Bay compared to freshwater and seawater (after Morel and others. 1993; *McKillop and others. 1992).

Ion	Freshwater (mg/L)	Dawson Bay (mg/L)	Marine (mg/L)
HCO_3^-	52.47	*120 - 438	145.22
SO_4^{2-}	6.63	3.2 - 161	2708.78
Cl^-	5.67	19.9 - 2063	19321.88
Ca^{2+}	13.23	26.5 - 97.3	408.79
Mg^{2+}	3.65	12.5 - 53.1	1293.03
Na^+	5.29	13.7 - 1300	10759.32
K^+	1.17	1.3 - 48	398.79

Plate 2-1. **1**. *Arcella vulgaris* Ehrenberg, 1830; x136. **2 - 3**. *Centropyxis aculeata* (Ehrenberg, 1832) strain "aculeata"; 2. Apertural view with few spines; x172. 3. Apertural view with six spines; x221. **4**. *Centropyxis aculeata* (Ehrenberg, 1832) strain "discoides": x164. **5 - 7**. *Centropyxis constricta* (Ehrenberg, 1843) strain "aerophila"; 5. Apertural view; x155. 6. 3/4 view; x174; 7. Side view: x243. **8**. *Centropyxis constricta* (Ehrenberg, 1843) strain "constricta"; x158. **9**. *Centropyxis constricta* (Ehrenberg, 1843) strain "spinosa"; x182. **10**. *Difflugia bidens* Penard, 1902; x142. **11 - 12**. *Difflugia corona* Wallich, 1864; 11. Specimen showing spines; x187. 12. Close up of crenulated aperture; x436. **13**. *Difflugia fragosa* Hempel, 1898; x162. **14 - 15**. *Difflugia oblonga* (Ehrenberg, 1832) strain "bryophila"; 14. Side view; x104. 12. Side view; x110. **16 - 18**. *Difflugia oblonga* (Penard, 1902) strain "glans"; 16. Side view; x 124. 17. Side view; x 169. 18. Apertural view; x159. **19**. *Difflugia oblonga* (Penard, 1890) strain "lanceolata"; x264. **20 - 21**. *Difflugia oblonga* (Ehrenberg, 1832) strain "oblonga"; 20. Apertural view; x135. 21. Side view; x79. **22 - 23**. *Difflugia oblonga* (Ehrenberg, 1832) strain "spinosa"; 22. Side view: x91. 23. Apertural view; x119. **24 - 25**. *Difflugia oblonga* (Ehrenberg, 1832) strain "tenuis"; 24. Side view; x96. 25. Side view; x101. **26**. *Difflugia protaeiformis* (Lamarck, 1816) strain "acuminata"; x122. **27 - 29**. *Difflugia protaeiformis* (Lamarck, 1816) strain "claviformis"; 27. Side view; x93. 28. Side view; x104. 29. Side view; x94.

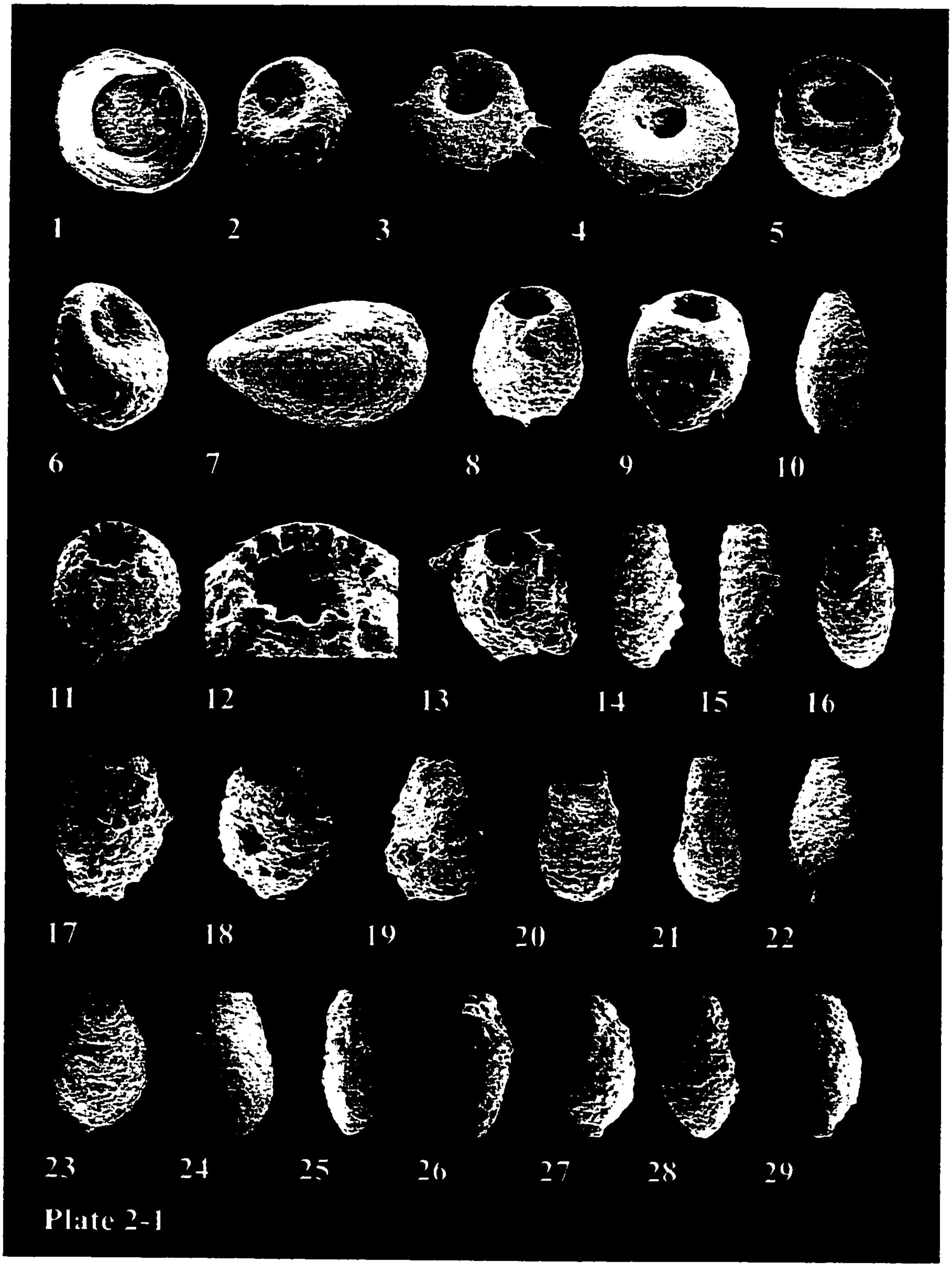


Plate 2-1

.Plate 2-2. **1**. *Difflugia urceolata* (Carter, 1864) strain "elongata"; x99. **2 - 3**. *Difflugia urceolata* (Carter, 1864) strain "urceolata": 31. Side view; x122. 32. Side view; x101. **4 - 7**. *Lagenodifflugia vas* Leidy, 1874: 33. Side view; x121. 34. Side view; x130. 35. Side view; x115. 36. Apertural view: x139. **8 - 10**. *Cucurbitella tricuspis* (Carter, 1856); 37. Side view: x146. 38. Attached to a branch; x150. 39. Apertural view: x200. **11 - 15**. *Cribroelphidium gunteri* (Cole, 1931). 40. Side view of a convoluted specimen: x141. 41.Side view: x121. 42. Side view: x92. 43. Side view: x113. 44. Side view; x73. **16 - 17**. *Annectina viriosa* Patterson and McKillop, 1991: 45. Corroded specimen: x82. 46. Side view; x134.

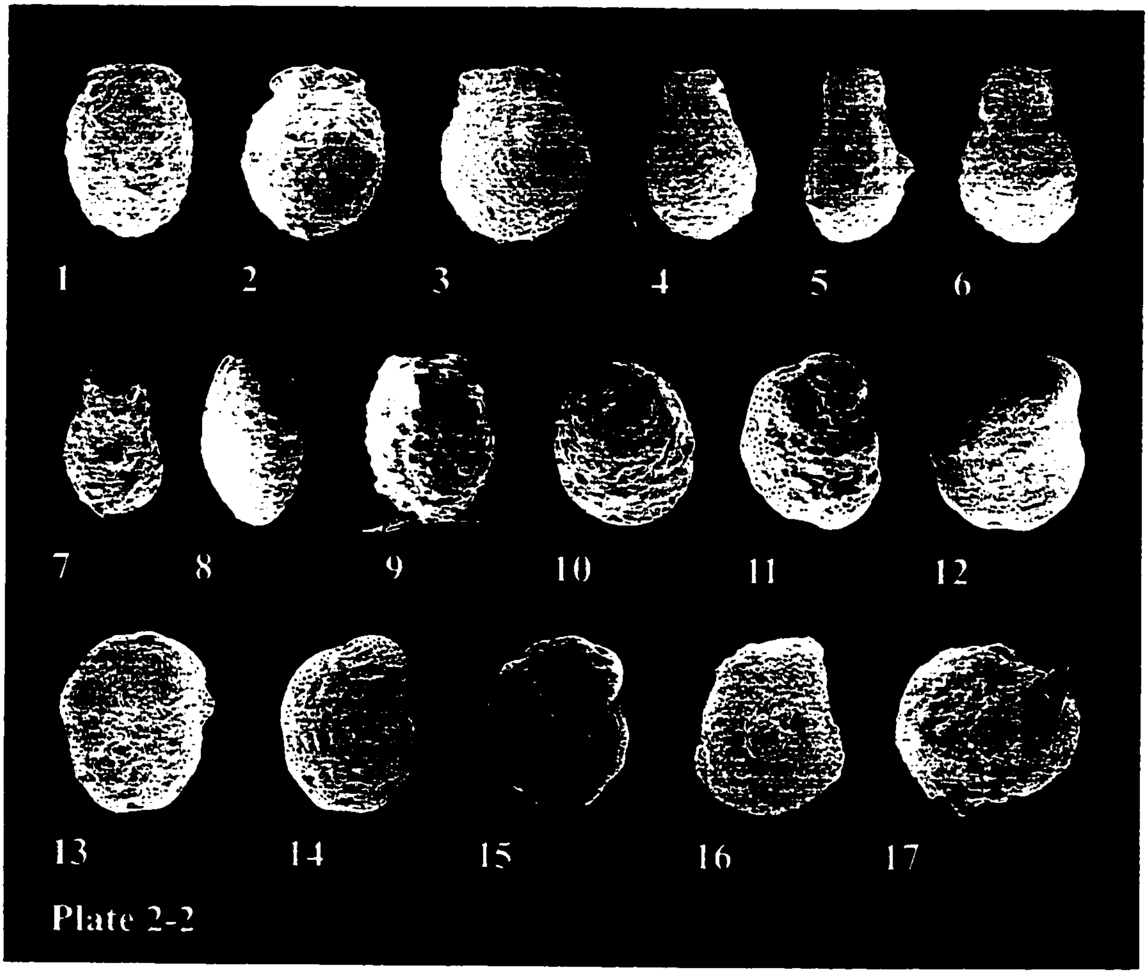


Plate 2-2

Plate 2-3. Specimens stained with Rose Bengal biological stain showing globs of protoplasm. **1.** *Cribroelphidium gunteri* (Cole, 1931). **2.** *Annectina viriosa* Patterson and McKillop, 1991. **3.** *Arcella vulgaris* Ehrenberg, 1830.

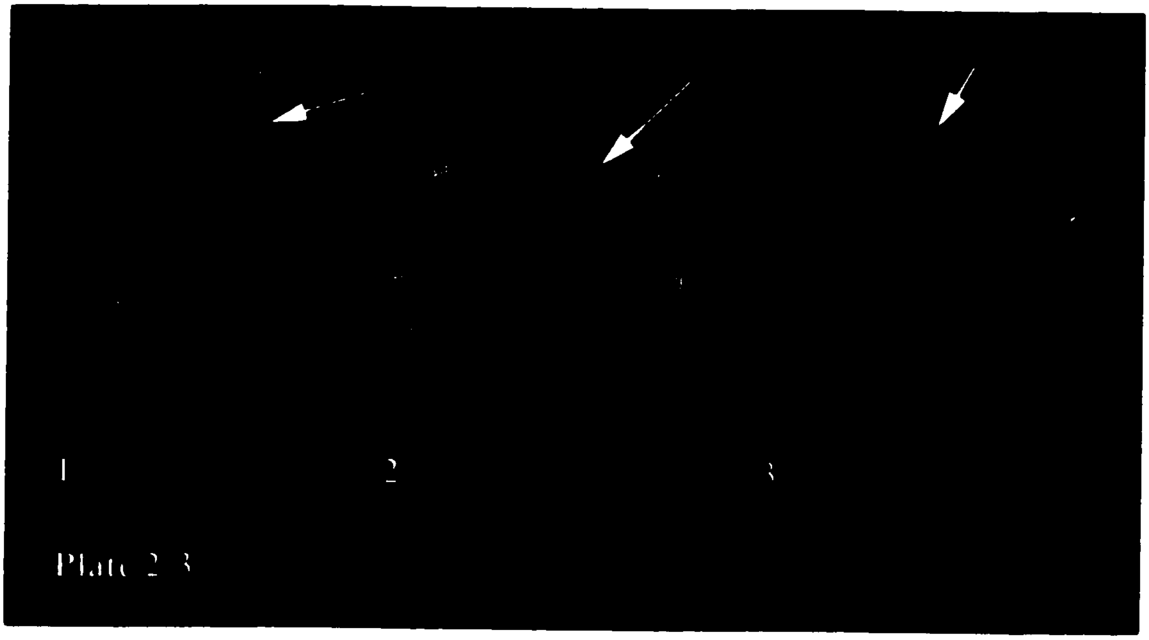


Plate 2.3

CONCLUSION

This research has placed a live foraminifera. *Cribroelphidium gunteri* (Cole. 1931) into a non-marine. inland setting where previous research had concluded that is was present in the fossil record. but. had not survived the cooler temperatures since the Holocene Hypsithermal warm interval. This is significant because it indicates that this foraminifera is not be restricted to marine environments. or that salt marsh conditions existed when *C. gunteri* was deposited in Point River Bay. This highly adaptable foram is able to adapt to low salt conditions. while being dependant upon a specific range of temperature to reproduce. This research has placed *Cribroelphidium gunteri* Cole. 1931 further north than any other known occurrence of this species in the world.

The range of environments presented in this natural laboratory set in northern Lake Winnipegosis. Manitoba. have given us an opportunity to investigate assemblages found elsewhere in a variety of environments. Moderately diverse freshwater assemblages. such as the **Moderate Diversity** and ***Difflugia* Assemblages**. were dominated by centropyxids and difflugids in Steeprock Bay; while brackish environments showed estuarine assemblages, such as ***Cribroelphidium*** and **Centropyxid Assemblages**, and were dominated by *Cribroelphidium gunteri* in Point River Bay and Salt River Bay. In addition. some stressed environments had assemblages dominated by opportunistic species. *Lagenodifflugia vas* Leidy, 1874. a high pH indicator represented the ***Lagenodifflugia* Assemblage** in German Lake. The ***Difflugia Corona* Assemblage** in

Sausage Lake, dominated by *Difflugia corona* Wallich, 1864, lives in a low diversity, chemically stressed environment.

This research has shown that Dawson Bay includes a variety of environments, found usually in separate geographical settings, that indicate diverse assemblages. Using this study as a baseline, a time line should be investigated in order to determine what assemblages and corresponding environments existed back to the Wisconsinan Glaciation.

GLOSSARY

Hostile	High stressed environment with small numbers of species of arcellaceans and or foraminifera due to any number of chemical or physical parameters mentioned in this report
Lake	Northern Lake Winnipegosis in the vicinity of Dawson Bay, including the bays and smaller lakes in this report, unless specified otherwise
Polluted	Any physical or chemical parameter that puts stress on an assemblage and restricts the number of species or taxa within that assemblage
Population	Number of taxa within an assemblage
Taxon	Number of species within an assemblage