

## A COMPARISON OF POSTGLACIAL ARCELLACEAN ("THECAMOEBIAN") AND POLLEN SUCCESSION IN ATLANTIC CANADA, ILLUSTRATING THE POTENTIAL OF ARCELLACEANS FOR PALEOCLIMATIC RECONSTRUCTION

FRANCINE M. G. MCCARTHY,<sup>1</sup> ERIC S. COLLINS,<sup>2</sup> JOHN H. McANDREWS,<sup>3</sup>  
HELEN A. KERR,<sup>4</sup> DAVID B. SCOTT,<sup>2</sup> AND FRANCO S. MEDIOLI<sup>2</sup>

<sup>1</sup>Department of Earth Sciences, Brock University, St. Catharines, Ontario, L2S 3A1

<sup>2</sup>Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia, B3H 3J5

<sup>3</sup>Department of Botany, Royal Ontario Museum, and Departments of Botany and Geology,  
University of Toronto, Toronto, Ontario, M5S 2C6, and

<sup>4</sup>Department of Fisheries and Oceans, Gulf Region, Moncton, New Brunswick E1C 9B6

**ABSTRACT**—Cores dating back to deglaciation were taken from three lakes in Atlantic Canada and analyzed for arcellaceans and pollen. Paleotemperatures and paleo-precipitation were calculated from the pollen data using transfer functions. A sudden warming is recorded by the pollen around 10,000 years B.P., followed by a general warming to the mid Holocene Hypsithermal, then by a decrease in temperature and increase in effective precipitation to the present. The three lakes, two in western Newfoundland and one in eastern Nova Scotia, contain similar late glacial (13–10 ka), early Holocene (10–8 ka), mid Holocene (8–4 ka), and late Holocene (4–0 ka) arcellacean assemblages. Immediately following retreat of the ice sheets, *Centropyxis aculeata*, *Centropyxis constricta*, *Diffugia oblonga*, *Diffugia urceolata*, and *Diffugia corona* were common. The latter part of the late glacial is characterized by sparse assemblages dominated by *C. aculeata*. The arcellacean record thus suggests a climatic reversal in Atlantic Canada between 11,500 and 10,000 years B.P., analogous to the Younger Dryas, although this is not recorded by the pollen. Species diversity increased sharply at the beginning of the Holocene, and *D. oblonga* is the dominant taxon in early Holocene sediments. *Diffugia oblonga* remained common through the mid Holocene, but percentages of *C. aculeata* were very low, and *Pontigulasia compressa* and *Diffugia bacillifera* peaked in abundance during the Hypsithermal. The late Holocene is characterized by a resurgence in *C. aculeata* at the expense of other taxa. The increase in *Heleopera sphagni* and *Nebella collaris* since 5,000 years B.P. at the two sites in southwestern Newfoundland reflects paludification in response to increased precipitation since the Hypsithermal. Because the changes in arcellacean assemblages are regionally synchronous in all three lakes and coincide with climatically driven vegetational successions indicated by the pollen record, arcellaceans appear to respond to climatic change, and thus may be useful paleoecological and paleolimnological indicators. With their quicker generation time, these protists may be better suited than pollen to recording short-lived phenomena, like the mid-Holocene Hypsithermal and the Younger Dryas reversal.

### INTRODUCTION

ARCELLACEANS (also referred to as thecamoebians, agglutinated rhizopods, or testate amoebae) are rhizopods characterized by a single rigid organic or agglutinated test into which the entire body can be withdrawn. Because their tests resist dissolution in low pH environments, unlike those of other freshwater organisms like molluscs and ostracods, arcellaceans are commonly preserved. Their small size (60–300  $\mu\text{m}$ ), combined with their world-wide distribution in large populations in a variety of freshwater environments, ensures that even in samples of relatively small volume, statistically significant numbers of tests will commonly be found. Their known stratigraphic range extends to the Carboniferous (Thibaudeau et al., 1987).

Although these attributes make arcellaceans potentially useful paleolimnological indicators, their modern ecology and biogeography is poorly known. Most work on arcellaceans has been done on peatlands from northern Europe (e.g., Schonborn, 1963; Heal, 1964; Corbet, 1973). Tolonen (1986) interpreted the ecology of about 20 limnic taxa in terms of trophic grade of lakes. Only a few studies of arcellacean distribution have been done in eastern North American lakes (e.g., Collins et al., 1990; Honig and Scott, 1987; Patterson et al., 1985; Scott and Medioli, 1983); however, these indicate that the distribution of arcellacean taxa is controlled by physical factors, such as climate and salinity.

This study compares the arcellacean succession since the retreat of the last ice sheets in three small lakes in Atlantic Canada with the fossil pollen succession in the same cores, to test whether arcellacean assemblages are sensitive to climate. Although

the previously cited studies attempted to use arcellaceans as paleoenvironmental indicators, they lacked the strong paleoclimatic and chronostratigraphic control that is provided by pollen in this study.

Late Quaternary fossil pollen data can be calibrated in terms of climate (Arigo et al., 1986). Pollen-climate transfer functions are developed using multiple regression of geographic stations of climatic data with pollen percentages in local surface samples. Webb and Bryson (1972) first applied transfer functions to reconstruct postglacial climate in the American Midwest, specifically air mass frequency, annual precipitation, and mean July temperature. Over the wider area of eastern North America, Bartlein and Webb (1985) found that 11 equations, each representing a region, were needed to compute the mean July temperatures for the postglacial. The results are reasonable except for early late glacial time (before 12,000 years B.P.) when recycled tree pollen gives unreasonably warm values (McAndrews, 1994).

The pollen succession from several sites in Atlantic Canada has been studied by Ogden (1987) and Livingstone (1968), among others. The data of Ogden (1987) for Penhorn Lake, Nova Scotia, are compared with arcellacean data from the same core in this study, while pollen and arcellacean data are presented from Robinsons Pond and Joe's Pond, Newfoundland.

### LOCATION

The three lakes originated with ice retreat from eastern Canada at the end of the Wisconsin glacial, and record con-

tinuous sedimentation to the present (Figure 1). Robinsons Pond, in southwestern Newfoundland (48°15.5'N, 58°48'W), is situated 40 m asl on the Robinsons Head Moraine along the shore of St. Georges Bay. The pond, with an area of ca. 5 ha, is surrounded by pastureland, with remnant patches of alder shrub. Wind off the sea may prevent the growth of trees. Joe's Pond (48°14.5'N, 58°46'W) (5.25 ha) lies 42.5 m asl, approximately 5 km inland from Robinsons Pond in a sheltered valley. A mature stand of spruce, fir, and birch surrounds the lake, with alder along the shoreline. Both lakes are in the Boreal Forest region of Rowe (1972). The July mean temperature measured at Stephenville is 16.0°C, January mean temperature is -5°C, mean annual precipitation is 1,200 mm, and the average length of the growing season is 160–170 days. Southwestern Newfoundland is characterized by balsam fir, together with black and white spruce; white birch is the dominant deciduous tree, and trembling aspen plays a lesser role. White pine, black ash, balsam poplar, and yellow birch occur as minor species.

Penhorn Lake lies in an interdumlin basin in Dartmouth, Nova Scotia (44°40.30'N, 63°33.33'W, 52 m asl). This small (5.2 ha) lake is in the Acadian Forest region of Rowe (1972); the Eastern (Atlantic) Shore of Nova Scotia is characterized by dense, low stands of balsam fir, black spruce, and white spruce, with white birch and hemlock. The July mean temperature measured in Halifax is 18.2°C, mean January temperature is -5°C, mean annual precipitation is 1,400 mm, and the growing season averages 200–210 days.

#### METHODS

The cores were collected using a modified Livingstone square rod piston sampler (Wright, 1967). Samples of 10 cm<sup>3</sup> at 10 cm intervals were sieved to retain the 0.063–0.5 mm size fraction for arcellaceans. The samples were not decanted, as is commonly done to remove fine organics, because light, highly organic or finely agglutinated taxa were found to be preferentially lost in this process, thus altering the fossil assemblages and resulting in incorrect paleoecological interpretations (McCarthy, 1984). The samples were stored in ethanol and examined under a binocular microscope at 32× magnification. Identifications follow Medioli and Scott (1983) and Patterson and et al. (1985). Common arcellacean species from these lakes are illustrated in Figure 2.

Samples of 0.9 ml volume were processed for pollen analysis using standard procedures (Faegri and Iversen, 1975). The samples were treated with 10 percent HCl, 10 percent KOH, HF, and acetolysis solution, then stained with safranin and mounted in silicone oil. Pollen densities were determined by spiking the samples with a known number of *Lycopodium clavatum* spores (Stockmarr, 1971). At least 200 upland pollen grains were counted per sample. Identifications follow McAndrews et al. (1973). Thermal analysis (weight loss on ignition) follows Dean (1974).

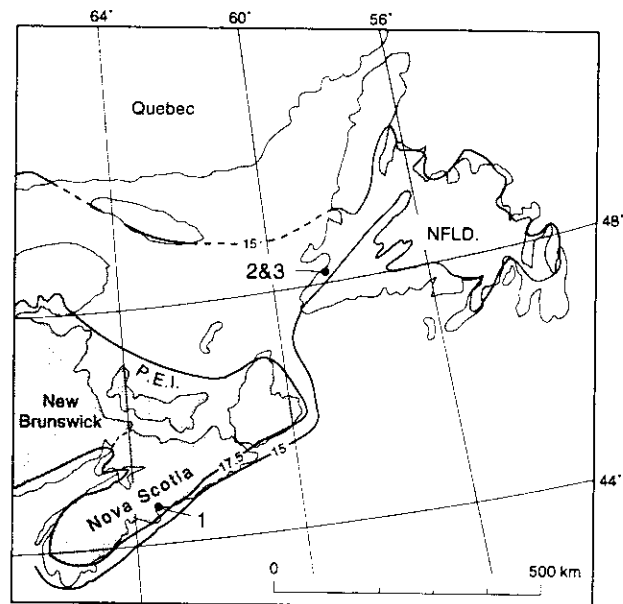


FIGURE 1—Map of the Atlantic Provinces showing the location of the study sites. 1, Penhorn Lake; 2, 3, Robinsons and Joe's Ponds. Also shown are mean July isotherms in °C; areas with mean July isotherms of 15°C or above are shaded dark gray.

Radiocarbon dating was done on bulk sediment by Geochron Laboratories, Cambridge, Massachusetts, and by the Isotope Laboratory of the University of Waterloo (Table 1).

The July mean temperature was estimated from the pollen data from transfer function equations of Bartlein and Webb (1985): in the Newfoundland cores, equation J was used for the Holocene and equation B for the late glacial; in the Nova Scotia core, equation I was used for the entire record, as it yielded the most plausible values. Mean annual precipitation was estimated using the transfer function of Gajewski (1988). Pollen and arcellacean data were plotted against years before present by interpolating between radiocarbon dates using CANPLOT (Campbell and McAndrews, 1992). Cluster analysis was performed on the arcellacean data shown in Tables 2–4 using CONISS (Grimm, 1987).

#### RESULTS

**Lithology.**—At Penhorn Lake, 410 cm were recovered before refusal occurred in a peaty black mud, with ca. 10 percent organic matter and 85 percent silicates (Figure 3.1). This unit spans 408–395 cm in the core, and 399–403 cm date 11,730 ± 440 years B.P. From 395 to 300 cm the sediments are brown sandy

TABLE 1—Radiocarbon dates pertaining to the sites studied. Radiocarbon dating was done on bulk sediment by Geochron Laboratories, Cambridge, Massachusetts, and by the Isotope Laboratory of the University of Waterloo.

Lab no.	Site	Depth (cm)	<sup>14</sup> C age	Reference (years B.P.)
GX-9962	Joe's Pond, Nfld.	289–291	3,300 ± 235	This paper
GX-9963	Joe's Pond, Nfld.	422–425	9,445 ± 380	This paper
WAT-1923	Joe's Pond, Nfld.	450–452	10,950 ± 80	This paper
GX-9964	Joe's Pond, Nfld.	490–495	10,130 ± 375	This paper
WAT-1929	Robinsons Pond, Nfld.	303–313	5,090 ± 70	This paper
GX-9965	Robinsons Pond, Nfld.	408–417	11,300 ± 620	This paper
GX-10693	Penhorn Lake, N.S.	270–273	9,036 ± 360	Ogden (1987)
GX-10694	Penhorn Lake, N.S.	399–403	11,730 ± 440	Ogden (1987)

silty mud almost devoid of organics, with silicates comprising upto 95 percent of the sediments. Sediments become more organic above, and sediments in the upper 300 cm contain between 28 and 50 percent organic matter and between 9 and 18 percent calcium carbonate, while silicates comprise a maximum of 59 percent of the sediments. Near the base of this gyttja, 270–273 cm date  $9,036 \pm 360$  years B.P. This late glacial lithological sequence, with inorganic clastics interrupting the deposition of organic sediments, is common in the Maritime Provinces, and is associated with the Younger Dryas reversal (Mott et al., 1986).

The lower 8 cm of a 460 cm long core from Robinsons Pond consist of red diamict, presumably till deposited by the last readvance of the Late Wisconsinan ice sheet down the Codroy Lowland around 12,600 years B.P. (Brookes, 1977). From 452–410 cm is red clay with sand layers that was probably derived from the fine fraction of the red diamict reworking into the pond following deglaciation. This interpretation is supported by the thermal analysis (Figure 3.2) which shows that the red clay is inorganic and low in calcium carbonate, like the underlying diamict. The next 10 cm (410–400 cm) consist of grey clay; this clay is slightly more organic than the underlying red clay with about 10 percent organic matter. Residue, composed mostly of siliclastics, still comprises over 80 percent of the sediments. A  $^{14}\text{C}$  age of  $11,300 \pm 620$  years B.P. was obtained from 408–417 cm at the contact between the red and grey clay (Table 1). Organic matter rises sharply at 400 cm to around 40 percent, and the sediments in the upper 4 m are brown sandy gyttja. In this unit, 303–313 cm dated at  $5,090 \pm 70$  years B.P.

The base of the core from Joe's Pond consists of inorganic clay (90 percent siliceous residue) from 500 to 490 cm (Figure 3.3). Organic matter increases to around 20 percent and the next 40 cm consist of silty gyttja. The top of this unit (450–452 cm) dates at  $10,950 \pm 80$  years B.P., significantly older than the underlying sample at 490–495 cm, which dates at  $10,130 \pm 375$  years B.P. The validity of these  $^{14}\text{C}$  dates will be discussed later. A sharp increase in organic matter to 70 percent at 450 cm marks deposition of brown gyttja, which persists to the present day. At 422 and 289 cm, sediments date  $9,445 \pm 380$  and  $3,300 \pm 235$  years B.P. respectively.

**Pollen.**—The pollen data from Penhorn Lake are redrawn from Ogden (1987) in Figure 3.1. Due to the low pollen counts in the lower portion of the Penhorn record, additional counts were done, and data from several levels were added together to yield the lower three spectra, at 309, 363 and 405 cm. Ogden (1987) interpreted the pollen assemblage in sediments deposited during the late glacial (13,000–10,000 years B.P.) as indicating open, tundra-like vegetation. He interpreted the low pollen density and low percentages of tree pollen deposited in the inorganic mud overlying the peaty organic mud as recording climatic cooling analogous to the Younger Dryas following initial warming after ice retreat. Sediments deposited 10,000–8,000 years B.P. record succession to closed boreal forest. The interval 8,000–4,000 years B.P. is marked by peaks in thermophilous taxa such as pine (*Pinus*) and hemlock (*Tsuga*), while the rise in spruce (*Picea*) around 2,000 years B.P. marks a return to cooler and possibly more moist conditions. This interpretation is supported by the estimates of July mean temperature between 12,000 and 10,000 years B.P. of  $16^\circ\text{C}$ , followed by a rapid warming around

9,000 years B.P., and peak temperatures (exceeding  $20^\circ\text{C}$ ) between 8,000 and 2,000 years B.P. After 2,000 years B.P., there was a cooling to an estimated value of  $19^\circ\text{C}$  at present. This compares with a modern measured July mean temperature of  $18.2^\circ\text{C}$ .

The pollen data from the Newfoundland lakes and the derived paleotemperature estimates are shown in Figure 3.2 and 3.3. The paleotemperature estimates appear to be accurate because temperature estimates from surface samples ( $15.6^\circ\text{C}$  at Joe's Pond and  $16.0^\circ\text{C}$  at Robinsons Pond) approximate the modern measured July mean temperature of  $16.0^\circ\text{C}$ . A complete late glacial-postglacial record is found only in the Robinsons Pond core, where inorganic clay just above the basal till is characterized by low pollen density dominated by pine and spruce pollen, representing long-distance transport or recycled pollen from the melting ice sheet (McAndrews, 1984). The pollen at Robinsons Pond records the establishment of tundra vegetation on the Robinsons Head Moraine following deglaciation about 12,000 years B.P. High percentages of herb pollen, such as sedges (Cyperaceae), grasses (Gramineae), and heather (Ericaceae) and of shrub birch (*Betula*), willow (*Salix*), and alder (*Alnus*) characterize pollen zone 1 at both Newfoundland sites. The resurgence of pine and spruce and increased pollen density, dated at  $11,300 \pm 320$  years B.P., may record the establishment of trees to form forest-tundra. The 10,130 years B.P. date from the base of the Joe's Pond core is rejected as too young, because the boundary between pollen zones 1 and 2 in Joe's and Robinsons Ponds appears to date synchronously at around 11,000 years B.P. Nevertheless, not too much importance can be attached to these dates because they were obtained from bulk sediment samples that may have been contaminated by old carbon, however they confirm the latest Pleistocene age for the lower 50 cm of the sequence at Joe's Pond.

The rapid increase in spruce and birch pollen around 10,000 years B.P. at both Newfoundland sites signals zone 2. This vegetational succession was accompanied by a steep increase in organic deposition in both cores. July temperature is estimated to have risen quickly from around  $10.5^\circ\text{C}$  to  $15^\circ\text{C}$  at the beginning of the Holocene at both Robinsons Pond and Joe's Pond. Balsam fir (*Abies*) colonized the area shortly after the beginning of zone 2. The rise in balsam fir at Joe's Pond was  $^{14}\text{C}$  dated at  $9,445 \pm 380$  years B.P.; the same vegetational change is interpolated to have occurred just over 10,000 years B.P. at Robinsons Pond on the coast. The mid Holocene Hypsithermal was recorded by the pollen succession at both sites, as shown by the estimates of July temperature, which peaked at  $16.4^\circ\text{C}$  at Robinsons Pond and  $16.6^\circ\text{C}$  at Joe's Pond. The Hypsithermal appears to have been diachronous in western Newfoundland, occurring ca. 5,600 years B.P. at Joe's Pond, but only ca. 4,000 years B.P. at Robinsons Pond. Because the Hypsithermal occurs in pollen zone 2 at Joe's Pond, but zone 3 at Robinsons Pond, this diachroneity is unlikely to be an artifact of radiocarbon dating. The apparent delay in the Hypsithermal and the absence of a peak in the thermophilous pine at Robinsons Pond may be due to its location atop the windswept coastal Robinsons Head Moraine.

At both sites, the percentage of alder, sedge, and grass pollen and *Dryopteris* spores rises sharply in the latter part of the Ho-

FIGURE 2—Bars = length in  $\mu\text{m}$ . 1, *Centropxyxis aculeata* (Ehrenberg); 2, *Centropxyxis constricta* (Ehrenberg); 3-9, *Diffflugia bacillifera* Penard; 10, *Diffflugia corona* Wallich; 11, *Diffflugia oblonga* Ehrenberg; 12, *Cucurbitella tricuspidis* (Carter); 13, *Diffflugia urceolata* Carter; 14, *Heleopera spaghi* (Leidy); 15, *Lecquereusia spiralis* Ehrenberg; 16, *Pontigulasia compressa* (Carter).

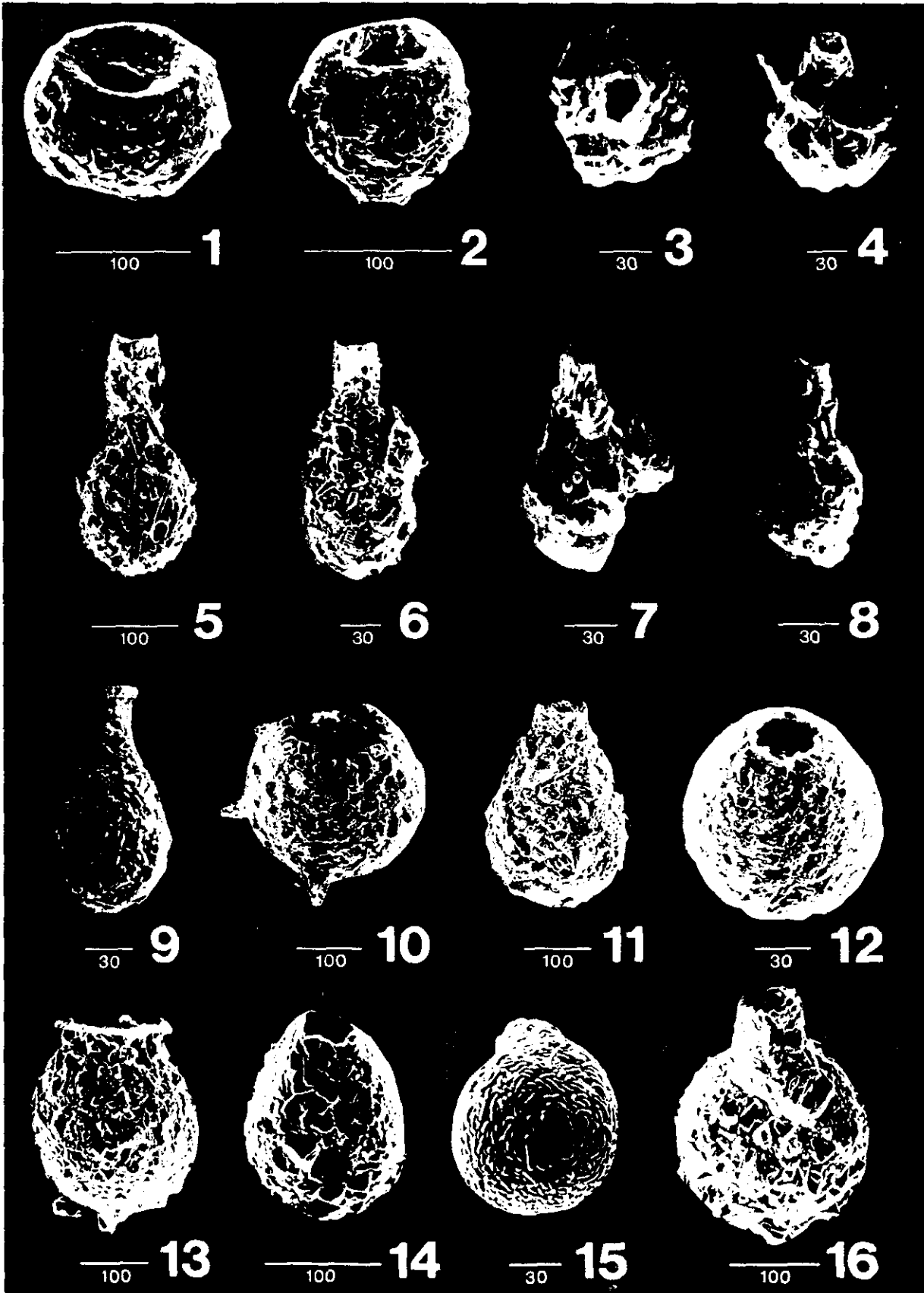


TABLE 2—Arcellacean percentages at Penhorn Lake, rounded to the nearest whole number, x = &lt;1%. Uncertainty estimates follow Patterson and Fishbein (1989).

Depth (cm)	1	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
Total population/10 cc	1,022	1,916	738	1,712	1,116	648	106	7	20	146	367	129	623	469	679	625	769	602	966	609	280	1,188	224	552
<i>Centropyxis aculeata</i>	15	22	51	91	79	50	92	86	40	10	46	50	2	2	3	2	33	27	2	4	5	67	42	90
Uncertainty +/-	1.25	0.89	3.4	0.48	1.49	3.9	6.9	172	120	6.2	6.8	19	0.3	0.4	0.4	0.3	2.9	3.3	0.2	0.6	1.7	1.86	11	1.6
<i>Centropyxis constricta</i>	1	x	x	x																				
Uncertainty +/-	0.1																							
<i>Cucurbitella tricuspis</i>	x	1																						
Uncertainty +/-																								
<i>Diffugia bacillifera</i>	2	3	3	1	2	4			10	20	10	12	9	10	23	7	9	9	1	12	6			
Uncertainty +/-	0.19	0.15	0.4	0.06	0.18	0.6			45	11	2.5	8.2	1.3	1.9	2.6	1	1.1	1.4	0.1	1.7	2			
<i>Diffugia corona</i>	30	22	8	3	9	21			10	3	4	2	3	7	4	4	2	4	6	5	7	3	9	1
Uncertainty +/-	2.05	0.9	1	0.17	0.73	2.6			45	2	1	1.5	0.5	1.4	0.6	0.6	0.3	0.6	0.8	2.3	0.24	3.7	0.2	
<i>Diffugia oblonga</i>	17	18	10	1	3	6	7	14	25	41	23	12	63	22	21	24	21	22	34	18	48	10	23	6
Uncertainty +/-	1.38	0.77	1.2	0.06	0.26	0.9	6.1	172	94	17	4.8	8.2	3.7	3.7	2.4	2.9	2.2	2.2	2.3	2.4	8.9	0.76	7.9	1
<i>Diffugia protaeiformis</i>	1	2			2																			
Uncertainty +/-	0.1	0.1			0.18																			
<i>Diffugia urceolata</i>	3	4	3	1	1	2				7	2	4	2	4	4	3	2	5	9	5	11	8	4	1
Uncertainty +/-	0.28	0.2	0.4	0.06	0.09	0.3				4.5	0.5	3	0.3	0.8	0.6	0.5	0.3	0.8	0.8	0.8	3.5	0.62	1.7	0.2
<i>Diffugia urens</i>	2	2	3	x	x	2	1		5		x	1	x	3	x	2	3	x	1		1	x		
Uncertainty +/-	0.19	0.1	0.4			0.3	0.9		24			0.8		0.6		0.3	0.4		0.1		0.4			
<i>Heleopera sphagni</i>	x	x																						x
Uncertainty +/-																								
<i>Lagenodiffugia vas</i>	1	3	x		x	x														2	1	1	4	
Uncertainty +/-	0.1	0.15																		0.3	0.4	0.08	1.7	0
<i>Lecquerusia spiralis</i>	x	1																						
Uncertainty +/-		0.05																						
<i>Nebella collaris</i>	x																							
Uncertainty +/-																								
<i>Pontigulastia compressa</i>	26	22	21	3	6	14			10	19	16	19	21	49	41	56	29	30	42	43	19	10	17	1
Uncertainty +/-	1.88	0.9	2.2	0.17	0.51	1.9			45	11	3.7	12	2.7	5.3	3.6	3.9	2.7	3.5	2.5	4	5.5	0.76	6.3	0.2



TABLE 3.—Arcellacean percentages at Robinsons Pond, rounded to the nearest whole number, x = <1%. Uncertainty estimates follow Patterson and Fishbein (1989). Percentages of foraminifera are shown for the lowermost sample, which contained no arcellaceans.

Depth in core (cm)	0	33	53	75	106	114	135	154	175	194	215	224	245	253	273	283	314	333	355	368	374	397	405	422	424	440	448						
Total population/10 cc	293	477	343	877	502	713	495	737	394	632	161	207	222	170	26	24	49	531	726	50	201	688	12	7	8	14	3						
Arcellaceans (%)																																	
<i>Centropyxis aculeata</i>	27	48	33	27	23	39	29	21	33	29	48	41	24	75	50	46	27	1	6	32	10	49	58	57	50	36							
Uncertainty +/-	5.1	4.5	5	2.9	3.7	3.6	4	2.9	4.6	3.5	7.7	6.7	5.6	6.5	19	20	12	0.8	1.7	13	4.1	3.7	28	37	35	25							
<i>Centropyxis constricta</i>	6	6	3	6	8	1	6	2	1	6	6	6	20	20	13	13	10	x	3	22	5	30	5	30	7								
Uncertainty +/-	2.7	2.1	1.8	1.6	2.4	0.7	2.1	1	1	3.7	3.7	5.3	5.3	5.3	13	8.4	8.4	x	1.2	1.2	3	3.4	3	3.4	13								
<i>Cucurbitella tricuspidis</i>	1	x	x	x	x	x	2	2	x	2	1	x	x	4	4	2	4	2			x	x											
Uncertainty +/-	0.3						0.4	0.4	0.3	0.6	0.6	4	15	15	8	6	3	4	2	2	x												
<i>Diffugia bacillifera</i>	1	4		5	2	2	4	2	x	4	4	4	7	7	11	6.6	1.5	1.4	3.9														
Uncertainty +/-	1.1	1.8		1.4	1.2	1	1.7	1	1.5	3	2.7	1.7	x																				
<i>Diffugia bacilliarum</i>																																	
Uncertainty +/-																																	
<i>Diffugia corona</i>	x	1	3	1	2	1	2	2	2	2	2	2	2	4	4	4	x	2	2	2	2	x											
Uncertainty +/-	0.2	0.8	0.1	0.4	0.1	0.4	0.3	0.5	0.3	1.2	0.9	x	15	15	15	15	x	0.3	0.3	6	1												
<i>Diffugia globulus</i>	1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Uncertainty +/-	0.2																																
<i>Diffugia oblonga</i>	31	26	39	36	44	34	35	42	44	31	34	29	28	12	23	4	49	19	46	16	79	11	42	43	50	14							
Uncertainty +/-	5.3	3.9	5.2	3.2	4.3	3.5	4.2	3.6	4.9	3.6	7.3	6.2	5.9	4.9	16	7.8	14	3.3	3.6	10	5.6	2.3	28	37	35	18	0						
<i>Diffugia protaeiformis</i>	2	2	x	2	3	x	2	x	2	1	x	x	1	8	8	4	4	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Uncertainty +/-	0.7	0.4		0.2	0.6	0.4	0.4	0.5	0.2	0.2	2	2	2	2	28	16	16																
<i>Diffugia urceolata</i>	1	x		2	x	x	2	x	x	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	29						
Uncertainty +/-	0.3			0.2			0.4			1.2	1.2	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	147							
<i>Heleopera sphagni</i>	9	x	6	x	3	5	x	3	3	6	6	3	5	2.8	5	4	4	x	1	14	3	7	7	7	7	7							
Uncertainty +/-	2.8	x	1.6	x	0.6	0.7	0.4	0.7	0.9	1.4	1.4	1.4	2.8	2.8	16	16	7.8	7.8	0.7	24	1.4	0.9	0.9	0.9	0.9	2							
<i>Lagenodiffugia vas</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Uncertainty +/-																																	
<i>Lecquerusia spiralis</i>	1	1	2	x	1	2	x	x	x	4	4	2	1	1	4	4	4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Uncertainty +/-	0.3	0.2	0.6	x	0.2	0.3	0.3	0.6	0.6	0.6	0.6	0.9	0.6	0.6	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
<i>Nebella collaris</i>	x	1		x	1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Uncertainty +/-	0.2																																
<i>Pontigulasia compressa</i>	15	7	11	18	13	14	17	25	13	14	3	12	18	2	4	17	2	76	37	2	2	2	2	2	2	2							
Uncertainty +/-	4.1	2.3	3.3	2.5	2.9	2.5	3.3	3.1	3.3	2.7	2.6	4.4	5.1	2.1	7.5	15	3.9	3.6	3.5	3.9	3.6	3.5	3.9	3.9	3.9	3.9							
Foraminifera (%)																																	
<i>Ephidium excavatum</i>																											33						
<i>Islandiella teretis</i>																											33						
<i>Bulinina marginata</i>																											33						

TABLE 4—Arcellacean percentages at Joe's Pond, rounded to the nearest whole number,  $x = <1\%$ . Uncertainty estimates follow Patterson and Fishbein (1989).

Depth (cm)	53	73	92	112	131	152	174	194	214	234	259	278	298	313	331	353	373	394	441	433	453
Total population/10 cc	144	163	111	158	103	157	47	55	84	25	57	62	287	399	1,327	17	2	3	0	6	0
<i>Centropyxis aculeata</i>	65	66	78	65	76	61	89	84	82	88	76	45	15	9	10	65	100	100		100	
Uncertainty +/-	16	14	15	14	18	15	21	24	18	42	32	40	4.4	2.1	0.68	134					
<i>Centropyxis constricta</i>	3	8		9	3	3			1				2	2	4						
Uncertainty +/-	2	4.5		5.2	2.8	1.9			1.2				0.7	0.5	0.29						
<i>Cucurbitella tricuspis</i>	6	3	5	5	6	6	2		6	4					x						
Uncertainty +/-	3.9	18	4.3	3	5.5	3.6	4.2		6.7	15											
<i>Diffugia bacillifera</i>		x			2	1		4	1	4	12	23	64	19	24						
Uncertainty +/-					1.9	0.6	0	7	1.2	15	19	29	8	3.9	1.34						
<i>Diffugia corona</i>		x		1	2	x						2		x	x						
Uncertainty +/-				0.6	1.9							3.2									
<i>Diffugia oblonga</i>	11	14	13	11	8	19	4	9	8	4	14	17	10	27	37	29					
Uncertainty +/-	6.8	7.4	10	6.2	7.1	9.8	8.2	15	8.8	15	21	23	3.1	4.9	1.76	121					
<i>Diffugia protaeiformis</i>						1															
Uncertainty +/-						0.6															
<i>Diffugia urceolata</i>		x		x		1		2			2	2	1		1	6					
Uncertainty +/-						0.6		3.6			3.4	3.2	0.3		3.81	24					
<i>Heleopera sphagni</i>				1		x		2				3	x		x						
Uncertainty +/-				0.6				3.6				4.7									
<i>Lecquereusia spiralis</i>	8	x	x		4	5			1					x							
Uncertainty +/-	5.1			0.6	3.7	3			1.2												
<i>Nebella collaris</i>	5	3	3	3		2	4														
Uncertainty +/-	3.3	1.8	2.6	1.8		1.2	8.2														
<i>Pontigulasia compressa</i>		3	x	2							5	8	7	40	22						
Uncertainty +/-		1.8		1.2							8.3	12	2.3	6	1.29						

locene. The boundary between zones 2 and 3 dates at  $5,090 \pm 70$  years B.P. for Robinsons Pond, but at  $3,300 \pm 235$  years B.P. for Joe's Pond. Because this diachroneity appears to be an artifact of radiocarbon dating, the younger date is rejected in plotting the pollen diagram from Joe's Pond.

**Arcellaceans.**—Five arcellacean assemblages (A–E) occur in the three lakes. The results of the cluster analysis serve to objectively illustrate the assemblages which were observed visually. On the whole, the statistical analysis supports identification of a succession of arcellacean zones over the past 12,000 years, although there are a few samples (e.g., those deposited around 11,000 years B.P. in Penhorn Lake) which do not fit at the level of confidence which fits the biofacies division. The oldest arcellacean assemblage at Penhorn Lake (assemblage A), spanning 12,000–11,500 years B.P. (Figure 4.1), is dominated by *Centropyxis aculeata* (Ehrenberg), together with *Centropyxis constricta* (Ehrenberg), *Diffugia oblonga* Ehrenberg, *Diffugia corona* Wallich, and *Diffugia urceolata* Carter. The same assemblage is found in late glacial sediments spanning ca. 12,500–12,000 years B.P. at Robinsons Pond (Figure 4.2), succeeding a sparse foraminiferal assemblage in the red clay overlying the diamic, comprised of *Elphidium excavatum*, *Islandiella teretis*, and *Bulimina marginata*. The equivalent interval was not recovered at Joe's Pond (Figure 4.3). Assemblage B, strongly dominated by *C. aculeata* spans the remainder of the glacial (to ca. 10,000 years B.P.) at all three lakes. Assemblage C, dominated by *D. oblonga*, was established with the shift to gyttja deposition in all three lakes at the beginning of the Holocene. This was succeeded by assemblage D, characterized by high percentages of *Pontigulasia compressa* (Carter) and *Diffugia bacillifera* Penard, around 8,100 years B.P. at Robinsons Pond, 7,800 years B.P. at Penhorn Lake, and 7,000 years B.P. at Joe's Pond. A resurgence in *C. aculeata* around 6,000 years B.P. at Robinsons Pond, 5,000 years B.P. at Joe's Pond, and 4,000 years B.P. at Penhorn Lake, marks assemblage E. This assemblage is similar to the late glacial assemblage A.

#### DISCUSSION

Paleoecological interpretations generally based on comparison of downcore faunal changes with modern fossil distributions

cannot be done because of the lack of baseline studies of modern arcellacean biogeography. Because only one study (Collins et al., 1990) of modern arcellacean distributions has allowed generalised conclusions to be drawn of their ecological tolerances (e.g., *Diffugia bacillifera* is common only south of Nova Scotia), our approach was to compare them with contemporary pollen records to see whether arcellaceans record late glacial through Holocene climatic changes. The similarity and synchronicity of the late glacial through Holocene palynological and arcellacean succession in the three lakes is summarized in Figure 5.

The red clay near the base of the core from Robinsons Pond appears to have been reworked from the underlying red diamic, probably deposited by the most recent glacial advance in the Codroy Lowland about 12,600 years B.P. (Brookes, 1977). The absence of arcellaceans in this unit, and the presence of shallow marine foraminifera (albeit in low numbers), has two possible explanations: 1) the Robinsons Head Moraine, now about 100 m asl was deposited at sea level and subsequently elevated with isostatic rebound, or 2) the foraminifera were reworked from the diamic, indicating that the glacier entrained glaciomarine sediments. Because this part of Newfoundland has experienced 75–80 m uplift since 13,800 B.P. (Brookes, 1977), and the pond now lies ca. 100 m asl, the sediments deposited during the retreat of the ice sheet could have been deposited in a shallow marine environment before isostatic rebound elevated the area above sea level, isolating Robinsons Pond. The pollen assemblage in these sediments is typical of glacial margin conditions. The low pollen density dominated by spruce and pine pollen reflect long distance transport from south of the ice margin, or pollen recycled from glacier ice (McAndrews, 1984).

Tundra, dominated by herb pollen, was established shortly after deglaciation around Robinsons Pond, probably within 500 years of deglaciation. In both eastern Nova Scotia and western Newfoundland, the late glacial tundra was associated with arcellacean assemblage A (*Centropyxis aculeata*, *Centropyxis constricta*, *Diffugia oblonga*, *Diffugia corona*, and *Diffugia urceolata*). These taxa, except for *D. corona*, were common at the arctic site studied by Collins et al. (1990), suggesting that they tolerate low temperatures. *Centropyxis aculeata* is an early colonizer in other lakes from eastern Canada (e.g., Honig and Scott,



Fig 3.1

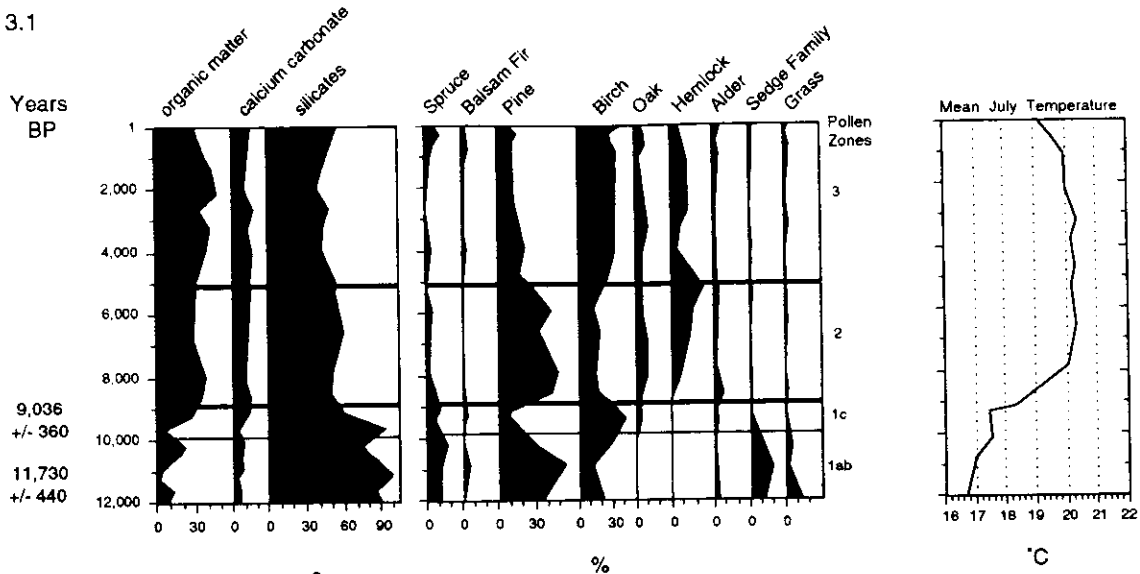


Fig 3.2

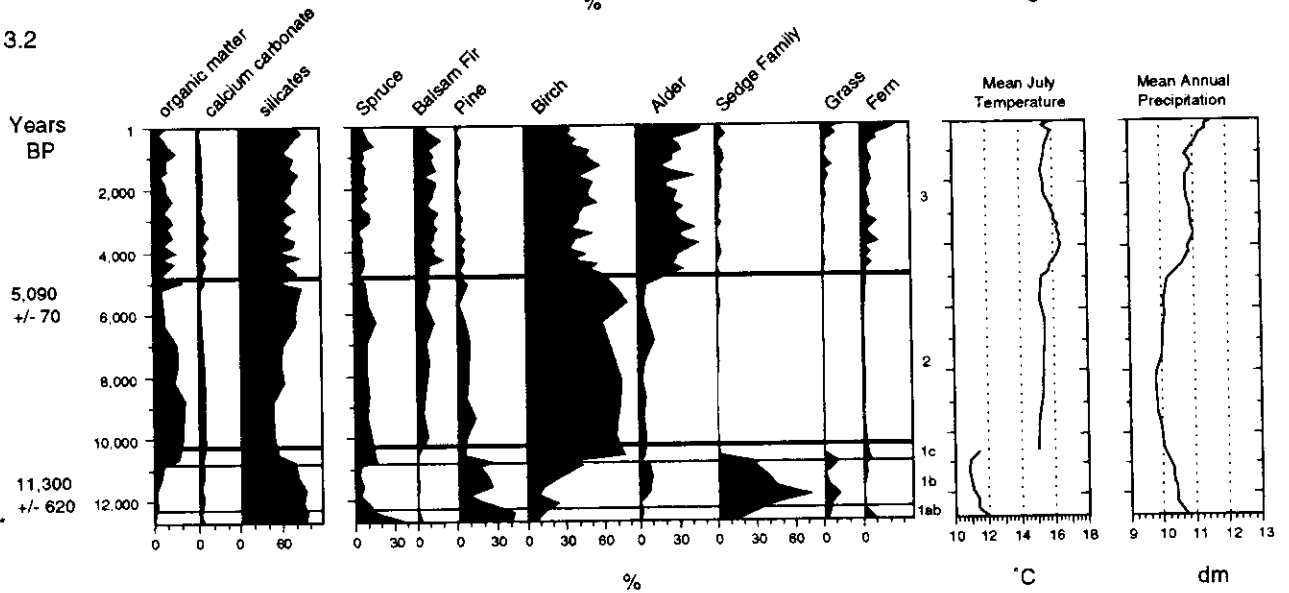


Fig 3.3

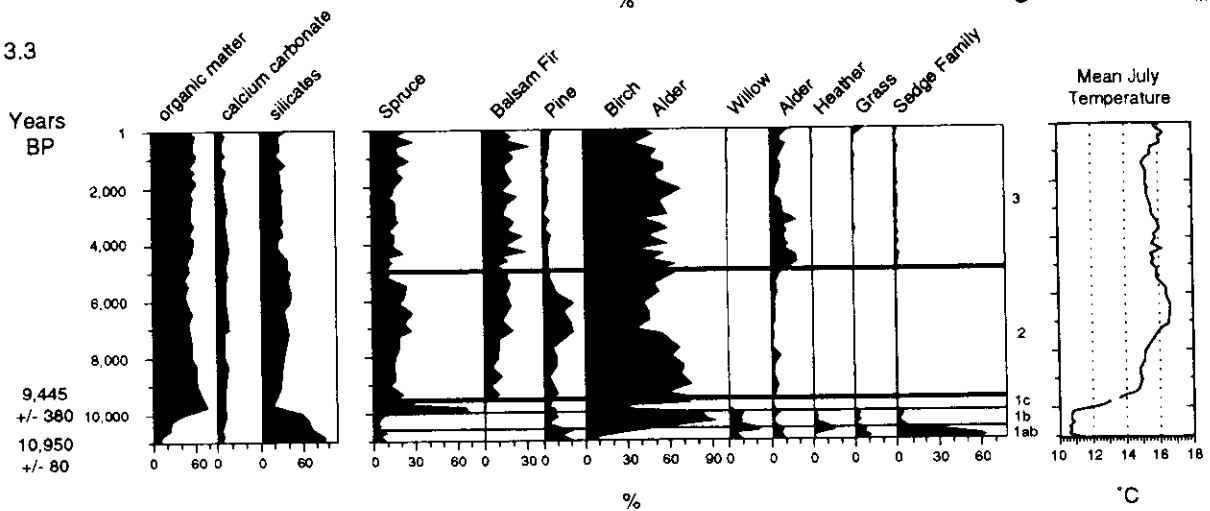


FIGURE 3—Fossil pollen and derived climate diagrams for Penhorn Lake (3.1), Robinsons Pond (3.2), and Joe's Pond (3.3); only the main fossil types are shown, but complete counts are deposited in the North American Pollen Database, Illinois State Museum, Springfield, Illinois, U.S.A. The pollen sum is 200. The percentage of sediment organic matter, calcium carbonate, and silicates, measured using loss-on-ignition, are shown. Penhorn Lake pollen data are from Ogden (1987) with emendations. Values are plotted against years B.P., interpolating between known dates.

Fig 4.1

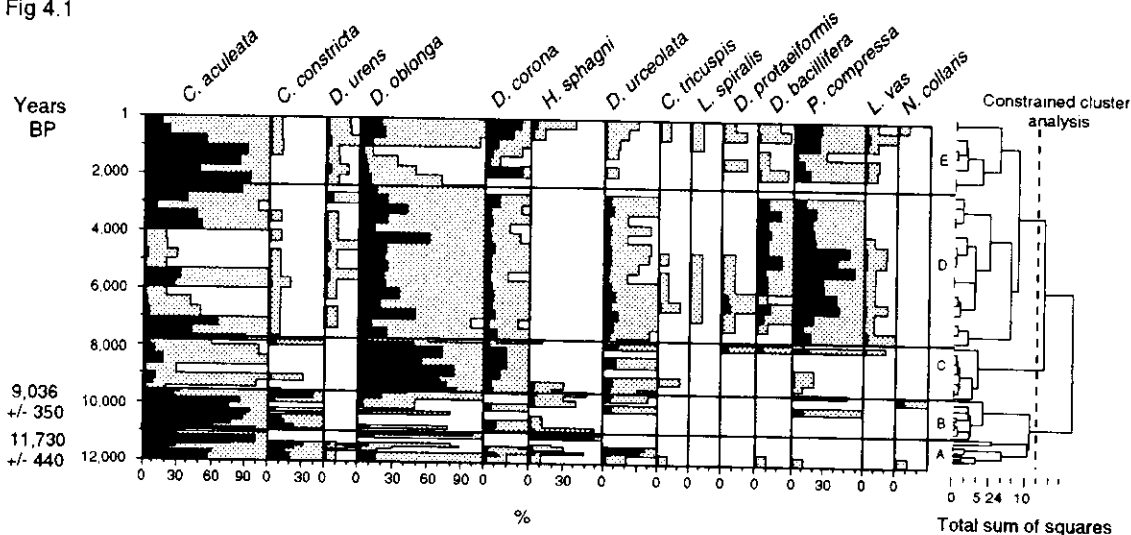


Fig 4.2

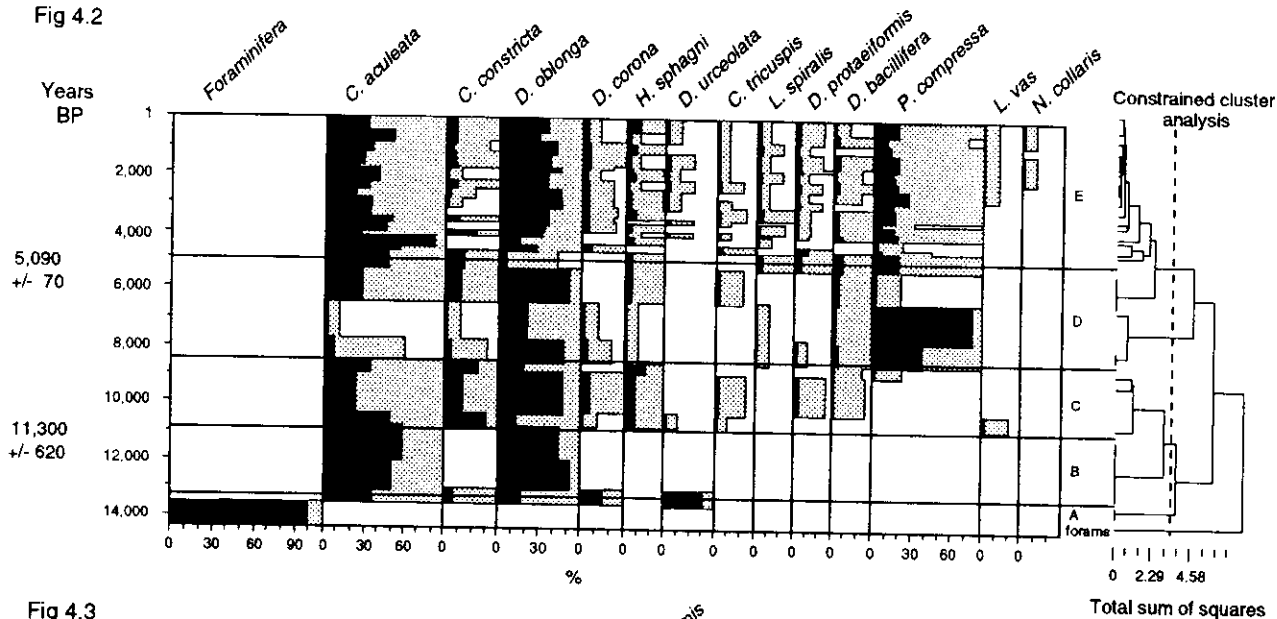


Fig 4.3

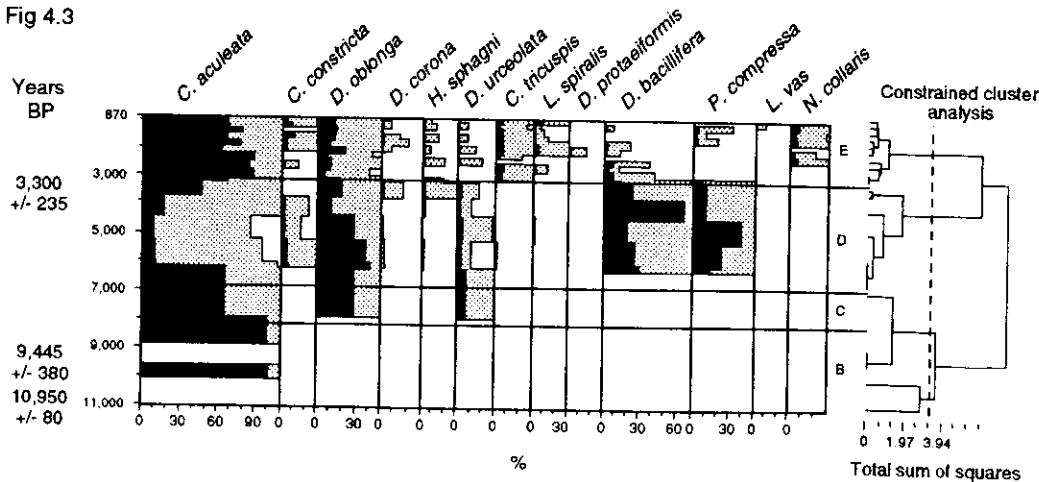


FIGURE 4—Arcellacean diagrams and cluster analyses for Penhorn Lake (4.1), Robinsons Pond (4.2), and Joe's Pond (4.3). The dashed line on each cluster analysis diagram illustrates the level of confidence that best describes our results. Only the main fossil types are shown, but complete counts are listed in Tables 2-4. The stippled area is 10× exaggeration.

Years B.P.	VEGETATION		ARCELLACEANS	
	Nova Scotia	Newfoundland	Nova Scotia	Newfoundland
0	POST HYPSTHERMAL - increasing spruce and alder	"PALUDIFIED" alder, sedges, ferns, grasses	Assemblage E ( <i>C. aculeata</i> , <i>D. oblonga</i> , <i>P. compressa</i> )	
2,000	LATE HYPSTHERMAL - increasing birch, decreasing pine			Assemblage E ( <i>C. aculeata</i> , <i>D. oblonga</i> , <i>P. compressa</i> )
4,000				
6,000	MID HYPSTHERMAL - maximum pine, hemlock	"ACADIAN FOREST" - spruce, balsam fir, pine, birch	Assemblage D ( <i>P. compressa</i> , <i>D. bacillifera</i> , <i>D. oblonga</i> )	Assemblage D ( <i>P. compressa</i> <i>D. bacillifera</i> , <i>D. oblonga</i> )
8,000	EARLY HYPSTHERMAL - increasing birch, then pine	"BOREAL FOREST" - spruce, birch, balsam fir, alder	Assemblage C ( <i>D. oblonga</i> )	Assemblage C ( <i>D. oblonga</i> )
10,000	LATE GLACIAL - sedges, grasses spruce	"TUNDRA" - sedges, grasses, heather, birch, willow, alder	Assemblage B ( <i>C. aculeata</i> )	Assemblage B ( <i>C. aculeata</i> )
12,000			Assemblage A ( <i>C. aculeata</i> , <i>D. urceolata</i> , <i>C. constricta</i> , <i>D. oblonga</i> , <i>D. corona</i> )	Assemblage A ( <i>C. aculeata</i> , <i>D. urceolata</i> , <i>C. constricta</i> , <i>D. oblonga</i> , <i>D. corona</i> )

FIGURE 5—Late glacial through Holocene vegetational and arcellacean succession in eastern Nova Scotia and western Newfoundland. The boundaries between assemblages at the Newfoundland sites are represented by dashed lines to illustrate the diachroneity of these boundaries.

1987; Patterson et al., 1985). The success of this taxon as an early colonizer may be due to its ability to tolerate harsh environmental conditions, such as slightly brackish water (Honig and Scott, 1987), cold arctic temperatures (Collins et al., 1990), and hyper-oligotrophic conditions. The species *C. aculeata* strongly dominates sediments deposited during the Younger Dryas reversal in all three lakes. Kerr (1984) and McCarthy (1984) found this species relatively easy to culture in bacteria-rich pondwater devoid of algae, suggesting that these organisms are bacteriophages, and therefore well suited to exploiting proglacial environments where there is low organic matter. This may explain the dominance of *C. aculeata* (arcellacean assemblage B) shortly after deglaciation, when the nutrients which had melted from the ice sheet had been depleted.

With the accelerated climatic warming around 10,000 years B.P., the organic content of the three lakes increased sharply, similar to other lakes in Atlantic Canada (Mott et al., 1986), and the boreal balsam fir, spruce, and birch, replaced tundra vegetation. This constitutes the "Early Hypsithermal" of Ogden (1987). A sudden change also occurred in the arcellacean population, with *Diffugia oblonga* increasing at the expense of *Centropyxis aculeata* in all three lakes (arcellacean assemblage C). This may be a direct response to warmer waters or an indirect response to increased organic matter deposited in these warmer waters. Relatively high percentages of *Heleopera sphagni* (Leidy) suggest a wetland community around Robinsons Pond during the early Holocene.

The Hypsithermal ("mid Hypsithermal" of Ogden, 1987) is marked in Penhorn Lake by peaks of pine and hemlock. Temperatures in Newfoundland were never sufficiently warm to allow expansion of hemlock, however pine does peak in Joe's

Pond during the mid Holocene between 6,500 and 4,500 years B.P. MacPherson (personal commun.) also identified a pine maximum at two other sites in Newfoundland, between 6,300 and 4,200 years B.P. The mid-Holocene pine maximum was not found in Robinsons Pond on the coast of St. Georges Bay, however, even though it is only five kilometres from Joe's Pond. The development of the Inner Labrador Current in the latter half of the Holocene, bringing very cold (0–2°C) water to water depths less than 300 m all around Newfoundland (Scott et al., 1984) may have caused a microclimatic variation, cooling Robinsons Pond but not further inland at Joe's Pond. The appearance of *Diffugia bacillifera*, *Lecquereusia spiralis* (Ehrenberg), *Diffugia protaeiformis* Lamarck, and *Pontigulasia compressa* around 8,000 years B.P. and the peak of *P. compressa* and *D. bacillifera* (Assemblage D) in all three lakes during the mid Holocene Hypsithermal suggests that these species are thermophilous. This is consistent with Collins et al. (1990), although low percentages of a large, coarsely agglutinated form of *P. compressa* were found in the arctic.

Late Holocene climatic cooling in Nova Scotia and Newfoundland is evident from the pollen records and the derived paleotemperature estimates, which show a decrease in mean July temperature of over 1°C from the Hypsithermal by 1,500 years B.P. Ogden (1987) reports an increase in alder, sedge, and spruce during the late Holocene, while an increase in alder, sedge, and fern marks the late Holocene in Newfoundland. The increase in these taxa probably reflects paludification around these lakes in response to increased precipitation and regional cooling.

The resurgence of *Centropyxis aculeata* (assemblage E) at the beginning of the late Holocene reflects climatic cooling, and the

presence of *Nebella collaris* (Ehrenberg) and significant percentages of *Heleopera sphagni* in the late Holocene sediments of Robinsons Pond suggest the establishment of wetlands, consistent with the paludification recorded by high percentages of pollen of wetland taxa such as grasses, sedges, ferns, and alder. Percentages of thermophilous taxa (e.g., *Diffugia bacillifera* and *Pontigulasia compressa*) increased in the latest Holocene, but never attained mid-Holocene levels. Assemblage E is similar to assemblage A, but E is more diverse. This probably reflects both the difficulty in migrating to and colonizing a new site compared with the ability of a species to withstand harsh environmental conditions once a population has been established at a site.

#### CONCLUSIONS

Cores from Robinsons Pond and Joe's Pond in southwestern Newfoundland, and Penhorn Lake in eastern Nova Scotia, exhibit similar late glacial through Holocene arcellacean successions (assemblages A–E), with characteristic late glacial, early Holocene, mid-Holocene Hypsithermal and late Holocene assemblages. The similarity of arcellacean succession and synchronicity in arcellacean assemblages in the three lakes suggests that changes in arcellacean assemblages occurred in a non-random manner in response to changes in the benthic freshwater environment in these shallow lakes during glacial through post-glacial time. In addition, changes in arcellacean assemblages coincide with changes in the pollen record, suggesting that climatic change was the major factor affecting arcellacean succession. Arcellaceans may therefore be useful as paleoclimatic indicators. The arcellacean succession in the lakes studied, for instance, allows the identification of the beginning of the Holocene, the mid-Holocene Hypsithermal, as well as the Younger Dryas reversal which is not recorded by the pollen in any of the lakes studied. The more distinct arcellacean signal could reflect the inability of these protists to adapt to and tolerate wide ranges of environmental conditions, as well as their rapid generation time, allowing small-scale environmental changes to be reflected quickly in the geologic record. Trees, in contrast, tend to have a wider range of tolerance, and their longer lifespan makes the identification of short-lived climatic phenomena difficult.

Some conclusions can be drawn regarding the paleoenvironmental significance of certain arcellacean taxa, based on this study and on published studies: 1) The species *Centropyxis aculeata*, which dominates the late glacial, tolerates harsh environmental conditions, such as slightly brackish water, cold temperatures, and sediments low in organic matter. This may explain its success as an early colonizer. 2) *Diffugia oblonga* is present but generally not abundant in early, predominately sandy late glacial sediments. With the increase in productivity and the inception of gyttja deposition in all three lakes around 10,000 years B.P., percentages of *D. oblonga* rise sharply, and thereafter this species consistently dominates, or else codominates with other diffugiid species, suggesting that it prefers more organic conditions than *Centropyxis aculeata*, but appears to tolerate low temperatures. 3) The absence of *Pontigulasia compressa* and *Diffugia bacillifera* before 8,000 years B.P. in the three lakes studied, and their peak abundance during the mid-Holocene Hypsithermal, suggests that they may require warm bottom waters. 4) The increased abundance of *Heleopera sphagni* and *Nebella collaris*, reported to be associated with aquatic plants in the literature, supports the interpretation of paludification around Robinsons Pond during the late Holocene initially based on the increase in wetland plants (e.g., alder, grasses, sedges, and ferns). This may be due to the inception of the cold Inner Labrador Current starting in the mid-Holocene (Scott et al., 1984).

Arcellaceans therefore provide information on local limnological changes (e.g., trophic status) as well as reflecting climatic changes which occurred in Atlantic Canada following deglaciation. Although these conclusions hold for the three lakes studied, further work must be done on modern and fossil arcellacean distribution to test whether these generalizations are universally applicable. We have shown that in a local context, arcellaceans can complement and improve paleoenvironmental interpretations based on the more commonly-studied fossil pollen.

#### ABBREVIATED TAXONOMY

Although this paper is not taxonomic in nature, we present a brief synonymy of the taxa discussed herein because arcellaceans have received relatively little study. A comprehensive systematic taxonomy can be found in Medioli and Scott (1983).

##### DIFFLUGIA BACILLIFERA Penard

Figure 2.3–2.9

*Diffugia bacillifera* PENARD, 1890, p. 146, Pl. 4, figs. 61–66.

##### CENTROPYXIS ACULEATA (Ehrenberg)

Figure 2.1

*Arcella aculeata* EHRENBURG, 1832, p. 91.

*Centropyxis aculeata* (Ehrenberg). STEIN, 1859, p. 43.

##### CENTROPYXIS CONSTRICTA (Ehrenberg)

Figure 2.2

*Arcella constricta* EHRENBURG, 1843, p. 410, Pl. 4, fig. 35, Pl. 5, fig. 1.

*Centropyxis aculeata* (Ehrenberg). DEFLANDRE, 1929, p. 340, text-figs. 60–67.

##### CUCURBITELLA TRICUSPIS (Carter)

Figure 2.12

*Diffugia tricuspis* CARTER, 1856, p. 221, fig. 80.

*Cucurbitella tricuspis* (Carter). MEDIOLI, SCOTT AND ABBOTT, 1987, p. 28–47, 4 Pls.

##### DIFFLUGIA BACILLIARUM Perty

*Diffugia bacillarum* PERTY, 1849, p. 27.

##### DIFFLUGIA CORONA Wallich

Figure 2.10

*Diffugia proteiformis* (sic) (Ehrenberg) subspecies *D. globularis* (Dujardin) var. *D. corona* WALLICH, 1864, p. 244, Pl. 15, fig. 4a–c, Pl. 16, fig. 19, 20.

*Diffugia corona* Wallich. ARCHER, 1866, p. 186.

##### DIFFLUGIA GLOBULUS (Ehrenberg)

*Arcella ? globulus* EHRENBURG, 1948, 9, p. 279.

*Diffugia globulus* (Ehrenberg). CASH AND HOPKINSON, 1909, p. 33, text-figs. 52–54, Pl. 21, figs. 5–9.

##### DIFFLUGIA OBLONGA Ehrenberg

Figure 2.11

*Diffugia oblonga* EHRENBURG, 1832, p. 90.

##### DIFFLUGIA PROTAEIFORMIS Lamarck

*Diffugia protaeiformis* LAMARCK, 1816, p. 95 (with reference to material in a manuscript by LeClerc).

##### DIFFLUGIA URCEOLATA Carter

Figure 2.13

*Diffugia urceolata* CARTER, 1864, p. 27, Pl. 1, fig. 7.

## DIFFLUGIA URENS

Patterson, MacKinnon, Scott, Mediolli

*Diffflugia urens* PATTERSON, MACKINNON, SCOTT, AND MEDIOLI, 1985, p. 135, Pl. 3, figs. 5-14.

## HELEOPERA SPHAGNI (Leidy)

Figure 2.14

*Diffflugia (Nebella) sphagni*, LEIDY, 1874, p. 157.*Heleopera sphagni* (Leidy) CASH AND HOPKINSON, 1909, p. 143, Pl. 30, figs. 4-9.

## LAGENODIFFLUGIA VAS Leidy

*Diffflugia vas* LEIDY, 1874, p. 155.*Lagenodiffflugia vas* (Leidy) MEDIOLI AND SCOTT, 1983, p. 33-34, Pl. 2, figs. 18-23, 27, 28.

## LECQUEREUSIA SPIRALIS (Ehrenberg)

Figure 2.15

*Diffflugia spiralis* EHRENBURG, 1840, p. 199.*Lecquereusia spiralis* (Ehrenberg), PATTERSON, MACKINNON, SCOTT, AND MEDIOLI, 1985, p. 135, Pl. 2, figs. 9, 10.

## NEBELLA COLLARIS (Ehrenberg)

*Diffflugia collaris* EHRENBURG, 1848b, p. 218.*Nebella collaris* (Ehrenberg) LEIDY, 1879, p. 145, 146, Pl. 22, 23, figs. 1-7, Pl. 24, figs. 11, 12.

## PONTIGULASIA COMPRESSA (Carter)

Figure 2.16

*Diffflugia compressa* CARTER, 1864, p. 22, Pl. 1, figs. 5, 6.*Pontigulasia compressa* (Carter), RHUMBLER, 1895, p. 105, Pl. 4, fig. 13a, b.

## ACKNOWLEDGMENTS

We thank I. Brookes, T. Duffett, and A. Khana for field assistance, J. G. Ogdon III for pollen data from Penhorn Lake, D. Siddiqi and C. Younger for laboratory assistance, M. Lozon for assisting with generating figures, V. Baki for computing assistance, and B. Deonarine and F. Thomas for SEM photography. The review by R. T. Patterson was of great assistance, and the comments of J. MacPherson on an early draft of this manuscript are greatly appreciated. Financial assistance for this project was through NSERC grants to F. M. G. McCarthy, D. B. Scott, F. S. Mediolli, and J. H. McAndrews.

## REFERENCES

- ARCHER, W. 1866. Quarterly Journal of Microscopical Science, new series, 6:185-188.
- ARIGO, R., S. E. HOWE, AND T. WEBB III. 1986. Climatic calibration of pollen data: an example and annotated computing instructions, p. 817-849. In B. E. Berglund (ed.), Handbook of Holocene Paleocology and Paleohydrology. John Wiley, New York.
- BARTLEIN, P. J., AND T. WEBB III. 1985. Mean July temperature at 6000 yr B.P. in eastern North America: Regression equations for estimates from fossil-pollen data, p. 301-342. In C. R. Harington (ed.), Climatic Change in Canada 5: Critical Periods in the Quaternary Climatic History of Northern North America. Syllogeus No. 55.
- BROOKES, I. A. 1977. Geomorphology and Quaternary geology of Codroy Lowland and adjacent plateaus, southwest Newfoundland. Canadian Journal of Earth Sciences, 14:2101-2120.
- CAMPBELL, I. A., AND J. H. McANDREWS. 1992. CANPLOT: A FORTRAN-77 program for plotting stratigraphic data on a postscript device. Computers and Geosciences, 18:309-335.
- CARTER, H. J. 1856. Notes on the freshwater Infusoria of the Island of Bombay: No. 1. Organisation. Annals and Magazine of Natural History, ser. 2, 18:221-249.
- . 1864. On freshwater Rhizopoda of England and India. Annals and Magazine of Natural History, ser. 3, 13:18-39.
- CASH, J., AND J. HOPKINSON. 1909. The British freshwater Rhizopoda and Heliozoa: Volume II, Rhizopoda, Part II: Royal Society, London: 1-166.
- COLLINS, E. S., F. M. G. MCCARTHY, F. S. MEDIOLI, D. B. SCOTT, AND C. A. HONIG. 1990. Biogeographic distribution of modern thecamoebians in a transect along the eastern North American coast, p. 783-792. In C. Hemleben and others (eds.), Paleocology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. Kluwer Academic Publishers, Amsterdam.
- CORBET, S. A. 1973. An illustrated introduction to the testate rhizopods in Sphagnum, with special reference to the area around Malham Tarn, Yorkshire. Field Studies, 3:801-838.
- DEAN, W. E. JR. 1974. Determination of carbonate and organic matter in calcareous sediment and sedimentary rock by loss on ignition: a comparison with other methods. Journal of Sedimentary Petrology, 44:243-248.
- DECLOITRE, L. 1953. Recherches sur les Rhizopodes thécamoebiens d'A.O.F. (Suite). Faune du Lac Tamna (Senegal). Bulletin de l'Institut Francais d'Afrique Noire, no. 31, 249 p.
- DEFLANDRE, G. 1929. Le genre *Centropyxis* Stein. Archiv für Protistenkunde, 67:322-375.
- EHRENBURG, G. C. 1832. Über die Entwicklung und Lebensdauer der Infusionsstiere, nebst fernerer Beiträgen zu einer Vergleichung ihrer organischen Systeme: Königliche Akademie der Wissenschaften zu Berlin Abhandlungen, 1831:1-154.
- . 1840. (No title): Königliche Preussische Akademie der Wissenschaften zu Berlin Bericht, 1840:197-210.
- . 1843. Verbreitung und Einfluss des mikroskopischen Lebens in Sud und Nord Amerika: Königliche Akademie der Wissenschaften zu Berlin Abhandlungen, 1841:291-446.
- . 1848a. Fortgesetzte Beobachtungen über jetzt herrschende atmosphärische mikroskopisch Verhältnisse: Bericht über die zur Bekanntmachung geeigneten Verhandlungen der Königlich Preussischen Akademie der Wissenschaften zu Berlin, 13:370-381.
- . 1848b. Über eigenthümliche auf dem Baumen des Urwaldes in Sud-Amerika zahlreich lebende Mikroskopische oft Kieselschalige Organismen: Königlich Preussischen Akademie der Wissenschaften zu Berlin, 1848:213-220.
- FAEGRI, K., AND J. IVERSEN. 1975. Textbook of Pollen Analysis (3rd edition). Munksgard, Copenhagen, 237 p.
- GAJEWSKI, K. 1988. Late Holocene climate changes in eastern North America estimated from pollen data. Quaternary Research, 29:255-262.
- GRIMM, E. C. 1987. CONISS: A FORTRAN-77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Computers & Geosciences, 13:13-35.
- HEAL, O. W. 1964. The abundance and micro-distribution of testate amoebae (Rhizopoda:Testacea) in Sphagnum. Oikos, 13:35-47.
- HONIG, C. A., AND D. B. SCOTT. 1987. Postglacial stratigraphy and sea-level change in southwestern New Brunswick. Canadian Journal of Earth Sciences, 24:354-364.
- KERR, H. A. 1984. Arcellaceans in Eastern Canada: selected biostratigraphic and biological studies. Unpublished honours thesis, Dalhousie University, Halifax, Nova Scotia, 49 p.
- LAMARCK, J. B. 1816. Histoire naturelle des animaux sans vertebres. Verdier, Paris, tome 2:1-568.
- LEIDY, J. 1874. Notice of some Rhizopods: Academy of Natural Sciences of Philadelphia Proceedings, ser. 3, 1874:155-157.
- . 1879. Freshwater Rhizopods of North America. United States Geological Survey of the Territories Report, 12:1-324.
- LIVINGSTONE, D. A. 1968. Some interstadial and postglacial pollen diagrams from eastern Canada. Ecological Monographs, 38:87-125.
- McANDREWS, J. H. 1984. Pollen analysis of the 1973 core from Devon Island Glaciers, Canada. Quaternary Research, 22:68-76.
- . 1994. Pollen diagrams from southern Ontario applied to archaeology. In R. MacDonald and B. Warner (eds), Great Lakes Archaeology and Palaeoecology: Exploring Interdisciplinary Initiatives for the Nineties. University of Waterloo. In press.
- , A. A. BERTI, AND G. NORRIS. 1973. Key to the Quaternary pollen and spores of the Great Lakes Region. Royal Ontario Museum Life Sciences Miscellaneous Publication, Toronto, Ontario, 61 p.
- MCCARTHY, F. 1984. Intraspecific variation in Arcellacea (Thecamoebians) from Eastern Canada and a selected biostratigraphic study.

- Unpublished honours thesis, Dalhousie University, Halifax, Nova Scotia, 41 p.
- MEDIOLI, F. S., AND D. B. SCOTT. 1983. Holocene Arcellacea (Thecamoebians) from Eastern Canada. Cushman Foundation for Foraminiferal Research. Special Publication No. 21, 63 p.
- , AND ———. 1987. Lacustrine thecamoebians (mainly arcellaceans) as potential tools for paleolimnological interpretations. *Palaeogeography, Palaeoclimatology and Palaeoecology*, 62:361–386.
- MEDIOLI, F. S., D. B. SCOTT AND B. H. ABBOTT. 1987. A case study of protozoan intraclonal variability: taxonomic implications. *Journal of Foraminiferal Research*, 17:28–47.
- MOTT, R. J., D. R. GRANT, R. R. STEA, AND S. OCCHIETTI. 1986. Late Glacial climatic oscillation in Atlantic Canada equivalent to the Allerod/younger Dryas event. *Nature*, 323:247–250.
- OGDEN, J. G. III. 1987. Vegetational and climatic history of Nova Scotia. I. Radiocarbon-dated pollen profiles from Halifax, Nova Scotia. *Canadian Journal of Botany*, 65:1482–1487.
- PATTERSON, R. T. AND E. FISHBEIN. 1989. Re-examination of the statistical methods used to determine the number of point counts needed for micropaleontological research. *Journal of Paleontology*, 63:245–248.
- PATTERSON, R. T., K. D. MACKINNON, D. B. SCOTT, AND F. S. MEDIOLI. 1985. Arcellaceans ("Thecamoebians") in small lakes of New Brunswick and Nova Scotia: modern distribution and Holocene stratigraphic changes. *Journal of Foraminiferal Research*, 15:114–137.
- PERTY, M. 1949. Über vertikale Verbreitung mikroskopische Lebensformen. *Naturforschende Gesellschaft in Bern Mitteilungen*, 1849: 17–45.
- PENARD, E. 1890. Etudes sur les Rhizopodes d'eau douce: Memoires de la Societe de Physique et d'Histoire Naturelle de Geneve, 31:1–230.
- RHUMBLER, L. 1895. Beitrage zur Kenntnis der Rhizopoden (Beitrag III, IV, und V). *Zeitschrift für Wissenschaftliche Zoologie*, 61, no. 1:38–110.
- ROWE, J. S. 1972. Forest Regions of Canada. Canadian Forestry Service, Publication 1300.
- SCOTT, D. B., AND F. S. MEDIOLI. 1983. Agglutinated rhizopods in Lake Erie: modern distribution and stratigraphic implications. *Journal of Paleontology*, 57:809–820.
- , P. J. MUDIE, G. VILKS, AND C. D. YOUNGER. 1984. Latest Pleistocene-Holocene paleoceanographic trends on the continental margin of eastern Canada: foraminiferal, dinoflagellate and pollen evidence. *Marine Micropaleontology*, 9:181–218.
- SCHONBORN, W. 1963. Die Stratigraphie lebender Testaceen in Sphagnum der Hochmoore. *Limnologica*, 1:315–321.
- STEIN, S. F. N. VON. 1859. Über die ihm aus eigener untersuchung bekannt gewordenen Süßwasser-Rhizopoden. *Königliche Böhmisches Gesellschaft der Wissenschaften Abhandlungen*, ser. 5, v. 10, Berichte der Sectionen:41–43.
- STOCKMARR, J. 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, 13:615–621.
- THIBAudeau, S. A., F. S. MEDIOLI, AND D. B. SCOTT. 1987. Carboniferous marginal-marine Rhizopods: a morphological comparison with recent correspondents. Abstract, Geological Society of America, Annual Meeting, Phoenix, p. 866.
- TOLONEN, K. 1986. Rhizopod analysis, p. 645–666. In B. E. Berglund (ed.), *Handbook of Holocene Paleoecology and Paleohydrology*. J. Wiley, New York.
- WALLICH, G. C. 1864. On the extent, and some of the principal causes, of structural variation among the diffugian rhizopods. *Annals and Magazine of Natural History*, ser. 3, 13:215–245.
- WEBB, T. III AND R. A. BRYSON. 1972. Late- and postglacial climate change in the northern Midwest, USA: Quantitative estimates derived from fossil pollen spectra by multivariate statistical analysis. *Quaternary Research*, 2:70–115.
- WRIGHT, H. E., JR. 1967. A square rod piston sampler for lake sediments. *Journal of Sedimentary Petrology*, 37:975–976.

ACCEPTED 10 DECEMBER 1991