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Full Length Research Paper

Biogeographic variation in Thecamoebian (*Testate amoeba*) assemblages in lakes within various vegetation zones of Alberta, Canada

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Thecamoebians (testate amoebae) have proven to be valuable proxies commonly used in environmental and paleoenvironmental studies. A better understanding of their geographic distribution and environmental parameters influencing this distribution is required for further thecamoebian research. Thecamoebians were analyzed from twelve lakes spanning five drainage basins and four vegetation zones, representing a variety of environmental and limnological parameters in Alberta, Canada. Species diversity is low throughout the study sites, ranging from 1.35 to 2.17, with various strains of *Difflugia oblonga*, *Centropyxis constricta* and *Centropyxis aculeata* dominating the fauna. Climate, as reflected in the vegetation zones, appears to be an influencing factor on species and strain distributions. Low-diversity assemblages strongly dominated by *C. aculeata* and C. *constricta,* characterize lakes in the rocky mountain region. Slightly, more diverse assemblages dominated by *D. oblonga* and *Cucurbitella tricuspis* characterize lakes in the grassland region. The highest thecamoebian diversity was found in both the Boreal Forest and Parkland zones. The Boreal Forest is dominated by *D. oblonga* together with *C. constricta*, *C. tricuspis* and *C. aculeata*, while the Boreal Parkland is dominated by *D. oblonga* along with *C. constricta* and C. *aculeata*.

Key words: Thecamoebians, *Testate amoebae*, biogeographic, Alberta.

INTRODUCTION

Thecamoebians (also called *Testate amoebae*) are protists belonging to the phylum Sarcodaria, superclass Rhizopoda. They are a diverse and important component of the microbial trophic level within the benthic community of lakes and wetlands, where they play a critical role in food webs as the intermediate between bacterial and benthic invertebrate communities (Patterson and Kumar, 2002; Beyens and Meisterfeld, 2001). These benthic protozoans, particularly those belonging to the Order Thecolobosa (Arcellinida), superfamily Arcellacea, produce a fossilizable test (shell) of pseudo-chitinous material that is variably agglutinated by different species (Medioli and Scott, 1983). The variable agglutination allows for the differential identification of species and strains. After death, their tests fossilize and are found in all aquatic and moist terrestrial sediments, although the preservation potential varies between species (Boudreau et al., 2005; Patterson and Kumar, 2002).

In lacustrine studies, thecamoebians have been successfully applied traditionally to paleoclimatic reconstructions (Boudreau et al., 2005; McCarthy et al., 1995; Patterson and Kumar 2002) and have been more recently used to investigate the impact of sulphide, silver (Reinhardt et al., 1998) and pyrite (Kumar and Patterson, 2000) mining in acid-sensitive lakes in Ontario (Patterson et al., 1996; Reinhardt et al., 1998; Kumar and Patterson, 2000; Patterson and Kumar, 2002; Roe et al., 2010). Also, they have shown usefulness in following aquatic reclamation development at an oil sands facility in north-eastern Alberta (McCarthy et al. 2008; Neville, 2010).

Processing of sediments for thecamoebian analysis typically follows one of two protocols depending on the

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type of research. One group of researchers follows the "lacustrine"/ "micopaleontological" method (Scott et al., 2001), while the other group follows the "wetland"/ "biological" method of sediment processing (Hendon and Charman, 1997; Tolonen, 1966 and 1986; Warner, 1990). Both methods produce viable numbers of thecamoebians, but unfortunately they do not observe the same species, so researchers cannot compare results. Climate (Collins et al., 1990; McCarthy et al., 1995; Yang et al., 2006; Neville et al. 2010) and lake trophic status (Yang et al., 2009) have been identified as major factors that can be used to explain biogeographic distribution of thecamoebian taxa. The distributions of testate amoebae in wetlands have been well examined globally (Smith 1982, 1996; Wilkinson, 1994; Mitchell et al., 2000; Booth and Zygmunt, 2005), however, few studies have examined the biogeographic distribution of thecamoebians in lakes. The investigation of thecamoebians in lakes employs the "lacustrine"/ "micopaleontological" method of thecamoebian processing. In China, Yang et al. (2005; 2006; 2009) investigated distributional factors related to the Yunnan Plateau. North American studies include broad transects along eastern North America (Collins et al., 1990), lake Erie (Scott and Medioli, 1983) and small lakes in New Brunswick, Nova Scotia and Newfoundland (Patterson et al., 1985; Honig and Scott, 1987; McCarthy et al., 1995). To date, the only distributional study of thecamoebians in Alberta was carried out by Booth and Zygmunt (2005), who use the "wetland"/ "biological" method of sediment processing. Due to the widespread distribution of thecamoebians, Booth and Zygmunt (2005) suggest that dispersal pat-terns are primarily controlled by local environmental conditions.

This study compares both the thecamoebian and limnological data to investigate the parameters controlling thecamoebian distribution in natural aquatic systems in Alberta, Canada. Lakes that date back to deglaciation less than 12,000 years ago, are most abundant where the water budget is positive, but are also present even in the most arid region in southeastern Alberta and were included in this study (Figures 1 and 2). The atlas *of Alberta Lakes* (Crosby et al., 1990) was used to choose sites from a variety of geographical settings representing a range of environmental parameters, including precipitation, temperature, evaporation, water budget, elevation, bedrock geology, surficial sediment and trophic status. The distribution of the lakes studied, ranged northeast-southwest from Gregoire Lake (56°27′N, 110°09′W) to the Spray Lakes Reservoir (50°54′N, 115°20′W).

METHODOLOGY

Sediment samples were collected from 13 locations across the province of Alberta, from four different vegetation zones (Rocky Mountain, Boreal Forest, Boreal Parkland and Grassland; Dyke et al., 2004) (Table 1, Figure 1) and five different drainage basins (Athabasca River, North Saskatchewan River, Battle River, Red Deer River and Bow River basins) (Table 1). Duplicate samples (two samples per lake) of approximately 200 mL of surface sediment were collected from each lake over a nine-day period in July 2008, using an Ekman grab sampler. Duplicate samples were collected from within 1 m of each. Water samples (~200 mL) were also collected from each site for later analysis. Field measurements of temperature and conductivity (uS/cm) were taken using a Hach Hydromet and dissolved oxygen (DO) at the sediment water interface was measured using a Hydrolab. To avoid complications introduced by lake stratification (Cole, 1979), all lakes were sampled within the first two meters of the shoreline. The sediment samples were transferred to glass jars and were stored at 4°C prior to shipping to Brock University for thecamoebian analysis. The water samples were transported to Syncrude Canada Ltd. (SCL) Edmonton Research facility where water analysis, including conductivity, pH, major ions, trace metals, ammonia and naphthenic acids, was performed using SCL standard analytical protocols (Syncrude, 2005).

Samples were prepared for thecamoebian analysis following the standard micropaleontological methods described in Scott et al. (2001). Subsamples of 5cc were sieved through 500, 63 and 45 μm mesh. Samples were stained with Rose Bengal to determine the presence of cytoplasm in the tests (Scott and Medioli, 1980; Bernhard, 2000). Tests stained using this method are generally reported to have been living at or shortly before the time of collection, while unstained tests indicate that the organism has died and is fossilized. Bernhard et al. (2006) have called this conclusion to question, proposing a new technique, which has not yet become standard (Bernhard et al., 2006). For quantitative analysis, the samples were placed in a gridded Petri dish and wet-counted using a dissecting binocular microscope. Thecamoebians were identified to species and strain, primarily using the key by Kumar and Dalby (1998), although reference was also made to photoplates and descriptions in various publications, notably Medioli and Scott (1983). Specimens were identified and species diversity was calculated using strains because strains have been found to convey useful information on aquatic subenvironments (Kumar and Patterson, 2000; Kauppila et al., 2006).

Twelve lakes contained sufficient numbers of thecamoebian tests allow for meaningful comparisons of assemblages. For statistical analysis, the absolute number of specimens examined, ranges from 200 to 1,000 per sample, although most researchers generally count approximately 300 specimens (Patterson and Fishbein, 1989). When the number of thecamoebians counted in the 5cc subsample did not reach 300, an additional 5cc subsample was processed and counted.

Species diversity was calculated using the Shannon-Weaver diversity index (SDI) (Shannon and Weaver, 1949). SDI is a measure of faunal diversity and is useful for indicating the relative health of the community from which the sample was taken. Harsh, unfavorable environmental conditions are normally characterized with an SDI between 0.5 –1.5, intermediate conditions range from 1.5 - 2.5 and favorable/stable conditions have an SDI >2.5 (Patterson and Kumar, 2002). The SDI is calculated using the following formula, where S is the species richness for each sample:

$$SDI = -\sum_{I}^{S}\left(\frac{Fi}{Ni}\right) * \ln\left(\frac{Fi}{Ni}\right)$$

The relative fractional abundance (F_i) was calculated for each taxonomic unit using:

$$Fi = \frac{Ci}{Ni}$$

where C_i is the species count and N_i is the number of individuals

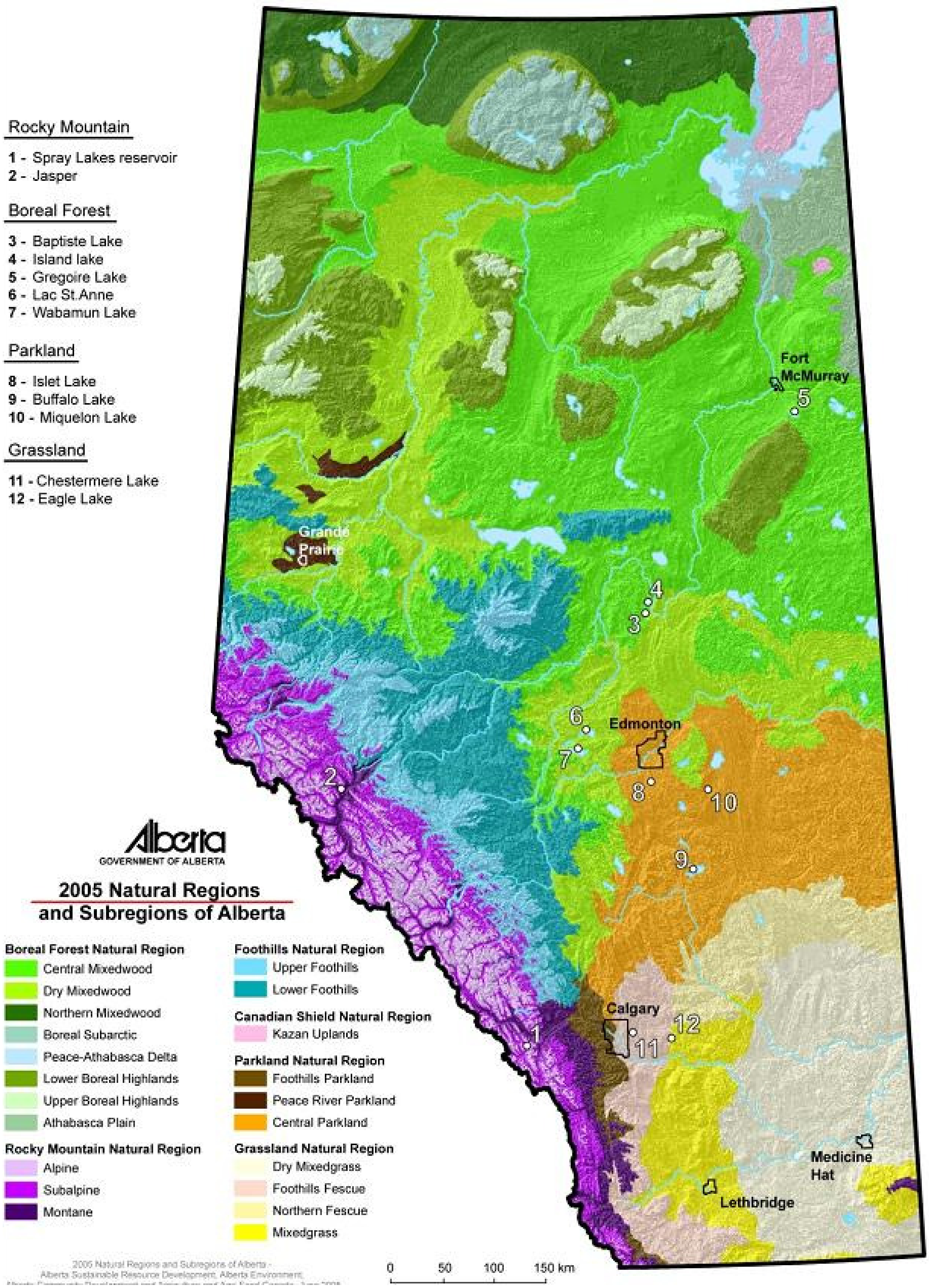

Figure 1. Map of Alberta illustrating the natural region (vegetation zone) boundary divisions and the locations of the study sites within each zone.

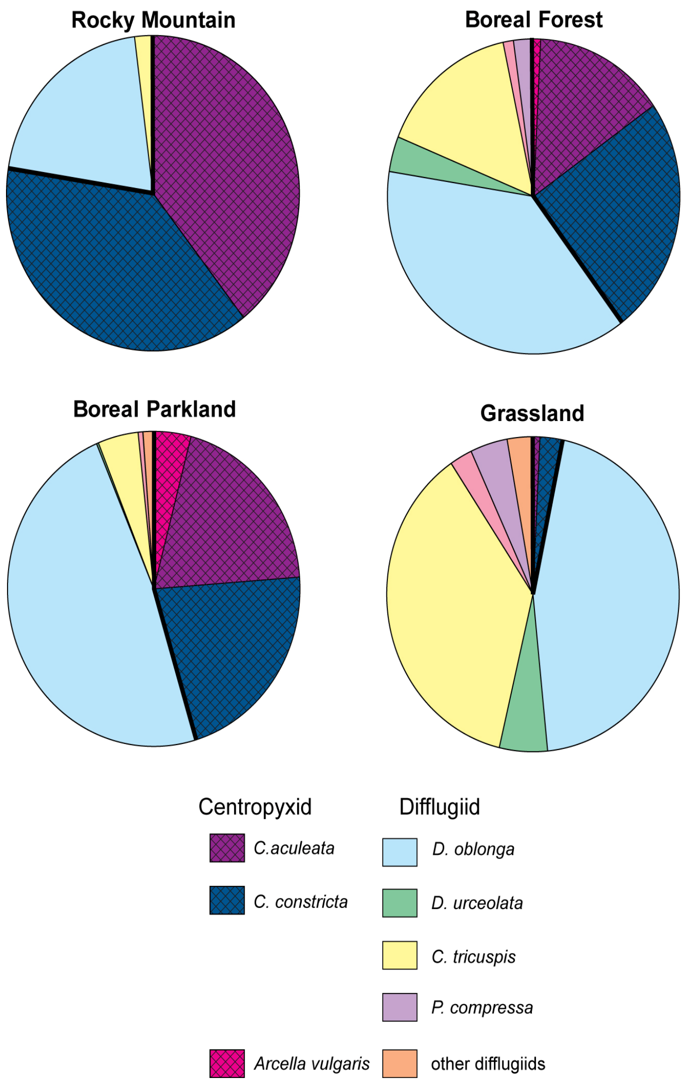

Figure 2. Pie graphs representing thecamoebian community composition within each vegetation zone.

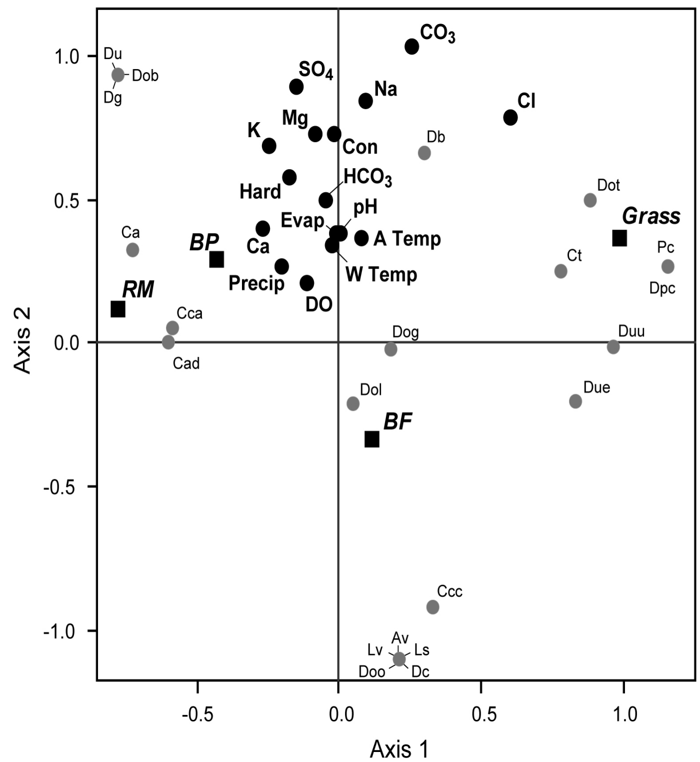

Figure 3. Bi-plot of canonical correspondence analysis (CCA) of vegetation zones, environmental and chemical variables and species observed throughout the study. RM=Rocky Mountain, BP=Boreal Parkland, BF=Boreal Forest, Grass=Grassland, Hard=water hardness, Precip=precipitation, W Temp=water temperature, A Temp=air temperature, Evap=evaporation, DO=dissolved oxygen, Con=conductivity (values located in Table 2 and 4). Species name abbreviations can be found in Table 5.

(total population) in the sample (Patterson and Fishbein, 1989). Data analysis was performed using Minitab version 15 (Minitab Inc. USA). Canonical correspondence analysis (CCA) was used to analyze population relationships among lakes. Data input included chemical and environmental parameters as well as thecamoebians abundances by vegetation zone.

RESULTS AND DISCUSSION

Climate regions can be identified from the vegetation zones (Table 1), which are a composite of temperature and precipitation together with non-climatic parameters like soil type. Mean annual temperature did not vary greatly across the study area, except for the high altitudes of the Rocky Mountain region, which were substantially cooler (Table 1). Lakes within each vegetation zone are seemingly very different from each other in terms of chemical composition and trophic status. However, a comparison of thecamoebian assemblages in lakes studied within each vegetation zone generated P-values greater than 0.05, suggesting no significant difference between lakes within each zone. There was also no significant difference (P-values greater than 0.05) between duplicate samples collected from the same lake. Yang et al. (2009) suggested that trophic status was the main factor driving thecamoebian distribution in lakes in China however that correlation was not observed in Alberta (Tables 1 and 2). Low-diversity assemblages (shannon diversity index (SDI) av 1.36) strongly dominated by *Centropyxis aculeata* and *Centropyxis constricta* with few *Difflugia oblonga* characterized both lakes in the Rocky Mountain region (Tables 2 and 3, Figure 3). These lakes contained the highest centropyxid/difflugiid ratio of lakes investigated as part of this study (Table 2). Collins et al. (1990) found centropyxids to be ubiquitous across eastern North America, from Florida to Baffin Island. Booth and Zygmunt (2005) also observed low species diversity in the Rocky Mountain region, but further comparison of the research results

Table 1. General characteristics of study sites including site locations, dates sampled, drainage basins and trophic status (Crosby et al., 1990). Sites are grouped by vegetation zone.

	Date sampled	Latitude	Longitude	Trophic status	Drainage basin
		Rocky mountain			
Spray lakes reservoir	25/07/08	N50°54′	W115°20′	Hypereutrophic	Bow river
Jasper	24/07/08	N52°56′	W118°01′	-	Bow river
		Boreal forest			
Baptiste lake	19/07/08	N54°45′	W113°33′	Hypereutrophic	Athabasca river
Island lake	21/07/08	N54°51′	W113°32′	Mesotrophic	Athabasca river
Gregoire lake	21/07/08	N56°27′	W110°09′	Eutrophic	Athabasca river
Lac St. Anne	18/07/08	N53°42′	W114°25′	Eutrophic	North Saskatchewan R.
Wabamun lake	18/07/08	N53°33′	W114°36′	Eutrophic	North Saskatchewan R.
		Boreal parkland			
Isle lake	19/07/08	N53°38′	W114°44′	Hypereutrophic	North Saskatchewan R.
Buffalo lake	27/07/08	N52°28′	W112°54′	Mesotrophic	Red deer river
Miquelon lake	27/07/08	N53°21′	W112°55′	-	Battle river
		Grassland			
Chestermere L.	27/07/08	N51°02′	W113°49′	Mesotrophic	Bow river basin
Eagle lake	27/07/08	N51°00′	W113°19′	Hypereutrophic	Bow river basin

Table 2. Summary of limnological and micropaleontological data for each study site. Sites are grouped by vegetation zone.

	Lake temp (°C)	Mean annual precip. (mm)	Mean annual evap. (mm)	Mean temp (°C)	Total # tests (N)	# of species (S)	% of total tests centropxids	Ratio of cent/diff	SDI
Rocky mountain									
Spray Lakes Reservoir	18.6	622	621	7.5	321	5	71	2.45	1.36
Jasper	18.4	620	620	8	303	4	84	5.3	1.35
Boreal forest									
Baptiste L.	22.1	493	638	12	293	9	56	1.27	1.83
Island L.	24.0	539	638	12	356	8	35	0.55	1.68
Gregoire L.	24.1	504	580	12	312	7	38	0.61	1.68
Lac St. Anne	16.6	549	642	12	346	9	44	0.79	1.78
Wabamun L.	23.2	534	642	12	574	17	28	0.39	2.17
Boreal parkland									
Islet L.	21.5	423	660	14	417	6	69	2.1	1.62
Buffalo L.	24.2	413	665	13	372	7	50	0.95	1.80
Miquelon L.	24.2	466	664	13	279	7	46	0.86	1.38
Grassland									
Chestermere L.	20.6	416	712	12.5	351	6	0	0	1.46
Eagle L.	21.8	376	712	12.5	375	9	6.4	0.07	1.66

Table 3. Water chemical analysis for each site, showing water hardness, major ions and metals. Sites are grouped by vegetation zone.

	pH	Cond. (µS/cm)	DO sed/ water interface (mg /L)	Hardness (mg/L as $CaCO_3$)	Na	K	Mg	Ca	Cl	SO_4	CO_3	HCO_3
Rocky mountain												
Spray lakes	7.69	285	7.6	147	2.0	1.0	10.5	41	0.9	38	0	145
Jasper	7.59	420	6.6	212	4.6	0.5	18.8	54	6.7	70	0	175
Boreal forest												
Baptiste lake	8.06	340	12.7	117	32	5.1	13.1	25	4.0	15	0	196
Island lake	7.32	459	3.9	155	44	10	21.8	26	8.9	6	0	304
Gregoire lake	7.23	147	7.2	66	3.9	1.0	5.0	18	2.1	7	0	75.6
Lac St. Anne	7.81	343	8.5	122	30	11	12.5	28	7.7	15	0	196
Wabamun lake	8.06	570	9.8	136	78	11	20.5	20	13	85	0	251
Boreal parkland												
Islet lake	7.50	318	2.8	139	12	13	19.7	23	6.0	9	0	186
Buffalo lake	8.75	2350	10	304	486	39	66	11	20	402	117	915
Miquelon lake	9.32	2690	5.7	726	356	63	145	49	31	1240	68	106
Grassland												
Chestermere L.	8.23	400	3.2	164	25	1.0	17.4	37	9.7	70	0	149
Eagle lake	9.09	1548	8	279	269	16	55.9	19	52	348	83	355

taxa (*Difflugia urens and urceolata*) produce higher diversity assemblages (SDI 1.38-1.80, av. 1.60) than in the Grasslands (Tables 2 and 3, Figure 2). Several strains of *C. constricta* and *aculeata* typically codominate the with theirs is impeded by the different protocols used for thecamoebian analysis. Booth and Zygmunt (2005) processed their samples using the protocol and taxonomy favored by wetland researchers (Hendon and Charman, 1997; Tolonen, 1966 and 1986; Warner, 1990), in producing very different assemblages.

Lakes in the Grassland region contained slightly more diverse assemblages (SDI= 1.56) dominated by various strains of *D. oblonga* and *Cucurbitella tricuspis. Pontigulasia compressa* and *Difflugia urceolata* were also present in both lakes in the Grassland region (Tables 2 and 3, Figure 2). In these lakes, centropyxids comprised less than 10% of the thecamoebian population (Table 2). Several strains of *D. oblonga* are important components of the assemblage in the Boreal Parkland zone, while *C. tricuspis* is only present in low quantities. The codominance of *C. aculeata* and *C "*aerophila*"* with *D. oblonga* and the occasional occurrence of other difflugiid Boreal Forest zone, with various strains of *D. oblonga* also abundant. *C. tricuspis* is a more common constituent in the Boreal Forest than in the Parkland and *P. compressa, Arcella vulgaris* and *D. urceolata* are also consistently present in the Boreal Forest, unlike in the Parkland (Table 3, Figure 2). The Boreal Forest contains the highest thecamoebian diversity (SDI 1.68-2.17, av. 1.83) found in this study.

The chemical and physical properties of the lakes studied were examined using CCA to see which properties mostly affected the thecamoebian distribution (Figure 3). Most of Alberta, experiences a negative water budget (Crosby et al., 1990), except for the Rocky Mountain region, which is slightly positive. Several of the lakes, particularly in the Boreal Parkland and Grasslands have high concentrations of ions or conductivities related to the high evaporative potential (Table 4). The CCA analysis revealed that no specific chemical nor environmental parameter overwhelmingly influenced the distribution of thecamoebians within the given vegetation zones. Interestingly, water hardness clusters with the main environmental parameters which are not often referred to in the literature. Hard water is one that has a high content of calcium (Ca^{2+}) and magnesium (Mg^{2+}) and in the Alberta lakes, these ions were balanced by either carbonate or sulphate ions. Chloride levels at all locations were relatively low so that this ion represented only a small fraction of the total anions. Sodium was low at most sites, except for two of the Boreal Parkland lakes (Buffalo and Miquelon Lake) and a Grassland lake (Eagle Lake) where the elevated sulphate ions were balanced predominantly by sodium rather than the calcium and magnesium. These lakes also had the highest conductivities. For this study, calcium and magnesium were used to calculate hardness, which has been expressed in terms of $CaCO_3$ (Table 4, Figure 3). Except for the three lakes

Table 4. Percent abundance (% A), standard error (error), test per cc and sum of thecamoebians observed at each study location.

Sample	**Spray lakes**		**Jasper**		**Baptiste lake**		**Island Lake**		**Gregoire lake**		**Lac St. Anne**		**Wabamun lake**	
Sum	321		303		293		356		312		346		574	
Individuals/cc	32		30		29		36		31		34		57	
	% A	**Error**	**% A**	**Error**	**% A**	**Error**	**% A**	**Error**	**% A**	**Error**	**% A**	**Error**	**% A**	**Error**
Arcella vulgaris (Av)	-	-	-	-	-	-	-	-	6.73	2.78	1.16	1.13	1.05	0.83
Centropyxis aculeata (Ca)	-	-	20.79	4.57	0.68	0.94	-	-	9.62	3.27	1.73	1.38	2.44	1.26
Centorpyxis aculeata "discoides" (Cad)	28.97	4.96	30.69	5.19	13.65	3.93	13.48	3.55	-	-	14.74	3.74	11.15	2.57
Centropyxis constricta "aerophila" (Cca)	42.06	5.40	32.67	5.28	34.13	5.43	21.91	4.30	-	-	26.59	4.66	3.83	1.57
Centropyxis constricta "constricta" (Ccc)	-	-	-	-	7.51	3.02	-	-	21.47	4.56	-	-	9.76	2.43
Lesquereusia spiralis (Ls)	-	-	-	-	-	-	-	-	-	-	-	-	0.52	0.59
Pontigulasia compressa (Pc)	-	-	-	-	-	-	-	-	-	-	2.31	1.58	2.09	1.17
Cucurbitella tricuspis (Ct)	3.74	2.08	-	-	17.06	4.31	9.55	3.05	10.26	3.37	19.94	4.21	6.62	2.03
Lagenodifflugia vas (Lv)	-	-	-	-	-	-	-	-	-	-	-	-	0.70	0.68
Difflugia protaeiformis "claviformis" (Dpc)	-	-	-	-	-	-	1.12	1.09	-	-	-	-	1.74	1.07
Difflugia bidens (Db)	-	-	-	-	1.02	1.15	-	-	-	-	-	-	1.05	0.83
Difflugia corona (Dc)	-	-	-	-	-	-	-	-	-	-	-	-	1.92	1.12
Difflugia urceolata "urceolata" (Duu)	-	-	-	-	-	-	-	-	6.73	2.78	0.58	0.80	-	-
Difflugia urceloata "elongata" (Due)	-	-	-	-	4.78	2.44	2.81	1.72	-	-	-	-	0.70	0.68
Difflugia oblonga "glans" (Dog)	9.35	3.18	15.84	4.11	7.51	3.02	10.11	3.13	39.42	5.42	21.10	4.30	32.06	3.82
Difflugia oblonga "lanceolata" (Dol)	15.89	4.00	-	-	13.65	3.93	38.20	5.05	-	-	11.85	3.41	18.29	3.16
Difflugia oblonga "oblonga" (Doo)	-	-	-	-	-	-	-	-	5.77	2.59	-	-	2.96	1.39
Difflugia oblonga "tenuis" (Dot)	-	-	-	-	-	-	2.81	1.72	-	-	-	-	3.14	1.43

Table 4. Contd.

Sample	**Islet lake**		**Buffalo lake**		**Miquelon lake**		**Chestermere lake**		**Eagle lake**	
Sum	425		385		304		351		375	
Individuals/cc	43		38		30		35		38	
	% A	**Error**	**% A**	**Error**	**% A**	**Error**	**% A**	**Error**	**% A**	**Error**
Arcella vulgaris (Av)	1.88	1.29	3.38	1.80	8.22	3.09	-	-	-	-
Centropyxis aculeate (Ca)	7.76	2.54	-	-	27.30	5.01	-	-	-	-
Centropyxis aculeata "discoides" (Cad)	22.88	4.56	17.14	3.76	-	-	-	-	1.60	1.27
Centropyxis constricta "aerophila" (Cca)	36.00	4.56	29.05	4.69	10.86	3.50	-	-	1.60	1.27

Table 4. Contd.

Centropyxis constricta "constricta" (Ccc)	-	-	-	-	-	-	-	-	3.20	1.78
Lesquereusia spiralis (Ls)	-	-	-	-	-	-	-	-	-	-
Pontigulasia compressa (Pc)	-	-	-	-	-	-	5.98	2.48	2.40	1.55
Cucurbitella tricuspis (Ct)	7.76	2.54	10.13	3.01	0.66	0.91	45.30	5.21	28.80	4.58
Lagenodifflugia vas (Lv)	-	-	-	-	-	-	-	-	-	-
Difflugia protaeiformis "claviformis" (Dpc)	-	-	-	-	-	-	-	-	5.60	2.33
Difflugia protaeiformis "acuminata" (Dpa)	-	-	-	-	-	-	-	-	-	-
Difflugia bidens (Db)	-	-	6.23	2.42	-	-	5.13	2.31	-	-
Difflugia corona (Dc)	-	-	-	-	-	-	-	-	-	-
Difflugia urens (Du)	-	-	-	-	0.33	0.64	-	-	-	-
Difflugia urceolata "urceolata" (Duu)	-	-	-	-	-	-	-	-	5.60	2.33
Difflugia urceloata "elongata" (Due)	-	-	-	-	-	-	5.13	2.31	-	-
Difflugia globula (Dg)	-	-	-	-	4.28	2.27	-	-	-	-
Difflugia oblonga "glans" (Dog)	9.88	2.84	12.47	3.30	40.79	5.52	17.09	3.94	36.80	4.88
Difflugia oblonga "lanceolata" (Dol)	14.82	3.38	18.92	3.83	-	-	21.37	4.29	-	-
Difflugia oblonga "bryophila" (Dob)	-	-	-	-	7.57	2.97	-	-	-	-
Difflugia oblonga "oblonga" (Doo)	-	-	-	-	-	-	-	-	-	-
Difflugia oblonga "tenuis" (Dot)	-	-	4.68	2.11	-	-	-	-	14.40	3.55

above, the pH of the various water sources were less than 8.2, which meant that bicarbonate was the main carbonate ion present.

Patterson et al. (1985) and Escobar et al. (2008) suggest pH and other water properties to be more influential than climate on the distribution of thecamoebians, but the research findings did not suggest that climate had any more control on distribution than water properties (Figure 3). In contrast to the research findings, in which DO cluster with all other parameters, Smirnov and Thar (2003) suggest that dissolved oxygen does not influence thecamoebian distribution, however many other authors suggest that certain species are very sensitive to dissolved oxygen content (Asioli et al., 1996; Scott and Medioli 1983). Inaddition, recent work by Roe at al. (2010) also found dissolved oxygen to be an important influencing variable. The Boreal Parkland contained the highest proportion of *A. vulgaris* which is possibly related to the overall high chemical composition, notably conductivity in two of the three lakes found in this region. *A. vulgaris* is typically considered an indicator of extremely unfavorable environmental conditions. It has been found in low pH, high chemical content environments (Boudreau et al., 2005; Patterson et al., 2000), as well as industrially impacted environments contaminated with Ag, Hg (Patterson et al., 1996) and those associated with oil sands process affected material, created by oil sands mining activity in Northern Alberta (Neville et al., 2010). *C. aculeata* and *C. constricta* are typically considered opportunistic (Boudreau et al., 2005) and tolerant of harsh environmental conditions including cold temperatures, marginally brackish waters and low nutrient availability (Collins et al., 1990; McCarthy et al., 1995) and are the dominant species in many modern Arctic lakes (Collins et al., 1990). *C. aculeata* and *C. constricta* were present in high numbers in the Boreal Forest and Parkland and dominated the Rocky Mountain thecamoebian community composition (Table 4). This is likely related to the low temperatures and concentrations of all chemical constituents found in the Rocky Mountain region (Table 3 and 4). *D. oblonga* was common in all the vegetation zones. It can thrive in almost any climate and tolerates climate extremes, including extreme cold as long as the sediment is sufficiently organic (Collins et al., 1990; McCarthy et al., 1995). The proportion

Table 5. The total number of tests (number of stained tests, interpreted as indicating the presence of cytoplasm in the test at the time of collection) and relative abundance of common thecamoebian species from each vegetation zone.

	Rocky mountain		Boreal forest		Boreal parkland		Grassland	
	Total # of tests (# stained)	% of fauna stained	Total # of tests (# stained)	% of fauna stained	Total # of tests (# stained)	% of fauna stained	Total # of tests (# stained)	% of fauna stained
A. vulgaris	0 (0)	0	31 (0)	0	44 (3)	7	0 (0)	0
C. aculeata	249 (59)	24	265 (63)	24	227 (24)	11	6 (0)	0
C. constricta	234 (47)	20	437 (93)	21	234 (43)	18	18 (0)	0
D. oblonga	129 (13)	10	833 (106)	13	541 (105)	19	327 (45)	14
D. urceolata	0 (0)	0	53 (5)	9	3 (0)	0	39 (0)	0
C. tricuspis	12 (0)	0	219 (50)	23	49 (33)	67	267 (120)	45
D. bidens	0 (0)	0	12 (0)	0	6 (0)	0	18 (9)	50
P. compressa	0 (0)	0	26 (0)	0	0 (0)	0	30 (0)	0
Other difflugiids	0 (0)	0	5 (0)	0	10 (2)	20	21 (0)	0

of the population composed of stained (living) tests remained relatively consistent and comprised only a small portion of the population in comparison to the total (stained + unstained) number of tests observed (Table 5). Hence, total populations were used to define assemblages as outlined by Patterson et al. (1985). Total populations include both stained and un-stained specimens, giving an indication of time-averaged environmental conditions, while living populations only indicate conditions at the time of collection. The total population has been shown to be a good indicator of long-term (duration observed depends on sedimentation rate) as opposed to seasonal conditions (Scott and Medioli, 1980). High percentages of stained *C. tricuspis* were found in the Boreal Parkland and Grassland zones, and the only stained specimens of *D. bidens* were found in the Grassland. 50% of the *D. bidens* observed in the grassland region were alive. *D. bidens* occurs in environments with increased terrigenous sediment input and high percentages sediment of organic matter (Patterson et al., 1996).

Conclusion

Thecamoebian communities are relatively different in most lakes across Alberta. Chemically, each lake is unique with no trends in terms of major ions across vegetation zones. When thecamoebian populations of lakes are grouped in terms of vegetation zones, identifiable populations appear. In an attempt to establish parameters influencing thecamoebian population distribution in relation to vegetation zones, environmental (temperature and precipitation) and chemical parameters were investigated. This study did not identify any specific population influencing parameters, as all parameters analyzed clustered together. This suggests that the biogeography of the drainage basin and sediment input may be of importance to thecamoebian distribution. Future research should include grain size distribution in order to understand better thecamoebian distributional controlling factors. Understanding environmental controls and the parameters influencing thecamoebian distribution at broader spatial scales will improve our ability to interpret fossil thecamoebian records. The centropyxid/difflugiid ratio appears to be a simple way of identifying a stressed environment. It is a tool that can potentially be expanded to assess stressors to the environment in mining municipal runoffs, oilsands etc. Knowing the natural population stressors may allow us to better develop and increase the sensitivity of this community to follow environmental changes both in terms of degrading (pollution) and improving (reclamation) and increase the likelihood of using thecamoebians as bioindicators during remediation and reclamation efforts, such as those taking place in the Athabasca Oil Sands of Alberta (McCarthy et al., 2007; 2008; Neville, 2010).

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