FLOOD RECONSTRUCTION USING CHIRONOMIDS (NON-BITING MIDGES) PRESERVED IN LACUSTRINE SEDIMENTS

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Abstract

Chironomids (non-biting midges) are insects with a larval stage living in aquatic ecosystems, including deltaic lakes. Their head capsules are made of chitin, a substance persisting in lake sediments for thousand of years. The distribution of sub-fossil chironomids in 61 lakes of the Peace Athabasca Delta (PAD) was used to determine if the larvae could be used as proxy indicators of flooding. In open lakes (i.e. lakes connected to a river), the percentage of lotic chironomid taxa was more than 30% while percentages of lotic taxa lower than 20% were found in close lakes (i.e. without any connection to a river). These limits of lotic taxa percentages were used to try to reconstruct the connectivity of two lakes (PAD 9 and Spruce Island Lake) in the last hundred years and compare the reconstruction to the known connectivity of the lakes. The technique reconstructed accurately the states of the lakes when they were open or closed at both sites. However, it was impossible to reconstruct the more subtle changes which characterized the "intermediate" state of the lakes. The method of reconstruction could be improved if the taxonomy of the sub-fossil chironomids would be further developed.

1. Introduction

Deltaic landscapes, such as the Peace-Athabasca Delta (PAD), located mostly within Wood Buffalo National Park in northern Alberta, Canada, consist of a multitude of lakes with various limnological and ecological conditions and these lakes seem to be extremely sensitive to natural and anthropogenic processes leading to dessication or flooding of the delta. In the PAD, the deltaic system might have been impacted by the regulation of the Peace River since 1968 which potentially lead to extended periods of dessication. But, those anthropogenic effects can be masked, or superimposed by the effects of ongoing climatic variability. The extended periods of low flood frequency and their resulting effects on biological productivity and diversity have raised some concerns (e.g. Prowse and Conly 2000). Since PAD is the largest freshwater boreal delta in the world and is recognized by the International Ramsar Convention on Wetlands, as well as UNESCO for its ecological, historical and cultural significance, the understanding of its natural and/or anthropogenic variations are of particular interest.

Prior studies of the PAD have focussed on evaluating and modelling flow regimes (e.g. Prowse and Lalonde, 1996; Leconte et al. 2001; Peters and Prowse, 2001) and ice-jam induced flood development during spring break-up or ricer ice-cover (Peters, 2003). Furthermore, hydrologic studies were conducted on a limited number of discrete water bodies of the PAD over limited timescales (e.g., Bennett et al. 1973; PADTS 1996; Pietronirio et al. 1999; Peters 2003). While these studies have provided important information, more studies are required to quantify delta-wide hydrological processes to

better anticipate regional hydroecological responses to future changes in river discharge and climate.

A multi-proxy (isotopes, diatoms, pigments, pollen, plant macrofossil) study was established in 2000 to a) provide the analytical tools to quantify past and present hydrological processes influencing the PAD system and b) use these tools to reconstruct the natural variability and to assess anthropogenic impacts on lakes within the PAD system (Hall et al. 2004; Wolfe et al. 2005; Wolfe et al. 2007). In a collaborative effort to analyse most of the proxies which might be indicative of lake level changes, it was decided in 2003 to add one more proxy (chironomids (non-bitting midges)) and evaluate their potential for reconstructing past hydrological processes. Chironomids have been previously used to reconstruct water level changes (Hofmann, 1998), to study the effects of flooding in rice field (Stevens et al. 2006) and in floodplain wetlands in south-eastern Australia (Quinn et al. 2000) and to reconstruct river flooding in France (Gandouin et al. 2005; 2006). In Lake Silvaplana, Switzerland, the increase of lentic and/rheophilous taxa has been associated with increase precipitation (Larocque et al. 2009). Here, we want to evaluate the potential of using chironomids for reconstructing hydrological processes in the largest freshwater boreal delta of the world. We expect that lentic taxa will have higher abundances in lakes which are connected to the major rivers, and that the abundances of lotic taxa can be used to reconstruct the historical water level fluctuations.

2. Methods

2.1 Study area

The PAD is formed by the Peace, Athabasca and Birch rivers at the western end of Lake Athabasca (Fig. 1). The PAD is located within the subhumid mid-boreal ecoclimatic region (Ecoregions Working Group, 1989). Based on 1971-2000 averages, mean annual air temperature is -1.9 ℃, mean January air temperature is -23.2 ℃ and mean July air temperature is 16.7° C. The annually average precipitation is 391.7 mm (Wolfe et al. 2005).
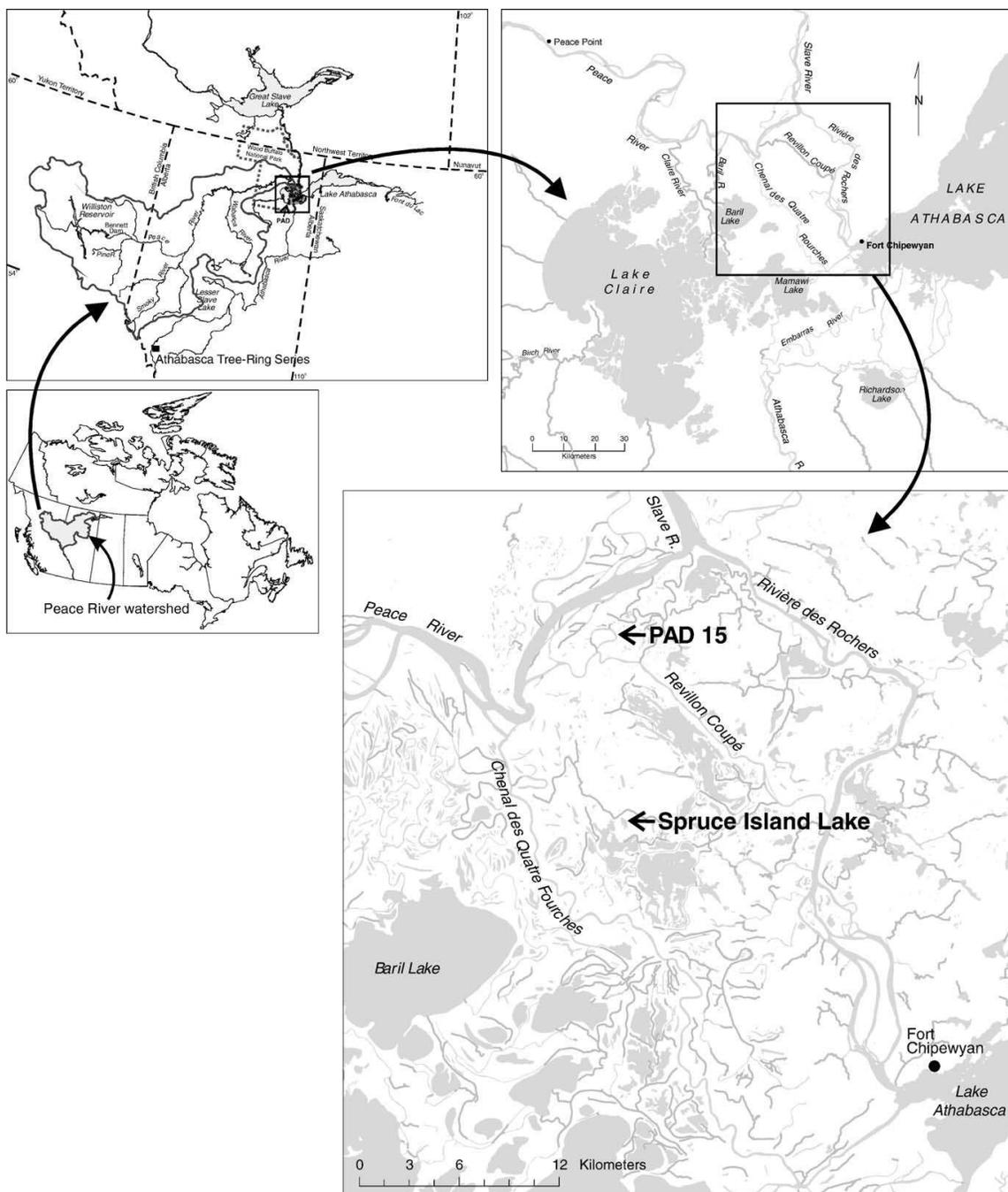
Figure 1. *Studied sites*

The PAD is composed of a myriad of lakes with varying characteristics and interconnected channels. Four large, shallow basins (lakes Claire, Baril, Mamawi, Richardson) dominate the interior of the PAD. Periodic ice-jam flooding has been identified as integral to the hydro-ecology of the PAD (Prowse and Lalonde, 1996). In the

absence of periodic flooding, water levels may decline and isolated basins may dry up completely (Prowse et al. 1996; Prowse and Conly, 1998; Pietroniro et al. 1999).

2.2. « Training set lakes »

61 lakes were sampled in the Peace-Athabasca Delta in October 2000. Sampled basins spanned the full range of apparent river influence. Water chemistry and chlorophyll concentration were measured on water samples. All samples were collected from 10 cm below the water surface at the deepest part of each basin. The PAD lakes are generally shallow (mean depth = 76 cm), nutrient-rich (mean TP = 84.4 µg/L), alkaline (mean pH = 8.2), and contain relatively high concentrations of major ions (Table 1). Evaporation/Inflow ratios were calculated for each of the study sites using an isotope-mass balance model as described in Wolfe et al. 2007 (Table 1). These ratios were used to characterize the lakes as "close", "restricted", "precipitation" or "open" (Table 1).

Table 1:Selected physical and chemical cahracteristics of the two studied lakes

Variable	Spruce Island	PAD 9
Maximum depth (m)	0.9	0.8
Total phosphorus (µg/L)	75.85	42.64
Dissolved phosphorus (µg/L)	21.37	31.92
Total nitrogen (µg/L)	2168.74	1923.52
Dissolved nitrogen (µg/L)	1831.92	1840.92
Chlorophyll a (µg/L)	9.48	1.13
Dissolved organic carbon (mg/L)	27.90	31.99
SiO_2 (µg/L)	124.50	6.11
pH	8.74	8.25
Alkalinity meq/L	3.75	4.62
Conductivity mS/cm	0.37	0.43
Ca (µg/L)	27.05	43.51
Mg (µg/L)	17.42	20.5
K (µg/L)	13.49	12.85

Surface sediment samples (0-1 cm) were collected using a mini-Glew gravity corer (Glew, 1991) and stored in plastic bags at 4 ℃ until analysed. The multi-proxy study included biological analyses of diatoms, pigments, pollen and plant macrofossils. Here, we present only the chironomid analysis.

A solution of KOH (10%) was added to the surface sediment samples overnight and the samples were then sieved in a 90 µm mesh. The residue was then place in a Bogorov counting tray and each head capsule was handpicked and mounted on a microscope slide in a solution of Hydromatrix. The taxonomy mainly followed Wiederholm (1983) and Oliver and Roussel (1983). Tanytarsini were separated into generic types or groups following Brooks et al. (2007). If mandibles were not present, the Tanytarsini were separated into groups of Tanytarsus with (with spur on the pedestal of the antenna) or Tanytarsus without (without spur on the pedestal of the antenna). Tanypodinae were

separated using Rieradevall and Brooks (2001). If the headcapsule was too dirty to differentiate the pores of the setae, it was classified as Pentaneurini or *Procladius* (larger headcapsule, square head, dark mandibles). Percentages of lotic taxa were then calculated, based on classifications established by Gandouin et al. (2006), Engels et al. (2008) and on the ecological knowledge of each taxon (e.g. Wiederholm, 1983; Larocque and Rolland, 2006; Brooks et al. 2007). A classification of these taxa can be found in Table 2.

Table 2. Lotic and lentic taxa

Lentic	Lotic
Phaenopsectra*,**	**Cricotopus***,**,***
Limnophyes*,**	**Nanocladius***,***
Cladopelma*,**,***	**Micropsectra***,***
Sergentia**,***	**Orthocladius***,***
Microtendipes*,**,***	Paracladopelma*
Ablabesmyia*,**	**Eukiefferiella***,***
Parakiefferiella*,**,***	
Psectrocladius*,***	
Endochironomus*,***	
Dicrotendipes*,***	
Glyptotendipes*,**,***	
Paratanytarsus*,***	
Tanytarsus*,***	

Legend: *: in Gandouin et al. 2006

**: in this study

***: in litterature (Larocque and Rolland 2006, Brooks et al. 2007)

2.1.3 Sites for historical reconstruction

Spruce Island Lake (PAD 5) (unofficial name; 58º50.82'N; 111º28.84'W) is a small (22.5 ha), shallow (0.9m) lake at 209.9 m a.s.l surrounded by mature forest on bedrock outcrops. It is located between the Chenal des Quatre Fourches and the Revillon Coupé (Fig. 1). In its present state, it is nutrient rich, relatively alkaline and supports extensive growth of colonial filamentous algae and submerged aquatic macrophytes including *Potamogeton* spp. and *Chara* spp. *Spargnium eurycarpum*, *Acorus calamus*, *Alisma plantago-aquatica* and *Typha latifolia* composed the emergent vegetation and cover shallow coves between the bedrock outcrops.

Three sediment cores (33-36 cm long) were collected in June 2001 using a modified KB gravity corer (Glew, 1989). All cores were sampled at 0.5 cm-intervals. KB2 (35.0 cm long) was used for organic carbon and nitrogen elemental content and cellulose oxygen isotope composition. KB3 (36.0 cm long) was used for radiometric dating and diatom, pigment and chironomid analyses. KB4 (33.0 cm long) was used for plant macrofossil analyses. Loss-on-ignition analyses were determined on all cores.

Samples from KB-3 were analysed for Lead[210] at the Environmental Radiochemistry Laboratory, Department of Fisheries and Oceans, Winnipeg, Manitoba. One to 3 g samples of dry sediment were analysed for every 0.5 cm sediment interval. The Constant Rate of Supply (CRS) model (Oldfield and Appleby, 1984) was used to establish the geochronology. The model is presented in Wolfe et al. (2005).

PAD 9 (58º46.46'N; 111º19.48'W) is also small (12 ha), shallow (0.9m) and located at 208.8 m a.s.l. The lake is located near Lake Athabasca, separated from it by an extensive (ca. 70 km^2) wetland (Fig. 1). The lake is also nutrient rich and relatively alkaline. The south shore is composed of bedrock outcrops while the remaining shoreline is marked by a double fringe of uprooting dead willow shrubs indicative of both lower and higher water levels in the past. During the growing season, the lake is highly productive with abundant *Ceratophyllum* and filamentous algae.

Five short cores were extracted in June 2001. KBI (30 cm long) was used for elemental and isotope geochemistry. KB2 (29.0 cm long) was used for plant macrofossil analysis. KB 4 (33.0 cm long) was used for dating, diatom, pigments and chironomid analysis. KB 3 (33.5 cm long) was retained as an archival core.

Samples from KB4 were analysed for Lead[210] at the Environmental Radiochemistry Laboratory, Department of Fisheries and Oceans, Winnipeg, Manitoba. Methods follow the ones used in PAD 5. The model is presented in Sinnatamby (2006). Table 3 summarizes the major characteristics of both studied lakes.

2.4 Chironomid analysis for reconstruction

A measured mass of dry sediment was placed in KOH 10% overnight at room temperature. Samples from Spruce Island Lake were placed in an ultrasonic bath for 2-3 seconds (Lang et al. 2003) and then sieved in a 90-µm mesh. Because the ultrasonic bath was not available when PAD 9 was analysed, the samples were directly sieved using a 90-µm mesh. The sub-sample remaining in the mesh was put in a Bogorov counting tray and looked at under a stereozoom microscope at 60X. Each chironomid headcapsule was individually picked and mounted on a microscope slide in Hydromatrix. Identification was made at 400-1000X using a light microscope. The taxonomy followed the method described for the training set lakes Head capsules with only half of the mentum were counted as half. Head capsules with less than half mentum were not enumerated. The abundances of lotic taxa

3. Results

3.1 Training set lakes

Seven of the 48 taxa identified in the 61 lakes used as a training set were found only or mainly in closed and restricted lakes (Fig 2). These are *Phaenopsectra*, *Cladopelma*, *Sergentia*, *Microtendipes*, *Parakiefferiella*, *Limnophyes*, and *Ablabesmyia*. Six of these taxa (*Phaenopsectra, Cladopelma, Microtendipes, Parakiefferiella, Limnophyes, Ablabesmyia*) were also described as strictly lentic in France (Gandouin et al. 2006) while *Sergentia* was identified as a taxon preferring inundated lakes in Finland (Engels et al. 2008) and described as a sublittoral to profundal taxon, thus lentic (Brooks et al. 2007; Francis 2001). *Phaenopsectra* and *Limnophyes* can be both lentic and lotic (Brooks et al. 2007; Brooks and Birks 2004; Heiri et al. 2004; Epler 1995; Oliver and Roussel 1983).

Figure 2. *Distribution of chironomid taxa in the 61 training-set lakes*

Gandouin et al. (2006) have also identified *Psectrocladius*, *Endochironomus*, *Dicrotendipes*, *Glyptotendipes*, *Paratanytarsus* and *Tanytarsus* as lentic taxa, Dicrotendipes nervosus-type, Paratanytarsus pencillatus-type and two types of Tanytarsus were described as taxa preferring isolated lakes (Engels et al. 2008) and the literature suggests that these taxa are indeed lentic (Larocque et al. 2006; Brooks et al. 2007). Here, *Dicrotendipes* had higher abundances in close and restricted lakes and *Psectrocladius sordidellus*-group was found at high percentage in one open lake, although it usually dominated restricted lakes. *Endochironomus* was not very abundant in some lakes along the gradient, *Glyptotendipes* was generally more abundant in some closed and restricted lakes while *Tanytarsus* seemed to increase along the gradient. Of these taxa, based on the literature and our results, *Phaenopsectra*, *Cladopelma*, *Sergentia*, *Microtendipes*, *Parakiefferiella*, *Limnophyes*, *Ablabesmyia*, *Dicrotendipes, Psectroladius* and *Glyptotendipes* were used to create the "Lentic taxa" percentages (Fig. 2).

Few taxa (*Cladotanytarsus* and *Cryptotendipes*) were found mainly in precipitation and open lakes and these taxa were found in low abundances. They were not found in the lakes in France (Gandouin et al. 2006) but was *Cladotanytarsus mancus*-type described as a taxon preferring inundated lakes in Finland (Engels et al. 2007) In the literature, *Cladotanytarsus* is described as littoral (Brooks et al. 2007; Larocque and Rolland 2006) while *Cryptotendipes* is found in lakes and rivers (Pinder and Reiss 1983). *Polypedilum* had percentages which increased in precipitation and open lakes but is described as a littoral taxon (Hofmann 1984). Gandouin et al. (2006) identified *Cricotopus*, *Micropsectra*, *Orthocladius*, *Eukiefferiella*, *Paracladopelma* and *Nanocladius* as lotic

taxa. Here, *Cricotopus* percentages increased along the gradient, *Paracladopelma* was in low abundances in very few lakes along the gradient and *Micropsectra* and *Eukiefferiella* were not present in the surface samples of the 61 lakes. *Orthocladius* had a tendency to increase in close lakes. *Nanocladius* (Cranston 1982), *Eukiefferiella* (Brooks et al. 2007) and some *Micropsectra* (Brooks et al. 2007) have been described as lotic taxa. *Cricotopus* and *Orthocladius* can be found both in rivers and lakes (Brooks et al. 2007) while *Paracladopelma* can be found in profundal zones of lakes (Brooks et al. 2007). Based on these results, *Cladotanytarsus*, *Cricotopus*, *Orthocladius*, *Micropsectra* and *Eukiefferiella* were used to calculate "lotic-taxa" percentages (Fig. 2).

The lentic and lotic percentages agreed relatively well with the defined categories (Fig 2). Only one of the closed lakes had lotic-taxa percentages higher than the average while only two of the precipitation and open lakes lotic-taxa percentages below the average. The lentic-taxa percentages were above average in most of the close and restricted lakes. Although their percentages were lower in the precipitation and open lakes, the lentic taxa still represented a generally high percentage of the taxa in all lakes. The lentic taxa could thus not be used to try to separate efficiently the lakes types. In Figure 3, the relationship between the percentage of lotic taxa and the ratio of lentic/lotic taxa suggests that lakes with more than 20% of lotic taxa are generally precipitation or open lakes. Only five of the restricted and close lakes had percentages of lotic taxa above 20%, while only two of the precipitation and open lakes had percentages of lotic taxa below 20%. From these results, we concluded that assemblages with 20% or more of lotic taxa probably indicate

situations where the lake is totally of partly connected to a river (or having higher precipitation) and could be used to indicate such situations in the past.

3.2 Reconstruction

The stratigraphic diagram of PAD9 was divided accordingly to the historical knowledge obtained from historical maps (1884, 1897, 1971), aerial photos (1927, 1955) and reconstructions by other proxies (Figure 3). Between 1903 and 1931, the lake was open. During this time interval, there was a striking increase of *Paracladopelma* and *Cricotopus*, two taxa considered as lotic by Gandouin et al. (2006) and *Polypedilum* which increased in precipitation and open lakes in our training set. The increase of these taxa has lead to the increased percentages (above 20%) of lotic taxa. *Chironomus anthracinus*-group and *C. plumosus*-group sharply decreased during this stage. During this phase the lentic taxa were mostly below average.

During the inundated phase, the chironomids reconstructed a variability from an inundated phase between 1579 and 1604 when the percentages of lotic taxa were above 20% and the lentic taxa were below average, followed by an episode (1604-1778 AD) when lotic taxa were below 20% suggesting a close situation, and the return of an inundated period between 1778 and 1903 with lotic taxa above 20% and lentic taxa mostly below average.

After the open state, the lotic-taxa percentages decreased below average while lentic-taxa percentages were generally above average. Some taxa were present only during that stage (*Ablabesmyia*, *Zalutschia lingulata pauca*) while *Chironomus plumosus*-group dominated the assemblages.

Figure 3. *Historical change of chironomid taxa in PAD 9*

The stratigraphical diagram of Spruce Island Lake (Fig. 4) was divided into three sections

based on a multi-proxy reconstruction (Wolfe et al. 2005). During the phase of

dessication (I<E, ca 1720-1777 AD), the chironomid assemblages were dominated by lentic taxa with *Glyptotendipes* type 2, *Glyptotendipes* and various taxa of *Tanytarsus* as dominant. *Cricotopus* were also abundant. The lotic-taxa percentages were generally below the 20% level suggesting a more open state of the lake. During the following phase, when the inflow was equal to the evaporation (ca 1777-1983 AD), some taxa such as *Pentaneurini*, *Tanytarsus* sp. B, *Tanytarsus* with spur and *Parachaetocladius* appeared. *Parakiefferiella* disappeared towards the end of the zone. *Chironomus plumosus*-group and *C. anthracinus*-group dominated the assemblages but *Cricotopus* were still important. In general, lotic-taxa percentages were higher than in the previous zone (25-40%), alternating with short periods when lotic-taxa percentages were below 20%. During the last zone (ca 1983-2000 AD), when the inflow was larger than evaporation, *C. anthracinus*-group disappeared as well as *Glyptotendipes* and *Glyptotendipes* type 2. *Eukiefferiella* and *Polypedilum* increased. Lotic-taxa percentages reached 30-40%.
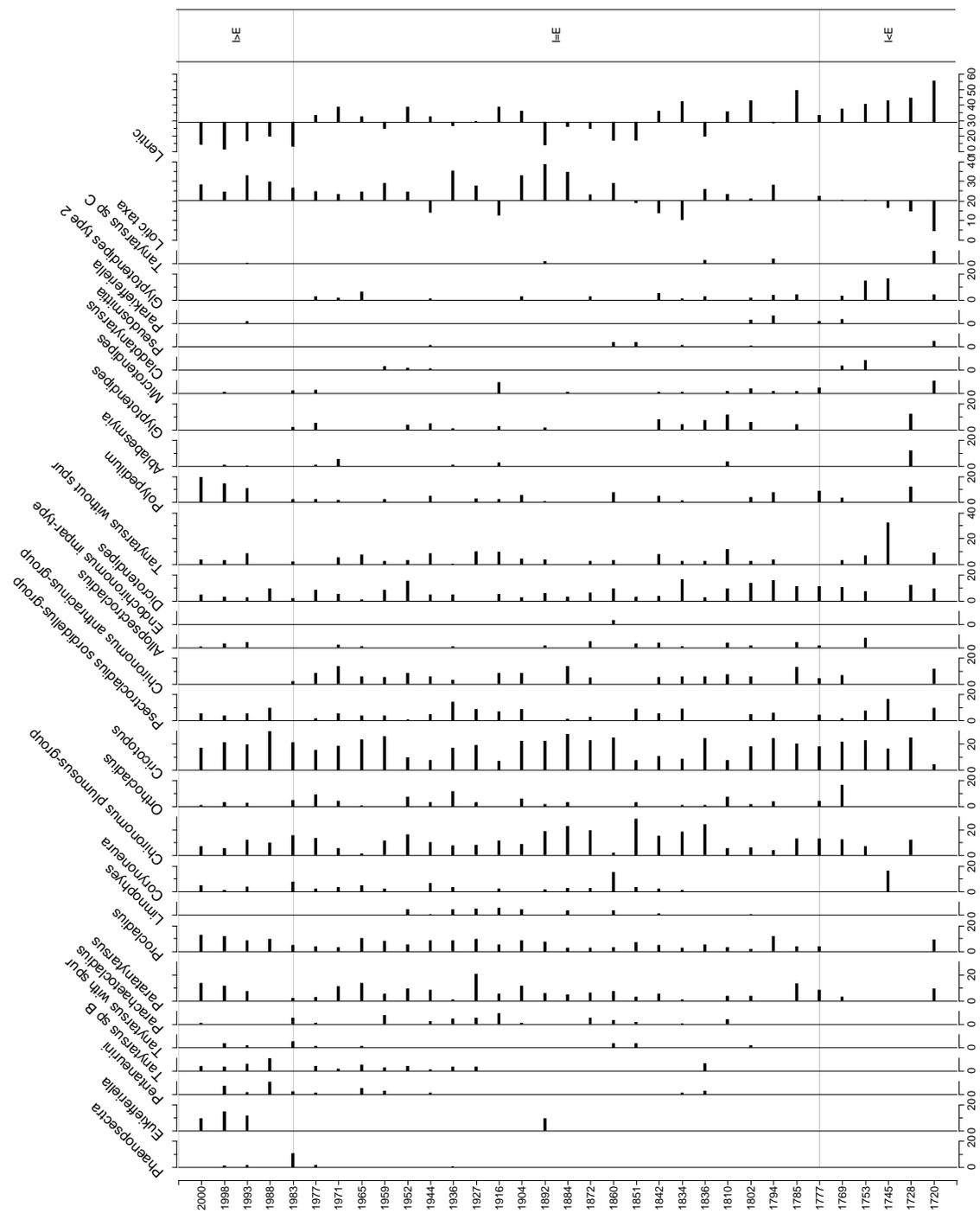
Figure 4. *Historical change in the chironomid assemblages in Spruce Island Lake*

4. Discussion

In the 61 lakes studied for the "training set" of the PAD, there were few taxa which were clear indicators of the close or open states of lakes. Similar results were found in inundated VS isolated lakes in Finland (Engels et al. 2008). However, when taxa were classified as lentic or lotic taxa based on other studies in lotic VS lentic systems (Gandouin et al. 2006) and the known ecology of the chironomids (as described in e.g. Brooks et al. 2007 and Larocque and Rolland 2006), the lakes classified as precipitation and open lakes had chironomid assemblages with percentages of lotic taxa generally above 20% while lakes classified as restricted and close lakes had percentages of lotic taxa below 20%. The 20% of lotic taxa was then used as a limit for determining if a lake was in an open or close state. In PAD 9 and in Spruce Island Lake, the open (or Inflow > Evaporation) state, defined either by historical maps, aerial photos and/or reconstruction using other proxies (Wolfe et al. 2005) was clearly associated with percentages of lotic taxa above 20% and the close (or Inflow < Evaporation) states were associated with percentages of lotic taxa below 20%. These results suggest that chironomids can indeed be used to reconstruct open or close states levels, at least in PAD 9 and Spruce Island Lake.

In-between levels (i.e inundated states in PAD 9 and Inflow = Evaporation states in Spruce Island Lakes) were sometimes harder to reconstruct using chironomids. According to the lotic percentages in PAD 9 during the inundated period, the lake would

have fluctuated between an inundated state to a close state and then back to an inundated state. Historical maps from 1884 and 1897 indicated that the lake was part of a shallow embayement of Lake Athabasca, and the inundated states at these dates are well represented by the percentages of lotic taxa higher than 20%. But before 1884, open-drainage diatom indicators, *Chara* oospores and constant cellulose-inferred $\delta^{18}O$ reconstructed the inundated state of PAD 9, while the chironomids inferred a close state between ca 1791 to 1629 AD when the lotic percentages were below the 20% limit. In Spruce Island Lake, the percentages of lotic taxa were below 20% at three times during the Inflow=Evaporation period reconstructed by other proxies (Wolfe et al. 2005). These excursions from the known history and/or the one reconstructed by other proxies might be due to the fact that various factors can affect the chironomid assemblages. Chironomids have been shown to be influenced by temperature (e.g. Walker et al. 1997), oxygen availability (Quinlan and Smol 1998), lake depth (Korhola et al. 2001), TP, eutrophication (e.g. Lotter et al. 1998) and macrophytes (Langdon et al. accepted). Changes in one of these factors through time might have affected the chironomid assemblages. These excursions could also be due to limits of the method. Most of the taxa included into lotic or lentic categories are in fact composed of many species, which were not separated in the taxonomy used for this study. *Cricotopus* for example, contain species which can be either lotic or lentic, but these species were not distinguished. Based of the 61-lake training set and the results from Gandouin et al (2006), *Cricotopus* was characterized as a lotic taxon, but the pooling of various species together with different ecological preferences probably contributed to the fact that the percentages of lotic taxa was not always representative of the state of the lake. An effort should be made to

separate these problematic taxa into various taxonomical groups. By doing so, the method could possibly apply better to extreme conditions (i.e. close and open states) but as well to in-between states. Rossaro et al. (2006) also identified genus such as *Eukiefferiella* and *Orthocladius* where species identification is really needed for a good ecological work.

5. Conclusions

The study of the chironomid distribution in deltaic lakes of the PAD suggest that chironomid percentages of lotic taxa can be used as an indicator of the open or close state of a lake. These percentages were used to reconstruct the know flooding history of two lakes of the PAD. In general, chironomid can be used to reconstruct adequately the open and the close status of lakes, however the intermediate states could not be reconstructed using chironomids. If the taxonomy of subfossil chironomid taxa would be better developed, it is possible that this technique would be better for intermediate states.

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