Newfoundland Studies

Environmental Changes at Port au Choix as Reconstructed from Fossil Midges

Sandra M. Rosenburg, Ian R. Walker and Joyce B. Macpherson

Volume 20, Number 1, Spring 2005

URI: https://id.erudit.org/iderudit/nflds20_1art04

See table of contents

Publisher(s)

Faculty of Arts, Memorial University

ISSN

0823-1737 (print)
1715-1430 (digital)

Explore this journal

Cite this article

Rosenburg, S. M., Walker, I. R. & Macpherson, J. B. (2005). Environmental Changes at Port au Choix as Reconstructed from Fossil Midges. *Newfoundland Studies*, *20*(1), 57–73.

Environmental Changes at Port au Choix as Reconstructed from Fossil Midges

SANDRA M. ROSENBERG, IAN R. WALKER,
and JOYCE B. MACPHERSON

INTRODUCTION

THE NORTHWESTERN COAST of the island of Newfoundland offers many potentially rich and exciting sites for palaeoenvironmental exploration. Intensive archaeological research at Port au Choix has led to the discovery of numerous, well-preserved prehistoric sites identified as Maritime Archaic Indian (MAI; Tuck 1976), Dorset and Groswater Palaeoeskimo (Harp 1964; Renouf 1994), and Recent Indian (Teal 2001). Archeological evidence can thus be compared to other palaeoenvironmental records to determine whether correlations exist.

Most terrestrial palaeoclimate reconstructions for Newfoundland have been inferred from palaeobotanical evidence (Macpherson 1982, 1995a, 1996; Anderson and Macpherson 1994). More recently, however, aquatic midges (especially the Chironomidae, or non-biting midges) have emerged as a promising new tool for palaeoclimate reconstructions (Battarbee 2000). This paper presents the first midge-based climate reconstruction for Newfoundland. Reconstructed summer lake water temperatures at Bass Pond are correlated to the initial settlement and subsequent migration and extinction of past cultures in the Port au Choix region.

Furthermore, although midges are recognized as useful palaeosalinity indicators, they have seldom been used as sea-level indicators (Walker 2001). We use a midge palaeosalinity inference model to demonstrate that midge records may yield important data relevant to coastal emergence and submergence patterns.

NEWFOUNDLAND and LABRADOR STUDIES 20, 1 (2005)
0823-1737

Fossil Midges as Palaeoenvironmental Indicators: A Brief Review

Chironomids (Class Insecta, Order Diptera) are common aquatic insects. Their life cycle includes four distinct stages: egg, larva, pupa and adult (Figure 1). The adult flies deposit eggs in water which later hatch into larvae. As larvae they are one of the most abundant organisms living in the bottom substrata of lakes, ponds and streams (Walker 1987). The larval stage consists of four consecutive instars (stages). At the end of each instar, a chitinous head capsule is shed. These head capsules (Figure 2) provide the basis for palaeoenvironmental assessments (Walker 2001). At the end of the fourth instar, the larvae pupate and later emerge as adult non-biting midges.

Midges have become important for palaeoclimatic studies because their remains are abundant and well preserved in lake sediments. In addition, the short life cycles of these insects (typically about one year in much of southern Canada) allow them to respond rapidly to changes in environmental conditions that may affect the lake (e.g., chemistry, temperature). As there are many different midge species, each with distinct ecological requirements, their assemblages in lake sediments can be good indicators of present and past ecological conditions (Walker 1987, 2001).

By examining fossil midge assemblages within each stratigraphic level in a lake sediment core, it can be determined how the assemblages have changed over time. By identifying the preserved head capsules of various Chironomidae, and examining how the species assemblage has changed over time, we may infer how climate and other aspects of the environment have changed.

Midge assemblages can be used to reconstruct water oxygen content, lake water acidity, and other water quality variables including, as is the focus of this paper, temperature and salinity (Walker 2001). Many recent studies in the Maritime provinces have used midge-temperature inference models to quantitatively reconstruct past climates and late-glacial climatic oscillations (i.e., the Killarney Oscillation and the Younger Dryas; Walker et al. 1991; Levesque et al. 1993, 1997). Walker (2001) provides a more extensive review of their use in palaeoecology.

Early midge research was qualitative, based, for example, on the subjective interpretation of changes in the abundance of cold-adapted species (Walker and Mathewes 1987). Recently, a more quantitative approach has been used. A mathematical model or transfer function derived from multivariate statistics is used to quantify the correlation between modern midge assemblages and surface water temperature. Ultimately, these models allow water or air temperatures to be quantitatively reconstructed (cf. Walker et al. 1997).

Past climatic changes would have affected the diverse resources required by prehistoric cultures. Thus, in response to climate change, aboriginal people may have either adapted their hunting, fishing, and survival technologies to the changing environment, or abandoned settlements and migrated to better locations. If the

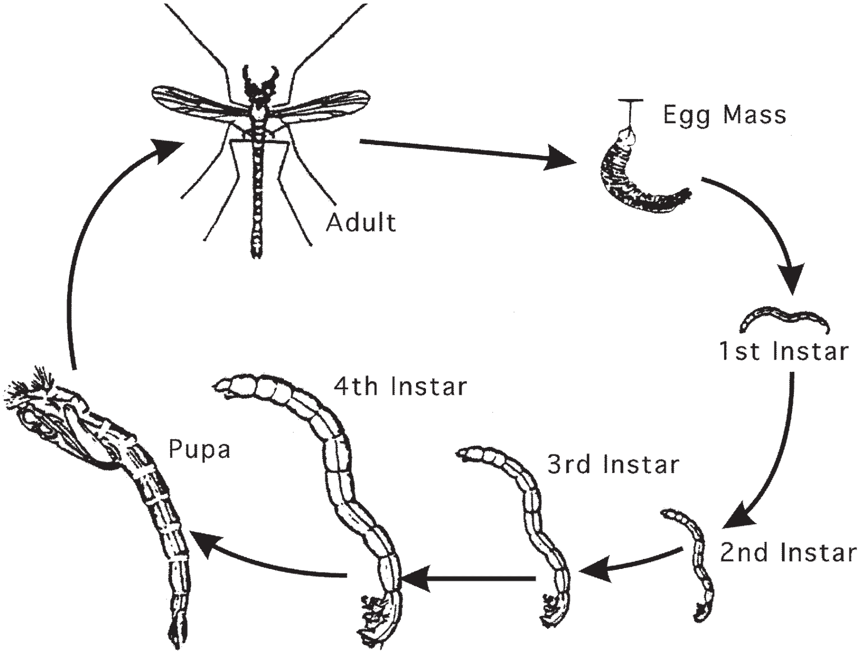

Figure 1. Chironomid life cycle (adapted from Walker 1987).

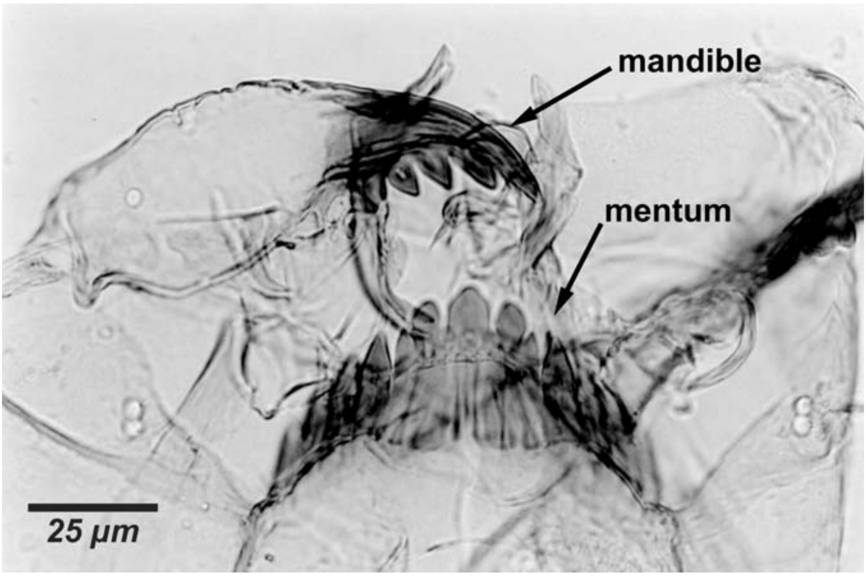

Figure 2. Fossil head capsule of Cricotopus ornatus *type, Bass Pond (170-cm level).*

people could not cope with the changing climate and resources, they and their culture would eventually disappear. Since midges are thought to be good indicators, they will be used to reconstruct past climatic changes, and to determine whether correlations exist with the archaeological records.

Midges are also sensitive to salinity and therefore fossil midge assemblages can be used to reconstruct the palaeosalinity history of a lake (Walker et al. 1995). Recent studies in western North America have related changes in salinity to climate (Heinrichs et al. 1997, 2001). However, since Bass Pond lies adjacent to the ocean, past changes in its salinity were likely driven by sea-level changes and salt-water intrusions from the Gulf of St. Lawrence during storms.

Port au Choix Case Study

Methods

Field and Laboratory Methods

Bass Pond is a small (~ 6.5 ha) lake, 9 metres above sea level, to the west of Port au Choix (Figure 3). It was sampled in the spring of 1993, using a Livingstone-type piston corer. A 210-centimetre-long core was removed from the deepest area of the pond (0.95 m). The core was then wrapped in aluminum foil and stored in a cold room at 4°C.

The sediment core was subsampled every 5 centimetres. Subsamples normally consisted of 1 cubic centimetre of sediment, but in some instances up to 2 cubic centimetres were examined in order to obtain a minimum of 50 chironomid head capsules per interval. Only the top 170 centimetres of the core was used, because the intervals from 175 to 210 centimetres contained too few head capsules to be statistically useful. Although the interval from 175 to 180 centimetres had only nine head capsules, five of these nine were noted as being morphologically very similar, or identical, to *Cricotopus ornatus* (Figure 2), an indicator of saline conditions (Walker et al. 1995; Heinrichs et al. 1997).

Isolation of midge head capsules from the lake sediment followed the procedures outlined by Walker (2001). Midge head capsules were identified at x100-400 magnification. Identifications were based on descriptions from keys by Oliver and Roussel (1983), Wiederholm (1983) and Walker (1988, 1996-2000). If a midge head capsule had more than half of a complete mentum (the principal toothed mouthpart of the insect, Figure 2), it was counted as one head capsule. If it contained exactly half of a mentum, it was counted as one half. Head capsules retaining less than half of the mentum were not counted.

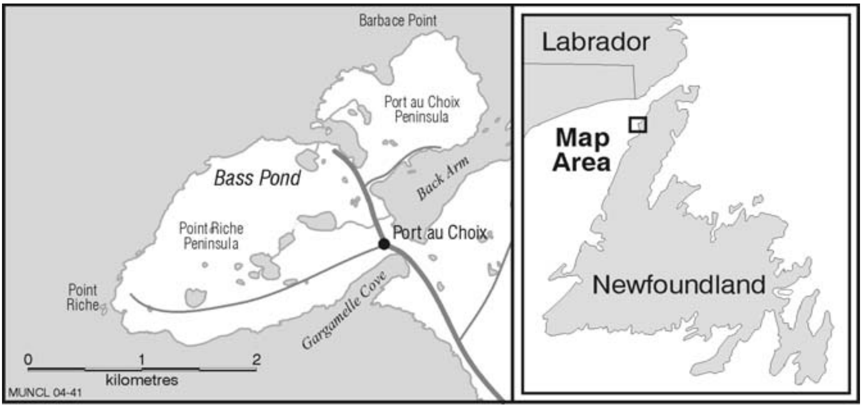

Figure 3. Map indicating the location of Bass Pond near Port au Choix, Newfoundland.

Statistical Methods

TILIA (version 2.0.b.4) was used to collate the raw data and a midge percentage diagram was generated in TILIA-GRAPH (version 2.0.b.5). The program CONISS was used to perform a stratigraphically constrained incremental sum-of-squares cluster analysis (Grimm 1987). This allowed intervals with major changes in midge communities to be distinguished throughout the core (Figure 4).

A midge-temperature inference model for Atlantic Canada developed by Walker et al. (1997) was used to infer summer surface-water temperatures for each interval in the core. This mathematical model demonstrates a significant relationship between summer surface-water temperatures and midge assemblages.

Since no midge-salinity inference model is available for eastern Canada, a preliminary reconstruction was attempted based on a mathematical model developed by Heinrichs et al. (2001) for western Canada. In using this model it is assumed that the midge-salinity relationships are similar in eastern and western Canada. The validity of this assumption needs to be carefully tested in future work, particularly in coastal/estuarine locations.

RESULTS

Chronology

All dates in the text have been converted to calibrated calendar years (cal BP; Table 1). A median basal date of 10,057 cal BP[1] was obtained for the 210-200-centimetre interval in Bass Pond through bulk radiocarbon dating (Table 1). This date has an unusual $^{12}C/^{13}C$ ratio (R. McNeely pers. comm.). It is possible that "radioactively

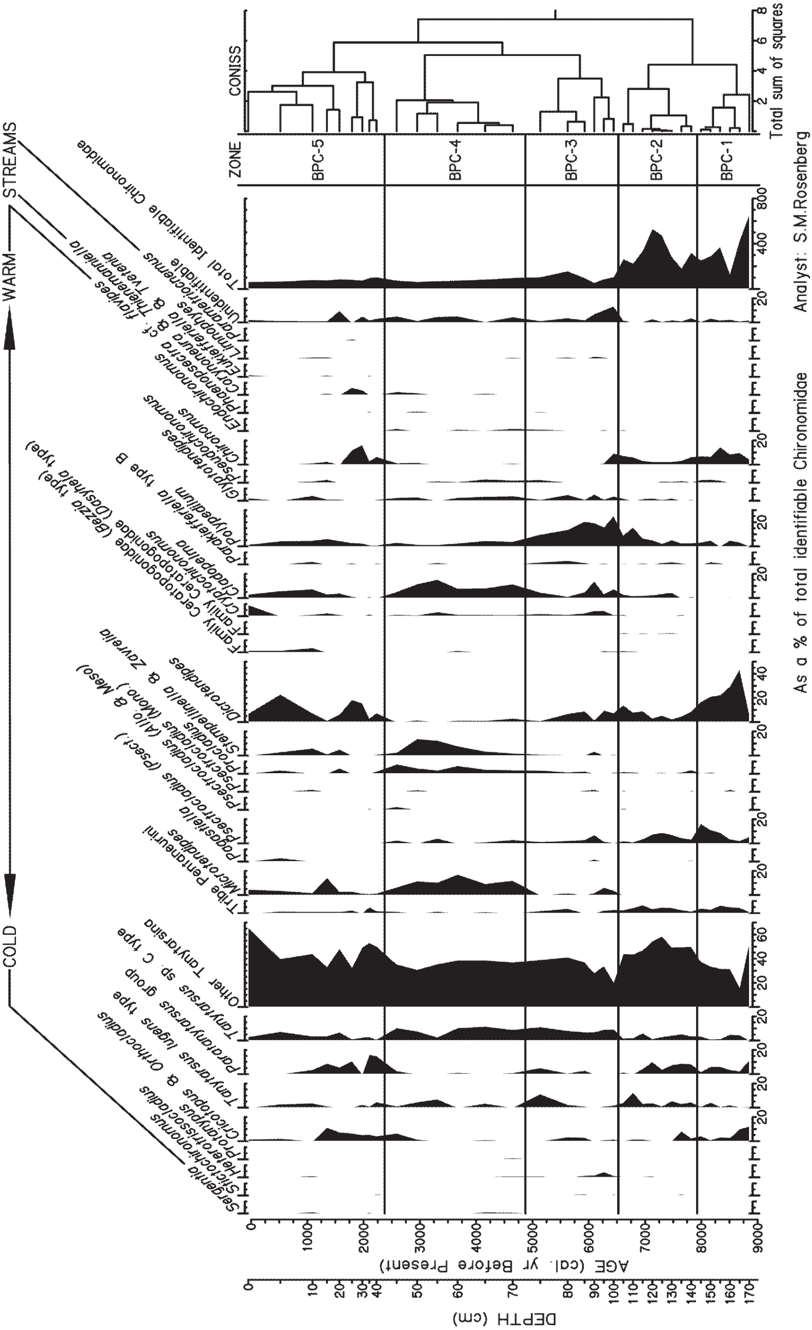

Figure 4. Midge percentage diagram from Bass Pond.

Table 1. Radiocarbon dates for the Bass Pond core

Depth (cm)	Radiocarbon date (yr BP)*	Lab Number	Analysis	Calibrated age (yr BP)**	Material Dated	Weight (mg)
10.5	1230 ± 60	Beta 115780	AMS	1068 (1149) 1256	*A. balsamea* twig	200
27/29	1980 ± 50	TO-8744	AMS	1877 (1927) 1990	*Nemopanthus* bark	66
40	2230 ± 60	TO-9162	AMS	2155 (2228) 2329	*Nemopanthus* twig?	41
60	3420 ± 60	TO-9163	AMS	3579 (3671) 3816	*Picea* bark	129
82	5100 ± 50	Beta 115782	AMS	5753 (5822) 5912	conifer bark	50
200-210	9380 ± 150	GSC-5661	Radiometric	9930 (10057) 10211	marine organic mud	150g

* one sigma probability distribution

** Calibration was carried out using Calib HTML version 4.4. Normalized dates with 1-sigma error were used as input to the calibration program. The decadal atmospheric calibration data set was chosen for all samples (Stuiver et al. 1998), except in the case of GSC-5661 where a 50% marine organic carbon content is arbitrarily assumed and a combination of atmospheric and marine calibration data sets is used by the program. Calibrated ages in the table represent the median value in parenthesis and the full range representing the 1-sigma probability distribution.

dead" carbon in the underlying carbonate rocks may have been incorporated into the sediment, producing a date that appears older than the actual age of the sediment. This seems likely since the Bass Pond sediment core contained high quantities of carbonates. Similar contamination effects have been noted at other sites in Atlantic Canada (Wolfe and Butler 1994; Stea and Mott 1998; Andrews et al. 1999) and elsewhere.

Radiocarbon dating using the atomic mass spectrometry method was carried out on terrestrial plant fossils from five other levels in the core (Table 1). Ages for other depths in the core were estimated by linear interpolation.

ZONE DESCRIPTIONS

The fossil record illustrates distinct fluctuations in the midge assemblages, based on the percentage abundances of individual midge species (Figure 4). In addition to chironomids, data are presented for *Bezzia* and *Dasyhela*-type biting midges (members of the family Ceratopogonidae). The diagram has been divided into five midge assemblage zones (BPC-1 through BPC-5; Table 2) based upon stratigraphically constrained incremental sum-of-squares cluster analysis. Zones mark where major changes in midge community composition occur and thus may relate to significant changes in palaeoclimate, palaeosalinity, or both. Some midge taxa are abundant throughout all five assemblage zones and thus are not useful as discriminators of environmental change. These ubiquitous taxa include members of the subtribe Tanytarsina (e.g., *Tanytarsus lugens* type, *Tanytarsus* sp. C type), as well as the Tribe Pentaneurini.

Table 2. Zonation of the Bass Pond core based on the chironomid stratigraphy (based on CONISS)

Zone Number	Depth (cm)	cal BP
BPC-5	42.5-0	2400-0
BPC-4	73-42.5	4900-2400
BPC-3	102.5-73	6500-4900
BPC-2	142.5-102.5	7900-6500
BPC-1	175-142.5	9000-7900

BPC-1 (9000 to 7900 cal BP)

In BPC-1, an increase in warm-adapted midges (e.g., *Chironomus* and *Dicrotendipes*) was observed (Figure 4). *Chironomus* is predominant in temperate lakes with summer bottom-water oxygen depletion (Walker 1987). *Dicrotendipes* is a midge widely distributed south of treeline (Oliver and Roussel 1983). These data may relate to a warming trend often seen in the early Holocene.

BPC-2 (7900 to 6500 cal BP)

A decline in temperate midge taxa (e.g., *Chironomus* and *Dicrotendipes*) was noted in BPC-2 (Figure 4). An apparent lack of cold-adapted species is generally noted in this zone, although towards the end of the zone a few fossils of the cold-water midge *Heterotrissocladius* were noted. *Heterotrissocladius* is abundant in arctic lakes as well as cold bottom waters of deep, pristine lakes in southern Canada (Walker et al. 1997). Since this pond is shallow, there is no summer refuge for cold-water insects in this lake. Consequently, most of the climate-inferred assessments in this study are based on the presence/absence of warm-adapted midge taxa which are mostly characteristic of shallow, near-shore environments.

BPC-3 (6500 to 4900 cal BP)

The significant reduction in overall midge abundance at the beginning of zone BPC-3 marks this zone change (Figure 4). The head capsule concentration decreased at the 110-centimetre interval, approximately 6500 cal BP (Figure 5); the average count below 100 centimetres was 325 head capsules per cubic centimetre, and the average above 100 centimetres was 86 head capsules per cubic centimetre. An increase in the abundance of several warm-adapted midge taxa (e.g., *Microtendipes*, *Polypedilum*, and *Stempellinella/Zavrelia*) was also observed. Both *Microtendipes* and *Polypedilum* are midges widely distributed south of treeline (Oliver and Roussel 1983).

BPC-4 (4900 to 2400 cal BP)

In Zone BPC-4, *Cladopelma*, *Microtendipes*, and *Stempellinella/Zavrelia* increased, at least initially, whereas *Chironomus*, *Dicrotendipes*, and *Polypedilum* decreased (Figure 4). All of these taxa are warm-adapted (Walker et al. 1997). Towards the end of zone BPC-4, several taxa (*Stempellinella/Zavrelia*, *Endochironomus*, *Glyptotendipes*, and *Microtendipes*) declined. All of these taxa are warm-adapted with distributions extending little, if at all, into arctic or alpine environments (Walker et al. 1997).

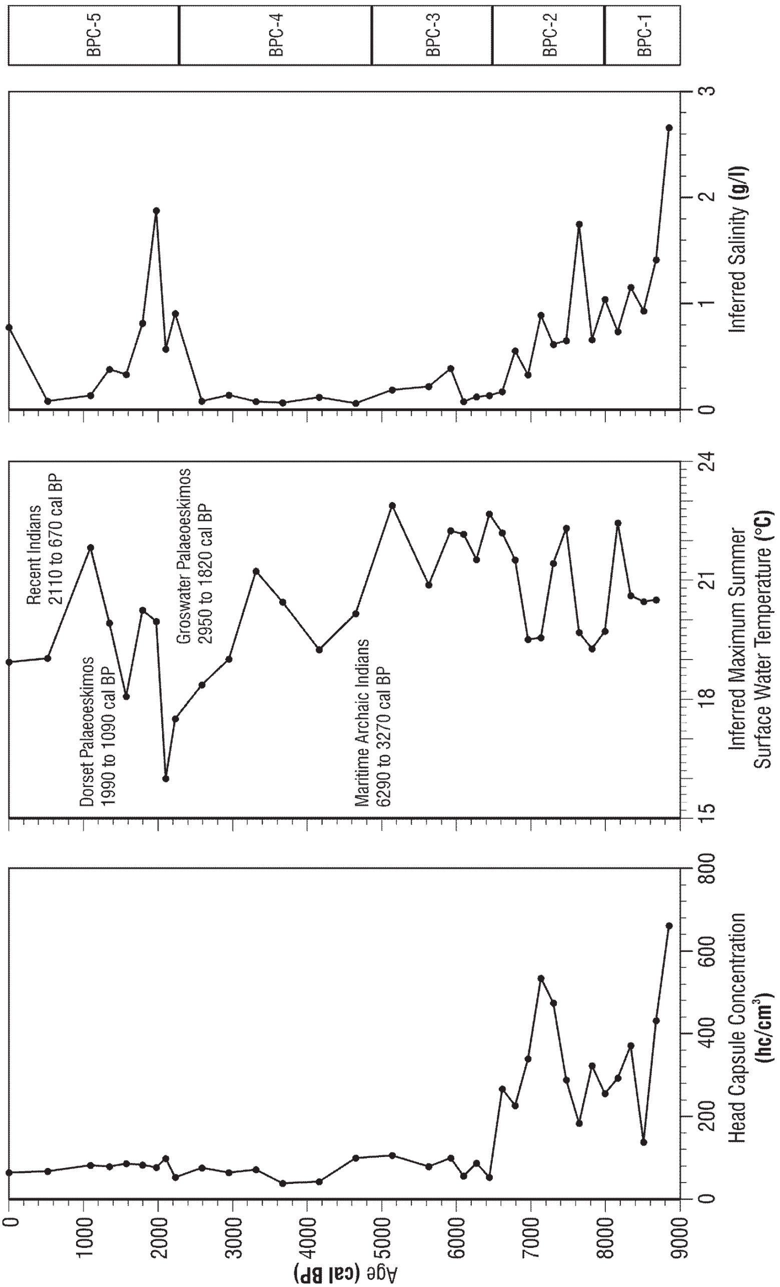

Figure 5. Midge-inferred palaeoenvironmental data for Bass Pond: head capsule concentrations in Bass Pond sediments, inferred maximum summer surface-water temperatures, and palaeosalinity reconstruction.

BPC-5 (2400 cal BP to the present)

In BPC-5, a resurgence of temperate midge taxa (e.g., *Chironomus*, *Dicrotendipes*, and *Microtendipes*) was observed (Figure 4). *Dicrotendipes* and *Microtendipes* are characteristic of warm, shallow-water habitats (Walker et al. 1997). Walker et al. (1997) have estimated the temperature optimum for *Chironomus* at 24.7ºC; however, the genus is widely distributed, with some *Chironomus* species' distributions extending even into the high arctic (Walker 1988).

Quantitative Midge Palaeotemperature Estimates

A midge-temperature inference model developed by Walker et al. (1997) was used to reconstruct temperature changes from Bass Pond's midge fossil record (Figure 5). Due to a lack of good analogues for the data point at 170 centimetres, it has been removed from the reconstructed palaeotemperatures. Apart from the basal sample (170-165 cm), early and mid-Holocene inferred summer water temperatures (Zones BPC 1 to 3) are generally warm, varying between 19 and 23ºC. A distinct cooling trend is indicated beginning in BPC-4, approximately 4900-2400 cal BP. The lowest inferred temperature, about 16°C, was reconstructed for about 2200 cal BP. This temperature minimum was followed by an inferred warming trend, with a maximum temperature of 22°C being reconstructed at the 20-centimetre level in BPC-5.

It is important to note that the temperature inferences are for maximum summer surface-water temperatures, which are typically 4°C higher than mean July air temperatures (Livingstone et al. 1999). Since Bass Pond is a very shallow lake, its surface-water temperature would tend to be slightly higher, at least briefly during the summer. The current mean July air temperature at Rocky Harbour, Newfoundland is 15.6°C; thus, a maximum summer surface-water temperature of ≥20°C would not be unusual today.

Midge Palaeosalinity Estimates

The palaeosalinity reconstruction for Bass Pond (Figure 5) indicates a decrease in salinity from 2.7 grams/litre initially (subsaline) to less than 0.6 grams/litre by 7000 cal BP. The reconstruction indicates freshwater conditions thereafter, with the exception of a salinity peak of 1.9 grams/litre around 2000 cal BP. The peak salinity at 2000 cal BP could record an exceptional storm surge, for example, linked to a hurricane. This idea is speculative. The salinity reconstruction should be verified using additional indicators (e.g., diatoms).

DISCUSSION

Relationship between inferred palaeoclimate and the archaeological record

The pattern of deglaciation and accompanying sea level changes has allowed many coastal archaeological sites to be well preserved in the Port au Choix region of Newfoundland (Tuck 1976; Grant 1994; Liverman 1994; Renouf 1999; Bell et al. this volume). The region offers researchers an opportunity to explore potential correlations between the long human cultural record and diverse other palaeoenvironmental data. Although it has been suggested that patterns of cultural migration cannot be inferred from vegetation history (Fitzhugh and Lamb 1985), previous palynological research (Macpherson 1995b) suggested that major climatic trends inferred at Bass Pond could be correlated with settlement patterns of both MAI and Dorset Palaeoeskimos.

The first evidence of the MAI (6290 cal BP; Bell and Renouf this volume) suggests their arrival at Port au Choix during a warm period in BPC-3 (Figure 5). Sustained MAI occupation (4800 cal BP; Bell and Renouf this volume) began during an inferred cooling period at the beginning of BPC-4. They disappeared more than 1500 years later with the beginning of a more drastic and prolonged inferred cooling trend (Figure 5).

At about 3000 cal BP, the Groswater Palaeoeskimos began to occupy the area (Bell and Renouf this volume). The midge-inferred temperature record suggests that the Groswater Palaeoeskimos occupied the region through a prolonged cool phase (Figure 5). The appearance of the Dorset Palaeoeskimos (around 2000 cal BP) occurred at a time when midge-inferred temperatures began to increase (Figure 5). The Recent Indian culture appeared as this warming trend continued. Whether these cultures became extinct as the region was subsequently repopulated by other people, or whether their populations just migrated to other areas is still open to debate.

It thus appears that summer temperature may be a significant indicator for the succession of cultures as revealed in the Port au Choix archaeological record. Since chironomids are thought to be among the best indicators of local climate change (Battarbee 2000), midge stratigraphies may provide key evidence for interpretation of the prehistoric cultural record.

Midge-inferred salinity

The initial occurrence of *Cricotopus ornatus* type chironomid remains at Bass Pond, and the midge-inferred palaeosalinity record both suggest a decreasing salinity trend at Bass Pond through the early Holocene, with freshwater conditions being established prior to around 7000 cal BP. Statistical tests suggest that the midge fauna at Bass Pond may portray a stronger palaeosalinity than palaeotemperature signal. The first axis of the midge fossil data in detrended correspondence analysis correlates more strongly with the palaeosalinity record (r = -0.88 on log (salinity)) than with the palaeotemperature record (r = 0.14).

The relatively great abundance of grasses (Poaceae) and other herbs in the pollen diagram from Bass Pond may be indicative of a salt marsh environment during Bass Pond's initial stages (Macpherson 1995b). Macpherson (1995b) places the isolation of Bass Pond at approximately 7500 cal BP (~130 cm) due to the rapid increase in the freshwater alga, *Pediastrum*, above this level. This estimate is 1000 years earlier than proposed by Grant's (1994) and Bell et al.'s (this volume) sea-level curves. As salinity decreased, so did the head capsule concentration in the sediments, indicating a transition from the more productive salt marsh to the less productive upland environment around 6500 cal BP (Figure 5). There is some variation in the emergence dates suggested by these indicators. The precise timing is difficult to resolve since the transition was likely very gradual, and different indicators will respond to different aspects of this transition. For example, the vegetation response may indicate when much residual salt had been leached from the marsh, and the resulting soil was sufficiently well drained to allow trees and shrubs to colonize the former marsh. The composition of the midge community was likely directly impacted by salinity, but the head capsule concentrations more likely reflect a slower decline in overall nutrient availability.

Interpretation of the later salinity peak around 2000 cal BP is more speculative, but may be due to a marine incursion (storm surge or tsunami) or the reworking of marine sediments. Intense tropical storms are common in Atlantic Canada. In contrast, little is known about tsunami frequency. Newfoundland was hit by a 12-metre tsunami in 1929 following an earthquake centred 350 kilometres south of the island (Liverman et al. 2001). Such events probably also occurred in the past. Bell et al. (this volume) link this salinity peak to anthropogenic factors.

The pattern of sea level regression and transgression along the west coast of Newfoundland varies markedly along a north-south axis. Since deglaciation, sea level has continuously fallen at the northern tip of the island (a type-A sea-level curve; Bell et al. this volume). However, farther south at St. George's Bay (Bell et al. 2003), sea level reached a lowstand about 9700 cal BP, and sea level has been slowly rising for several millennia (producing a type-B relative sea-level curve). Bell et al. (this volume) place the transition between these two patterns of sea-level change to the south of Port au Choix. The coastline at Port au Choix would therefore have emerged continuously since deglaciation. Emergence was likely very rapid initially, but may have been much slower after 7000 cal BP (Bell et al. this volume). This slow emergence of Bass Pond would be consistent with the gradual transition we perceive in the pollen and midge fossil data, thereafter allowing occasional salt-water incursions to have occurred.

CONCLUSION

Analysis of Bass Pond sediments provided an indication of past changes in palaeoclimate and palaeosalinity. Changes in the midge-inferred temperatures show some degree of correspondence with the disappearance of the Maritime Archaic culture (3270 cal BP), the subsequent appearance of the Groswater Palaeoeskimos (3000 cal BP), and the appearance of the Dorset Palaeoeskimo people (2000 cal BP). Furthermore, the midge-inferred palaeosalinities appear to provide a useful indication of basin isolation from the sea. Thus, although they have rarely been used in this context, midge palaeoecological studies may be usefully applied in future archaeological and sea-level research.

Acknowledgements

In addition to two anonymous reviewers, we wish to thank Dr. R.G. Lalonde and Dr. P. Dill, Biology Department, Okanagan University College, for their constructive comments on our Port au Choix research. We gratefully acknowledge funding for the project provided by the Natural Sciences and Engineering Research Council of Canada via a Discovery Grant awarded to I.R.W.

Note

[1]Dates are expressed in the text in calibrated calendar years before present (cal BP) as either a one-sigma probability age range or a median probability single age.

References

Anderson, Thane W. and Joyce B. Macpherson (1994), "Wisconsinan late-glacial environmental change in Newfoundland: a regional review." *Journal of Quaternary Science* 9: 171-178.

Andrews, John T., Lloyd D. Keigwin, Frank Hall, and Anne E. Jennings (1999), "Abrupt deglaciation events and Holocene palaeoceanography from high-resolution cores, Cartwright Saddle, Labrador Shelf, Canada." *Journal of Quaternary Science* 14: 383-397.

Battarbee, Richard W. (2000), "Palaeolimnological approaches to climate change, with special regard to the biological record." *Quaternary Science Reviews* 19: 107-124.

Bell, T. and M.A.P. Renouf (this volume), "Introduction."

Bell, Trevor, Martin J. Batterson, David G.E. Liverman, and John Shaw (2003), "A new late-glacial sea-level record for St. George's Bay, Newfoundland." *Canadian Journal of Earth Sciences* 40: 1053-1070.

Bell, T., I.R. Smith, and M.A.P. Renouf (this volume), "Postglacial Sea-Level History and Coastline Change at Port au Choix, Great Northern Peninsula, Newfoundland."

Fitzhugh, William W. and Henry F. Lamb (1985), "Vegetation history and culture change in Labrador prehistory." *Arctic and Alpine Research* 17: 357-370.

Grant, Douglas R. (1994), "Quaternary Geology of Port Saunders map area, Newfoundland." Geological Survey of Canada, Paper 91-20, 59 p.

Grimm, Eric C. (1987), "CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares." *Computers and Geoscience* 13: 13-35.

Harp, E., Jr. (1964), *The Cultural Affinities of the Newfoundland Dorset Eskimo.* Ottawa: National Museum of Canada.

Heinrichs, Markus L., Susan E. Wilson, Ian R. Walker, John P. Smol, Rolf W. Mathewes, and Kenneth J. Hall (1997), "Midge and diatom-based palaeosalinity reconstructions for Mahoney Lake, Okanagan Valley, British Columbia, Canada." *International Journal of Salt Lake Research* 6: 249-267.

Heinrichs, Markus L., Ian R. Walker, and Rolf W. Mathewes (2001), "Chironomid-based paleosalinity records in southern British Columbia, Canada: a comparison of transfer functions." *Journal of Paleolimnology* 26: 147-159.

Levesque, André J., Francis E. Mayle, Ian R. Walker, and Les C. Cwynar (1993), "The Amphi-Atlantic Oscillation: A proposed late-glacial climatic event." *Quaternary Science Reviews* 12: 629-643.

Levesque, André J., Les C. Cwynar, and Ian R. Walker (1997), "Exceptionally steep north-south gradients in lake temperatures during the last deglaciation." *Nature* 385: 423-426.

Liverman, David, Martin Batterson, David Taylor, and Janice Ryan (2001), "Geological hazards and disasters in Newfoundland and Labrador." *Canadian Geotechnical Journal* 38: 936–956.

Liverman, David G.E. (1994), "Relative sea-level history and isostatic rebound in Newfoundland, Canada." *Boreas* 23: 217-230.

Livingstone, David M., André F. Lotter, and Ian R. Walker (1999), "The decrease in summer surface water temperature with altitude in Swiss Alpine lakes: a comparison with air temperature lapse rates." *Arctic, Antarctic and Alpine Research* 31: 341-352.

Macpherson, Joyce B. (1982), "Postglacial vegetational history of the Eastern Avalon Peninsula, Newfoundland, and Holocene climate change along the Eastern Canadian Seaboard." *Géographie physique et Quaternaire* 36: 175-196.

Macpherson, Joyce B. (1995a), "A 6 ka BP reconstruction for the island of Newfoundland from a synthesis of Holocene lake-sediment pollen records." *Géographie physique et Quaternaire* 49: 163-182.

Macpherson, Joyce B. (1995b), "Palaeoenvironments." In *West Coast of Newfoundland Field Trip Guide*, edited by David Liverman and Martin Batterson, pp. 55-61. St. John's: CANQUA-CGRG meeting.

Macpherson, Joyce B. (1996), "Delayed deglaciation by downwasting of the Northeast Avalon Peninsula, Newfoundland: an application of the early postglacial pollen record." *Géographie physique et Quaternaire* 50: 201-220.

Oliver, Donald R. and Mary E. Roussel (1983), "The Insects and Arachnids of Canada, Part II: The Genera of Larval Midges of Canada; Diptera: Chironomidae." *Agriculture Canada Publication* 1746, 263 p.

Renouf, M.A.P. (1994), "Two Transitional Sites at Port au Choix, Northwestern Newfoundland." In *Proceedings of Arctic Prehistory, Taylor-Made: Papers in Honour of W.E. Taylor*, edited by J.-L. Pilon and D. Morrison, pp. 165-196. Canadian Museum of Civilization, Hull, Quebec.

Renouf, M.A.P. (1999), "Prehistory of Newfoundland hunter-gatherers: extinctions or adaptations?" *World Archaeology* 30: 403-420.

Stea, Ralph R. and Robert J. Mott (1998), "Deglaciation of Nova Scotia: stratigraphy and chronology of lake sediment cores and buried organic sections." *Géographie physique et Quaternaire* 52: 1-26.

Stuiver, Minze, Paula J. Reimer, Edouard Bard, J. Warren Beck, G.S. Burr, Konrad A. Hughen, Bernd Kromer, Gerry McCormac, Johannes van der Plicht, and Marco Spurk (1998), "INTCAL98 Radiocarbon age calibration 24,000-0 cal BP." *Radiocarbon* 40: 1041-1083.

Teal, M.A. (2001), "An archaeological investigation of the Gould site (EeBi-42) in Port au Choix, Newfoundland: new insight into the Recent Indian Cow Head complex." MA thesis, Department of Anthropology, Memorial University of Newfoundland.

Tuck, James A. (1976), *Newfoundland and Labrador Prehistory*. Ottawa: Archaeological Survey of Canada, National Museum of Man, 127 p.

Walker, Ian R. (1987), "Chironomidae (Diptera) in palaeoecology." *Quaternary Science Reviews* 6: 29-40.

Walker, Ian R. (1988), "Late-Quaternary palaeoecology of Chironomidae (Diptera: Insecta) from lake sediments in British Columbia." PhD thesis, Simon Fraser University.

Walker, Ian R. (1996-2000), "The WWW Field Guide to Subfossil Midges." (http://www.ouc.bc.ca/eesc/iwalker/wwwguide/). Accessed 18 December 2003.

Walker, Ian R. (2001), "Midges: Chironomidae and related Diptera." In *Tracking Environmental Change using Lake Sediments, Volume 4, Zoological Indicators*, edited by John P. Smol, H. John B. Birks, and William M. Last, pp. 43-66. Dordrecht: Kluwer Academic.

Walker, Ian R. and Rolf W. Mathewes (1987), "Chironomidae (Diptera) and postglacial climate at Marion Lake, British Columbia, Canada." *Quaternary Research* 27: 89-102.

Walker, Ian R., Robert J. Mott, and John P. Smol (1991), "Allerød-Younger Dryas lake temperatures from midge fossils in Atlantic Canada." *Science* 253: 1010-1012.

Walker, Ian R., Susan E. Wilson, and John P. Smol (1995), "Chironomidae (Diptera): quantitative palaeosalinity indicators for lakes of western Canada." *Canadian Journal of Fisheries and Aquatic Sciences* 52: 950-960.

Walker, Ian R., André J. Levesque, Les C. Cwynar, and André F. Lotter (1997), "An expanded surface-water palaeotemperature inference model for use with fossil midges from eastern Canada." *Journal of Paleolimnology* 18: 165-178.

Wiederholm, Torgny (1983), "Chironomidae of the Holarctic region. Key and Diagnoses. Part 1 — Larvae." *Entomologica scandinavica, Supplement* 19. 457 p.

Wolfe, Alexander P. and Deborah L. Butler (1994), "Late-glacial and early Holocene environments at Pine Hill Pond, Newfoundland, Canada: evidence from pollen and diatoms." *Boreas* 23: 53-65.