9-22-2005

Lake-Level Influences on Chironomid-Based Reconstructions of Paleotemperature

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Final Report for Period: 08/2000 - 07/2005
Submitted on: 09/22/2005
Principal Investigator: Dieffenbacher-Krall, A. C.
Award ID: 0082680
Organization: University of Maine
Title:
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Project Participants

Senior Personnel

Name: Dieffenbacher-Krall, Ann

Worked for more than 160 Hours: Yes

Contribution to Project:

Dieffenbacher-Krall conducted the lake-level study portion of this project, supervised late-glacial chironomid analysis, and supervised undergraduate students, Chase, and Whittaker.

Name: Borns, Harold

Worked for more than 160 Hours: No

Contribution to Project:

Borns conducted geological field work to establish the southern margin and re-advance distance of the Younger Dryas ice cap in Maine.

Name: Fastook, James

Worked for more than 160 Hours: No

Contribution to Project:

Fastook directed Sayles in ice cap modelling using the 'University of Maine Ice Sheet Model: UMISM'.

Name: Jacobson, George

Worked for more than 160 Hours: No

Contribution to Project:

Jacobson advised graduate student Chase and consulted on interpretation of lake level and chironomid results.

Post-doc

Graduate Student

Name: Chase, Geneva

Worked for more than 160 Hours: Yes

Contribution to Project:

Geneva Chase was supported by the grant as a graduate research assistant. She assisted with obtaining cores, subsampling and loss-on-ignition analysis of the cores, and received extensive training in chironomid analysis from Professor Les Cwynar, Department of Biology, University of New Brunswick. She complete chironomid analysis on close-interval (0.5 cm) samples from Whitehead Lake covering the period from the Late Glacial through the Younger Dryas. Chase developed a master's thesis project based on her work on sediment from Whitehead Lake, and Pennington Pond, a second lake in northern Maine. She reconstructed late-glacial temperature changes in northern Maine finding a strong cooling associated with the Younger Dryas. Chase completed her work and received her M.S. degree in May 2004.

Name: Whittaker, Thomas

Worked for more than 160 Hours: No

Contribution to Project:

Whittaker assisted with some of the laboratory analysis and conducted preliminary isotopic analysis of Whitehead Lake gastropods. He has used Whitehead Lake carbonate data for an independent geochemical analysis of the lake's Holocene carbon budget.

Name: Wanamaker, Alan

Worked for more than 160 Hours: No

Contribution to Project:

Building on Whittaker's work, Wanamaker used Whitehead Lake carbonate data to develop a model for reconstructing precipitation quantities by means of carbonate values.

Undergraduate Student

Name: Perry, Ethan

Worked for more than 160 Hours: No

Contribution to Project:

Ethan Perry assisted with coring of Whitehead and Bennett Lakes developing expertise in summer coring of Maine lakes.

Name: Sayles, Christopher

Worked for more than 160 Hours: No

Contribution to Project:

Sayles developed a computer model of the northern Maine Younger Dryas ice cap for his senior honors thesis.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Name: Smith, Colby

Worked for more than 160 Hours: No

Contribution to Project:

Colby Smith was trained to sieve sediment, and pick and identify plant macrofossils, and select terrestrial plant remains for radiocarbon dating during the fall semester, 2001. Smith graduated with a B.S. in Geology in December. He began graduate work in Geology at the University of Maine in January 2002 and received his M.S. in May 2003.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2002

REU Funding: No Info

Name: Braman, Elizabeth

Worked for more than 160 Hours: No

Contribution to Project:

Elizabeth Braman completed subsampling of Whited Lake sediment cores and developed the skills to take high-resolution digital photographs of lake cores.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2002

REU Funding: No Info

Name: Barteaux, Steven

Worked for more than 160 Hours: Yes

Contribution to Project:

Barteaux was trained to sieve sediment and remove and mount chironomid remains. He studied chironomid identification with Chase and perfomed an independent study of some Whitehead Lake samples for a senior 'Cap Stone' research project.

Years of schooling completed: Other

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2002

REU Funding: REU supplement

Name: Collette, Sharanda

Worked for more than 160 Hours: No

Contribution to Project:

Collette learned to sieve sediment samples and remove and mount chironomid remains from Whitehead Lake samples. Her work was supported in part by a federal work-study grant.

Years of schooling completed: Sophomore

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2002

REU Funding: No Info

Name: Palmer, Kristina

Worked for more than 160 Hours: No

Contribution to Project:

Palmer learned to sieve sediment to remove plant macrofossils and to identify and count macrofossils. She assisted with macrofossil analysis of Whitehead Lake cores. Her work was supported, in part, by a federal work-study grant.

Years of schooling completed: Sophomore

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2002

REU Funding: No Info

Organizational Partners

University of New Brunswick

Les Cwynar, Professor, Department of Biology, University of New Brunswick, has provided training in chironomid analysis to Chase and Dieffenbacher-Krall. He assisted with chironomid analysis of Whitehead Lake Holocene-age samples and collaborated on analysis of chironomid data and resolving the impact of lake-level changes on chironomid-based estimates of paleotemperature. We are developing a secondary joint project comparing chironomid data from two other lakes, for which we have completed high resolution lake-level studies, with Holocene lake levels. In addition, we will be jointly examining surface samples from varying water depths from several Maine lakes. Cwynar served as a graduate committee member for Chase.

Other Collaborators or Contacts

Andrea Nurse, Research Scientist, Climate Change Institute, University of Maine, has collaborated on lake-level studies in northern Maine.

Activities and Findings

Research and Education Activities:

The objectives of this study are to determine the influence of lake-level changes on chironomid-based temperature estimates by means of an independent measure of Younger Dryas temperature changes in northern Maine. Our field area surrounds the location of a Younger Dryas ice cap. By refining knowledge of the maximum extent of the ice cap, and providing late-glacial water balance data, a computer model will be used to determine the temperature drop required to initiate formation and advance of the ice cap. Temperature estimates thus derived will be compared to those inferred from chironomid remains. Chironomid and lake-level analysis of Holocene-age sediment, coupled with Cwynar's work on Whitehead Lake surface samples, should illuminate the joint impact of temperature and water depth on chironomid assemblages.

We have completed high resolution lake-level analysis of Whitehead (Whited) Lake, and analysis of late-glacial chironomids from Whitehead Lake, located just east of the ice cap site, and Pennington Pond, located just west of the ice cap site. Chironomid analysis of Holocene-age samples from Whitehead Lake is all but complete. We reviewed previous geological work in northern Maine and conducted aerial photograph interpretation in preparation for excavations and other field work in northern Maine. We excavated and examined a section of Younger Dryas-age glacial till overlying organic peat, and cored an additional lake, Cranberry Pond, to determine the southern margin of the ice. We also located the terminal moraine of the re-advance. Runs of the ice cap model, conducted by Christopher Sayles under the direction of Fastook, were compared to chironomid-inferred Younger Dryas temperature estimates.

Lake-level reconstruction was accomplished by fine interval loss on ignition, gross sediment structure, macrofossil, and grain size analyses of each of six cores from varying water depths from Whitehead Lake. Forty three radiocarbon dates were used to develop comparable chronologies for the cores. Chironomid remains were extracted from approximately 160 samples from Whitehead Lake and Pennington Pond, identified, and counted.

Preliminary results of our lake-level work, and a comparison with other regional records, was presented at the Northeast Section Meeting of the Geological Society of America in Springfield, Massachusetts, March 26, 2002. This information has now been published in the Journal of Paleolimnology (see below). The methods used in this study, preliminary results, and their implications were presented to a group of K-12 science teachers on May 8, 2002. A field trip to Whitehead Lake and discussion of the project was conducted in September 2002 for the benefit of students and staff of the University of Maine Climate Change Institute. Methods were demonstrated to a class of archaeology students in April 2003. An overview of the project and preliminary results were presented at the North American Chironomid Taxonomy Meeting, Fredericton, New Brunswick, May 18, 2004. Results of lake-level study were presented to water resource professionals and state agency personnel at the Maine Water Conference, March 22, 2005.

Findings: (See PDF version submitted by PI at the end of the report)

The Whitehead Lake cores contain evidence of a dry late-glacial period with perhaps a modest increase in lake level at the middle of the Younger Dryas period (Fig. 1). Water levels increased significantly, though gradually, until about 8600 cal yrs BP. An intense dry period lasting from about 8600 to 8000 cal yrs BP may be consistent with the 8200 cal yr Event observed in the Greenland ice cores. Our evidence suggests that this event was manifested in northern Maine as a dry period. Conditions in northern Maine were dry from abut 7200 cal yr BP until an extremely rapid rise in water level occurred shortly before 3000 cal yr BP. The period of maximum dryness, about 5200 to 3200 cal yr BP, and the rapid water level increase about 3000 cal yr BP, are consistent with records from Mansell Pond in central Maine (Almquist et al. 2001), Mathews Pond in northern Maine (Nurse 2003), and Crooked Pond in eastern Massachusetts (Shuman et al. 2001). Water levels rose fairly steadily after 3000 cal yr BP, interrupted by brief, mild reversals at 2900, 2200, and 1400 cal yrs BP. Water levels did not reach modern levels until the past several hundred years. Lake levels are currently higher than at any other time since deglaciation. The addition of the two high-resolution lake-level studies from northern Maine to the body of lake-level-change literature provides clear evidence of regional water balance change.

Results of isotopic analysis of gastropod shells from Whitehead Lake, conducted by Thomas Whittaker, were inconsistent with lake-level changes inferred by the aforementioned multi-proxy, multi-core study. Thus, we infer that gastropod isotopes are indicative of change in seasonality of precipitation rather than lake-level (closed vs. open basin) changes. Observed lake-level changes may have been a consequence of changes in season of major precipitation receipt rather than actual changes in the amount of annual precipitation. The effect of increased snowfall combined with decreased summer rains on lake level cannot currently be distinguished from a decrease in total annual precipitation. We hope to conduct a future modern analogue study of precipitation and a combined lake-level, isotope, chironomid study of additional lakes to allow us to resolve the individual effects of temperature, water balance, and seasonality of precipitation on Holocene lake levels.

Chironomid analysis of Whitehead Lake and Pennington Pond late-glacial-age samples determined that Younger Dryas temperatures were an average of about 4-5? C cooler than the period immediately preceding the onset of the Younger Dryas period, with a maximum temperature drop of 8.5-10? C (Figs. 2 and 3, Chase 2004). Timing of the temperature drop and rapid, post-YD temperature rise are consistent with other data from northern Maine and New Brunswick. Preliminary modeling of the northern Maine YD ice cap indicates that a temperature drop of 11? C would have been necessary to create the ice cap (Sayles 2004), a considerably greater decrease than suggested previously be pollen data. Our preliminary interpretation is that chironomid remains may in fact have underestimated temperature changes, possibly as a consequence of low lake levels during the late-glacial period. The results illustrate the need for high-resolution, well dated pollen studies from the region. Chironomids provided no clear evidence of the Killarney/Gerzensee Oscillation in northern Maine.

New chironomid work, in collaboration with Cwynar, on modern surface samples from various water depths, and analysis of Holocene chironomids from the three lakes for which we now have high-resolution Holocene lake-level records, should further illuminate the impact of water depth on chironomid-based temperature inferences.

Analysis of Holocene-age chironomid samples from Whitehead Lake indicate that the temperature may have been lower in the region at the time of the 8600-8200 cal yr BP dry period, a result consistent with the cold 8200-yr Event observed in the Greenland ice cores and elsewhere. Temperature reconstructions based on chironomids for Holocene-age material is, unfortunately, equivocal. The chironomid/temperature transfer-function currently in use for the Northeast (Walker et al. 1997) is based on modern samples from lakes that are primarily north and east of our study lakes. It does not include sufficient data from lakes in locations that are as warm or warmer than our study lakes probably were for most of the Holocene. Thus, although the transfer-function is appropriate for cold late-glacial periods, it is not suitable for quantitative estimates of Holocene temperatures for our region. However, qualitative inferences can be made. We plan to expand the modern training set to develop a suitable Holocene transfer function in a subsequent research project.

A particularly interesting result is the development of carbonate as a lake-level proxy for carbonate lakes. Our examination of carbonate content of Whitehead Lake cores has determined that carbonate alone may be an acceptable, and much more rapid and inexpensive, means of reconstructing past lake levels. We have further been able to determine changes not only in lake depth through time, but also lake surface area, water volume, and depth of the regional water table.

Because our study included high resolution macrofossil analysis of six well-dated cores across a single basin, we were able to refine our interpretation of the water-depth significance of individual macrofossil types. Rather than relying on modern analogue studies from basins that may have been significantly different from our own, we could observe changes in macrofossil abundance across the depth gradient, through time, of our study lake.

A further result is the discovery that dry conditions in northern Maine appear to correspond with low North Atlantic summer sea surface temperatures from a site on the eastern side of Greenland (Fig. 4, Sarnthein et al. 2003), a result having broad implications for drivers of New England water balance.

By locating the terminal moraine, we have determined the southern margin of the Younger Dryas ice re-advance in northern Maine and ascertained the minimum re-advance distance.

Training and Development:

Chase and Dieffenbacher-Krall received training in chironomid analysis developing a skill new to the University of Maine. Chase's work on this project developed into her master's thesis (degree awarded May 2004).

Dieffenbacher-Krall and Nurse attended a week-long training workshop, Chironomids: Water Quality and Environmental Change, at the Environmental Change Research Centre, University College, London, January 2003.

A total of eight undergraduate student have assisted with both field and laboratory work, gaining research skills and valuable experience. Whittaker, a student whose work was funded outside this grant, developed an independent project involving isotopic analysis of gastropod shells from Whitehead Lake, and a second project modeling the carbonate budget of the lake through the Holocene. Sayles conducted modeling of the YD ice cap as an independent honors thesis. Barteaux developed his work in chironomid analysis for this project into his undergraduate senior 'capstone' project. Barteaux is currently a master's student in education at the University of Maine preparing to become a grade 8-12 science teacher. Two highschool students obtained field experience in lake coring.

We have developed a chironomid reference collection for the University of Maine. We have modified the Bogorov trays typically used for chironomid picking to significantly decrease the time required to train laboratory assistants and decrease the amount of time required to pick each sample.

Outreach Activities:

Results of lake-level study were presented to water resource professionals and state agency personnel at the Maine Water Conference, March 22, 2005. We are now able to translate our lake-level study results into terms that will be useful for water resource planning. We can demonstrate to resource planners changes in available water, i.e., lake water volume and depth of water table.

Journal Publications

Dieffenbacher-Krall, A.C., A.M. Nurse, "Late-glacial and Holcoene record of lake levels of Mathews Pond and Whitehead Lake, northern Maine, USA", Journal of Paleolimnology, p. 283-310, vol. 34, (2005). Published,

Books or Other One-time Publications

Chase, G.E., "Late-Glacial climate as inferred from chironomid assemblages from Aroostook County, Northeastern Maine.", (2004). Thesis, Published
Bibliography: Thesis (M.S.), University of Maine

Web/Internet Site

URL(s):

Description:

Other Specific Products

Product Type:

Instruments or equipment developed

Product Description:

We have developed a modified Bogorov counting dish to increase speed and accuracy of picking chironomid remains from lake sediment. These were custom made by a private machinist.

Sharing Information:

Design shared with researchers from University of New Brunswick and Harvard Forest.

Contributions

Contributions within Discipline:

The remains of chironomids, non-biting midges who begin their lives as larvae in lake sediment, are currently used to estimate past temperatures (summer surface water temperature). These temperature estimates are based on modern studies of the chironomids found in the surface sediment of lakes from various regions representing a spectrum of summer surface water temperatures. Using a transfer function, the species assemblage of chironomid remains found in sediment is converted to temperature. Thus, this one climate parameter can be determined for points of time in the past by examining the chironomid remains found in sediment that was deposited in earlier times. This method is now being used for various sites in northeastern North America, the Canadian arctic and Alaska, and Europe, and is being developed for South America and New Zealand.

The transfer function currently in use for northeastern North America (Walker et al. 1997) yields temperature estimates that agree in timing and direction with estimates made by other methods, such as pollen analysis. However, the magnitude of temperature changes determined by chironomid analysis is much greater than those inferred by any other methods. The original study of modern chironomid ecology from which the northeastern North American transfer function originated (Walker et al. 1991), and subsequent studies, indicate that water depth has almost as great an impact on chironomid assemblage as does temperature. With chironomid studies now being conducted across the globe, resolution of the impact of water depth on temperature estimates is of great importance.

The project is advancing use of a biotic indicator by testing the calibration for both late-glacial and Holocene times. The project has refined temperature estimates for a period of rapid climate change, the Younger Dryas Chronozone, through the use of two independent lines of evidence. The project will improve characterization of an interval, the Hypsithermal, with a climate warmer than that of today through use of a refined biotic indicator for temperature in conjunction with lake-level studies. The project is providing a record of both temperature and water balance (precipitation minus evaporation) for the past 12,000 14C yrs for northern New England, a region currently under-represented in existing studies. The project has revealed a simpler, inexpensive means of reconstructing lake-level changes of small, closed-basin, carbonate lakes. The project provides strong evidence for regional, rather than local, changes in late-glacial and Holocene water balance, and has found correspondence between these changes and climate evidence from other parts of the North Atlantic region, a finding that has tremendous implications for drivers of dry or wet conditions across the Northeast.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Eight undergraduate students have obtained experience in field or laboratory research in geology and paleoecology including two who conducted and presented their first independent research projects, one of whom is working toward a master's degree in grade 8-12 science education. One graduate student completed a master's degree within the funding and scope of the project. Methods and results of the project have been shared with K-12 science teachers, and undergraduate students outside the disciplines of biology and geology.

Contributions to Resources for Research and Education:

We have established a reference collection of northern Maine chironomids, which will assist with their identification in future projects.

Contributions Beyond Science and Engineering:

Previously, the paleohydrology of New England was poorly resolved. This study adds a record of past lake levels for a region that was inadequately represented in the current body of literature. An understanding of how water balance has changed in the past is essential for understanding how it may change in the future. We can now provide quantitative estimates of past lake volumes and depth of water table. Information about past changes can aid the ability to predict future shifts in available water resources, such as droughts, governments, industries, and communities can better prepare for them. We will continue to present this information to resource management and policy personnel and are seeking additional venues by which to do this.

Categories for which nothing is reported:

Contributions: To Any Other Disciplines

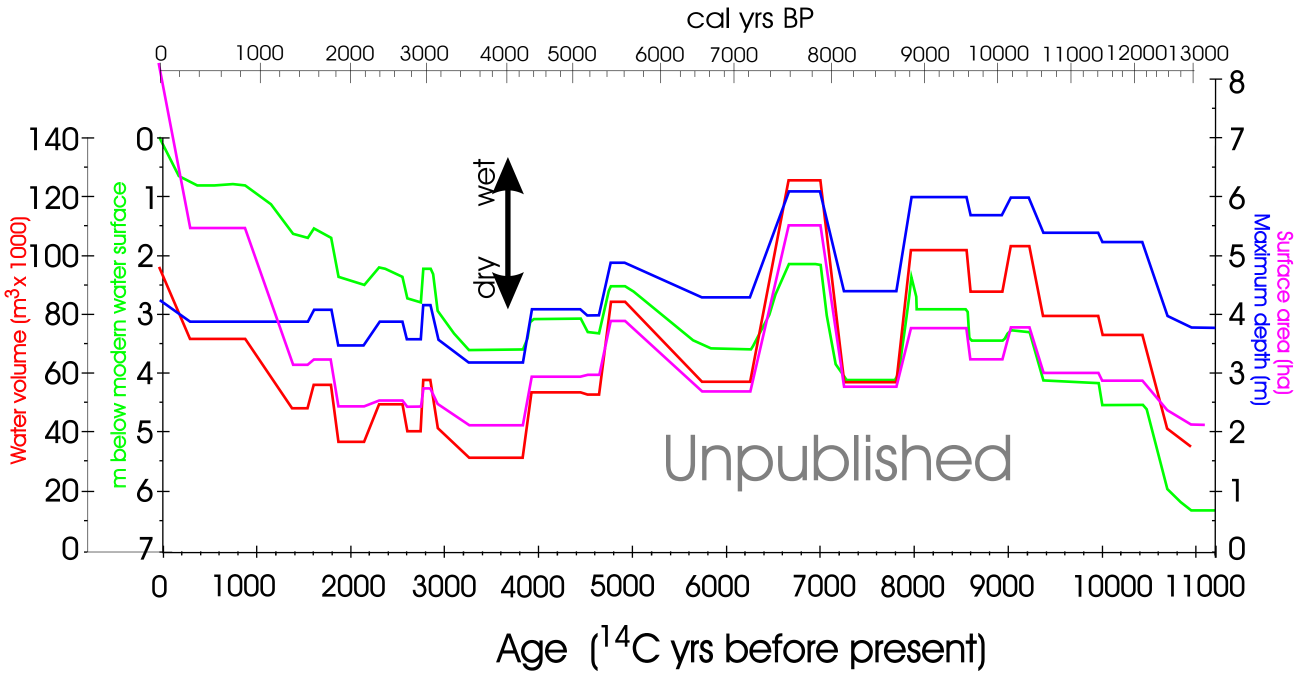

Fig. 1. Changes in Whitehead Lake water quantity for the past 11,000 ^{14}C years. Reconstruction is based on sediment matrix structure, macrofossil assemblages, organic content, and mineral grain sizes of six radiocarbon-dated cores from a transect of water depths. Green line indicates water depth at times past relative to modern water level (from Dieffenbacher-Krall and Nurse 2005), which was used as a benchmark. This curve also represents depth to surface of groundwater table. Infilling with sediment over time changes basin morphology. Thus, maximum water depth (blue), lake surface area (magenta), and lake water volume (red) are also shown.

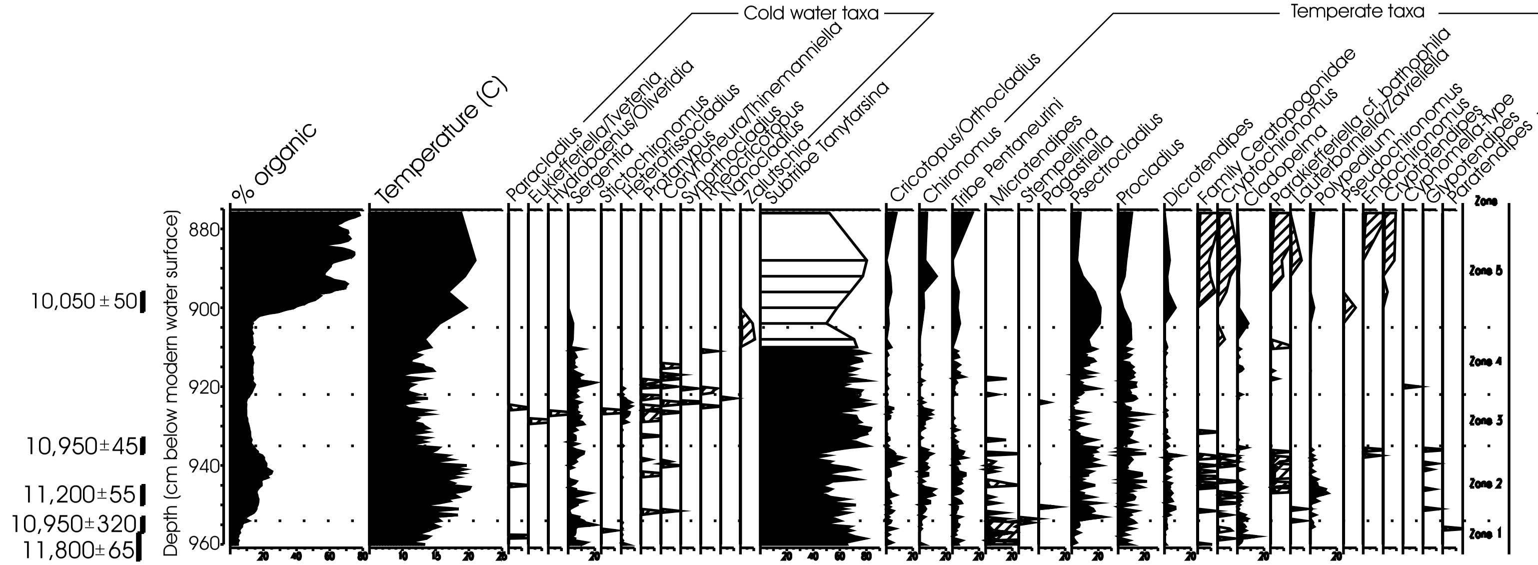

Fig. 2. Chironomid percentage diagram for Whitehead Lake. Organic content of sediment is shown. Temperature estimates are based on chironomid transfer function (Walker et al. 1997). Shading indicates 10x exaggeration.

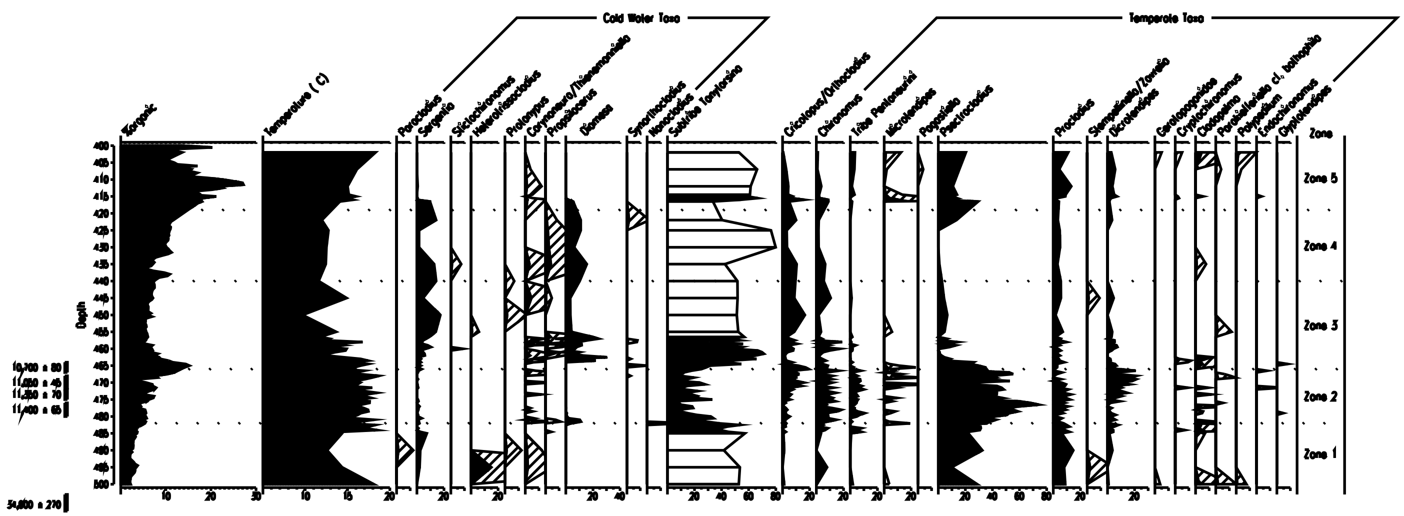

Fig. 3. Chironomid percentage diagram for Pennington Pond. Organic content of sediment is shown. Temperature estimates are based on chironomid transfer function (Walker et al. 1997). Shading indicates 10x exaggeration.

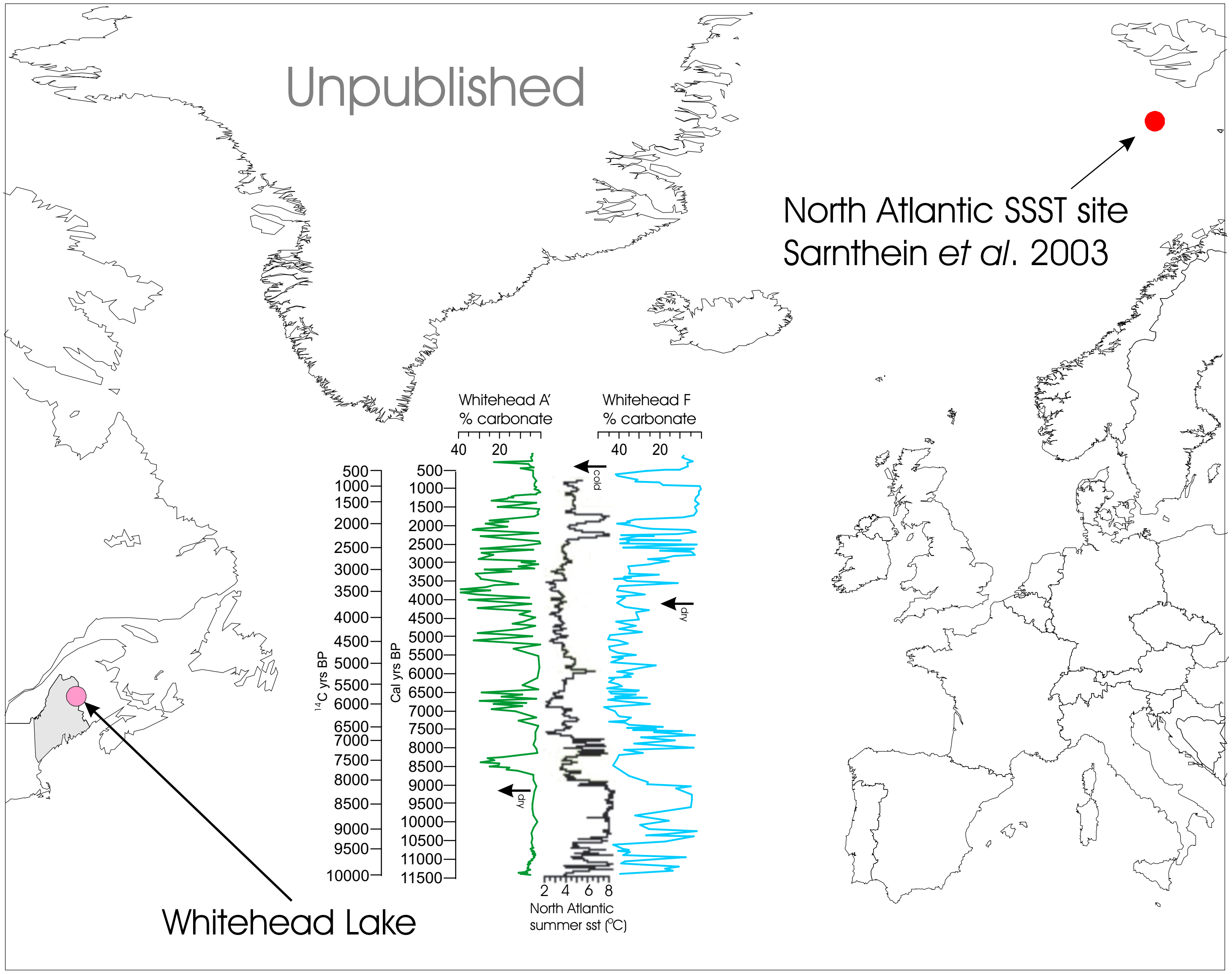

Fig. 4 Comparison of carbonate percentage curves for Whitehead Lake deep-water cores A' and F (lake-level proxy), and North Atlantic summer sea surface temperatures inferred from forams (Sarnthein et al. 2003).