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Multiproxy paleoecological evidence of Holocene climatic changes on the Boothia Peninsula, Canadian Arctic

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A B S T R A C T

A study of chironomid remains in the sediments of Lake JR01 on the Boothia Peninsula in the Central Canadian Arctic provides a high-resolution record of mean July air temperatures for the last 6.9 ka. Diatom and pollen studies have previously been published from this core. Peak Holocene temperatures occurred prior to 5.0 ka, a time when overall aquatic and terrestrial biological production was high. Chironomid-inferred summer air temperatures reached up to 7.5°C during this period. The region of Lake JR01 cooled over the mid- to late-Holocene, with high biological production between 6.1 and 5.4 ka. Biological production decreased again at ~2 ka and the rate of cooling increased in the past 2 ka, with coolest temperatures occurring between 0.46 and 0.36 ka, coinciding with the Little Ice Age. Although biological production increased in the last 150 yr, the reconstructed temperatures do not indicate a warming during this time. During transitions, either warming or cooling, chironomid production increases, suggesting an ecosystem-level response to climate variability, seen at a number of lakes across the Arctic.

Introduction

The composition of lake sediments provides information regarding changes in environmental conditions through time. Multi-proxy studies are particularly important, as the different lines of evidence of past climatic conditions provided by each proxy can be used in comparison to one another, providing a more comprehensive picture of the effect of climatic change on the lake ecosystem through time.

In this study we examine the climatic history over the last 6.9 ka of Lake JR01, located on the Boothia Peninsula in the southern Canadian Arctic, using a multi-proxy approach. Little is known regarding Holocene climatic conditions in this region. Previous studies have analyzed pollen and diatoms in the sediments of Lake JR01 (LeBlanc et al., 2004; Zabenskie and Gajewski, 2007), but quantitative temperature reconstructions are only available from the pollen record (Zabenskie and Gajewski, 2007; Gajewski, 2015a). Although the time-space evolution of the postglacial climates of the Canadian Arctic has been reconstructed (Gajewski, 2015a), these results need verification from high-temporal resolution, well-dated multi-proxy series.

We focus our attention on the chironomids in Lake JR01's sediment record, generating both qualitative estimates of the past biological production of this lake and a chironomid-based mean July air temperature reconstructions using a newly-developed Arctic-wide training set (Fortin et al., 2015). Although there remain gaps in our understanding of the chironomid-temperature relationship, and the importance of indirect limnological variables that co-vary with temperature is not completely known, calibration studies nevertheless consistently identify plausible relationships with chironomid abundance and air temperature (Eggermont and Heiri, 2012). Estimates of past temperatures are assessed and compared to previously-published pollen and diatom analyses of the lake. Taken together, the biological, physical and chemical proxies at Lake JR01 indicate that environmental conditions were warmer and that overall lake production was higher prior to 5.0 ka than they are at present. Furthermore, at Lake JR01 and other lakes across the Arctic, isolated peaks in chironomid production during the Holocene are observed at times of inferred temperature transitions, both into warmer and cooler conditions, indicative of an ecosystem-level response to changes occurring in the lake's environment.

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Study site

Lake JR01 is located in the southern Boothia Peninsula in the middle-Arctic vegetation zone (Fig. 1; 69°54′N, 95°4.2′W, 120 m asl, 5.4 m deep). This small lake (0.7 by 0.03 km) is underlain by Precambrian Shield and carbonitic bedrock (Dyke, 1984) and is surrounded by prostrate dwarf shrubs and herbaceous tundra (CAVM, 2003). Two small streams that run through sedge meadows drain into the lake. Water chemistry indicates that this lake is oligotrophic (TP = 0.04 mg l^{-1}) and circumneutral to basic (pH = 8.1) (Hamilton et al., 2001; LeBlanc et al., 2004). Deglaciation in this area occurred around 9.5 cal ka BP (Dyke, 2004).

Methods

A sediment core measuring 485 cm, collected from the central part (5.4 m deep) of ice-covered Lake JR01 was used for this study. Diatom and pollen analysis were previously conducted on this same core (LeBlanc et al., 2004; Zabenskie and Gajewski, 2007).

The core was collected using a Livingstone piston corer (5 cm diameter) and the top 80 cm was collected in a clear plastic tube attached to the drive rods to preserve the sediment water interface. The top 20 cm was extruded in the field at 0.5 cm intervals. The remaining sediment was wrapped in plastic and aluminum foil and stored at 4°C.

Continuous measurements of magnetic susceptibility and sediment loss on ignition, at one or 0.5 cm intervals, were reported in Zabenskie and Gajewski (2007) and followed standard methods (Dean, 1974). For this study, sediment biogenic silica was measured every 0.5–2.0 cm downcore using 0.5 cm^3 samples and a wet alkaline digestion technique (1% Na_2C0_3 base and reduced molybdosilic acid spectrophotometry) (DeMaster, 1981; Conley, 1998; Conley and Schelske, 2001; Fortin and Gajewski, 2009).

Radiocarbon and ^{210}Pb dates were reported in LeBlanc et al. (2004) and Zabenskie and Gajewski (2007). The oldest date at 544 cm was recovered from a second sediment sequence collected from the Lake JR01, which was correlated to the first sequence based on the magnetic susceptibility measurements. This deepest portion of the second core could not, however, be used for further analysis as it contained no microfossils and only contained a layer of organic material (Bryophytes, plant fragments and chironomids) that provided the date. The age model was developed for this paper using BACON (Blaauw and Christen, 2011) on the ^{210}Pb and calibrated ^{14}C dates (Fig. 2). All dates were calibrated using Intcal13 (Reimer et al., 2013) and are reported as ka, 1000 yr before present, with a base of AD 1999, the year in which the sediment core was collected, to avoid the use of negative ages.

A total of 122 levels was sampled for chironomids, providing over 20,000 whole head capsules (HC) for analysis. Sediment samples were taken every 1–5 cm depending on sediment

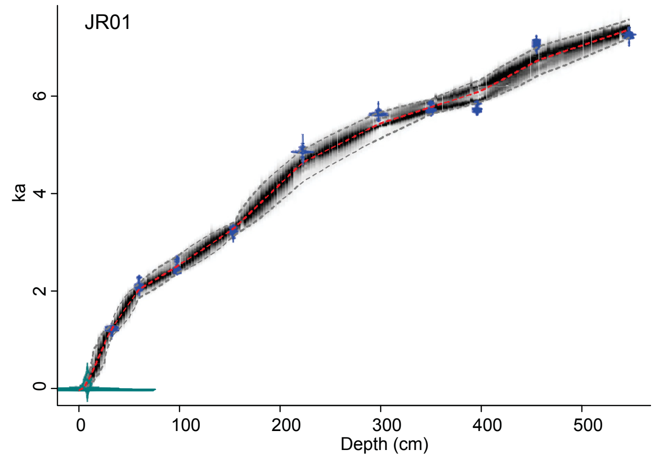

Figure 2. Sediment chronology at Lake JR01, see text for details.

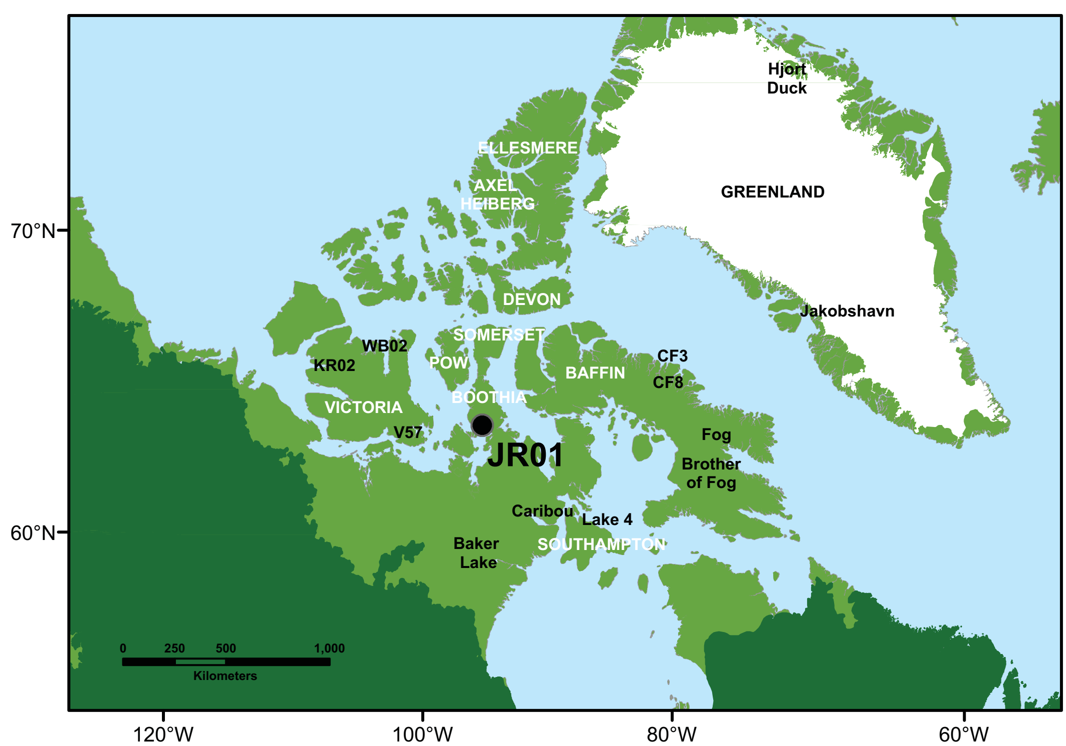

Figure 1. Location of Lake JR01 in the Canadian Arctic. Other studies referenced in the text are also shown (see text for references).