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Anthropogenic versus climatic control in a high-resolution 1500-year chironomid stratigraphy from a southwestern Greenland lake

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ABSTRACT

We performed a high-resolution study of chironomid assemblages in a sediment core retrieved from Lake Igaliku in southern Greenland. The well-dated core is located within the former Norse Eastern Settlement and covered the last 1500 yr. The comparison of chironomid stratigraphy (PCA axis scores) with instrumental temperature data, land use history and organic matter in the sediment over the last 140 yr suggested that the primary changes in chironomid fauna in 1988 ± 2 yr were driven by the shift to modern agriculture in the catchment. This unprecedented change in chironomid fauna was most likely triggered by a shift in in-lake processes. Within the instrumental period, subtle variations in the chironomid assemblages that occurred before 1988 ± 2 yr were significantly correlated with summer temperatures even in times of traditional extensive sheep farming in the catchment. The relevance of the chironomid-derived climate signal over the last 1500 yr was supported by its good concordance with previous studies in west Greenland and in the Arctic. The chironomid assemblage therefore appeared to be a valuable proxy for climate changes within the Norse colony area. Synchronous changes in Norse diet and chironomid-reconstructed climate give new insights into the interplay of Norse society with climate.

Introduction

In light of the need for a better understanding of the interactions between human societies and their environment in the current context of global change, South Greenland appears to be an unrivaled open-air laboratory, characterized by a unique history of human–environment relationships. At the end of the 10th century, the Norse colonized the agriculture-free areas in the Eastern Settlement (~61°N), and somewhat later, the Western Settlement (~64°N) (Gad, 1970). The rhythm (collapse or progressive demise) and the causalities of the abandonment during the 15th century remain a matter of debate (Dugmore et al., 2012; Massa et al., 2012a). The Norse most likely failed to cope with a complex interplay of the unpredictable climate and environmental changes of the Little Ice Age and socio-economic conjunctures (Dugmore et al., 2012). Approximately five hundred years later, spurred on by Denmark, agriculture resumed in southern Greenland at the beginning of the 20th century.

The land-use effects on the local environment of the Norse Eastern Settlement have been demonstrated by archeological surveys (Dugmore et al., 2005) and by multi-proxy studies of natural archives such as lake sediments (Fredskild, 1978; Massa et al., 2012a) soil or peat records (Ledger et al., 2013). In contrast, changes in the local climate over the last 1500 years are still sparsely documented by only a few records. The available datasets include the well-known records from the Greenland ice sheet, with the closest one (Dye-3) lying more than 400 km from the Eastern and Western settlements, several paleoceanographic studies performed along the West Greenland Shelf (Lassen et al., 2004), and lacustrine records in which the period of interest was studied at low resolution (Axford et al., 2013). To date, no continental record of climate change for the last 1500 yr is available within the Norse colony area.

In lakes, chironomid larvae are benthic organisms that produce chitinous remains (head capsules) during their development. Past changes in communities are reconstructed after extraction and identification of head capsules preserved in the sediment. Temperature was identified as one of the key factors controlling chironomid assemblage distribution at a large geographical scale (Eggermont and Heiri, 2012; Walker and Cwynar, 2006). Accordingly, chironomid assemblages are widely considered to be a valuable climate proxy in the sediment record (Walker and Cwynar, 2006). Chironomids have been successfully used as quantitative paleoclimatic indicators in arctic lakes (e.g., in Iceland: Axford et al., 2008; Langdon et al., 2011; in arctic Canada: Porinchu et al., 2009; Medeiros et al., 2012; and on Baffin Island: Thomas et al., 2011). Nevertheless, chironomid assemblages are potentially affected by a variety of environmental conditions interacting in complex ecological processes (Brodersen and Quinlan, 2006; Eggermont and Heiri, 2012; Velle et al., 2010). In addition to temperature, the most commonly recognized influencing factors are trophic status (Brooks et al., 2001), oxygen conditions (Quinlan and Smol, 2001), organic matter in the sediment (Verneaux and Aleya, 1998) and salinity (Eggermont et al., 2006). Therefore, in times of low-amplitude temperature changes, the

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influence of temperature may be outmatched by the influence of other environmental factors on the chironomid response. In southwestern Greenland, the study of the modern distribution of chironomids by Brodersen and Anderson (2002) showed that both climate (temperature) and in-lake processes (trophic state) were possible interacting forcing factors for the chironomid community.

The main objective of this paper is to assess the ability of chironomid assemblages to track climate change within the Norse Eastern Settlement area. Therefore, chironomid assemblages and the organic matter accumulation rate were analyzed at a high resolution in a sediment core from Lake Igaliku that has been extensively studied for pollen (Gauthier et al., 2010), diatoms (Perren et al., 2012) and sedimentology (Massa et al., 2012a). We aim to (1) reconstruct the changes in the chironomid assemblages during the last 1500 yr; (2) decipher the respective influence of human-induced and climate-induced (i.e., summer temperature) changes on the chironomid fauna; (3) assess the reliability of the possible chironomid-derived climate record; and (4) if relevant, provide new insights into the relationship between the Norse society and local climate changes.

Study site

Settings

Lake Igaliku (61°00′N, 45°26′W, 15 m asl) is a small lake located in southern Greenland (Fig. 1). It occupies a low valley between the head of Igalikup Kangerlua (Igaliku fjord) and Tunulliarfik fjord (Erik's fjord), at ca. 2 km northwest of the present-day town of Igaliku. The lake has a surface area of 34 ha and a maximum depth of 26 m (Fig. 1). Water drains into the lake from a relatively low relief catchment (maximum altitude of 300 m asl) of 3.1 km^2. A small outlet on the northern shore drains into the Tunulliarfik fjord. The basement rocks are primarily Ketilidian Julianehåb granite (Allaart, 1976), unconformably overlain by sandstones and lavas, all forming the Eriksfjord formation (Poulsen, 1964).

The study area is characterized by a subcontinental, subarctic climate. The meteorological station at Narsarsuaq (17 km north of the lake, Fig. 1) has a mean annual temperature of 0.9°C, with a maximum in July of 10–11°C, 194.8 days/yr with frost and annual precipitation of 615 mm (Cappelen et al., 2001).

Land-use history

Igaliku lies at the very location of the medieval settlement of Garðar in the center of the former Eastern Settlement. The area was settled soon after the Landnám, and Garðar is believed to have been the residence of the daughter of Erik the Red. Garðar was most likely the most important place in the Eastern Settlement as it became the Bishop seat as well as a probable Greenlandic assembly site (Jones, 1986; Sanmark, 2009). The high status of Garðar has been further supported by archeological fieldwork. Fifty-two Norse structures have been recognized, including byre–barn complexes, livestock pens, goat and sheepfolds and an irrigation system (Nørlund and Roussell, 1929). The catchment of Lake Igaliku was most likely used as extensively grazed grassland. Indeed, pollen and coprophilous fungi from the Igaliku lake sediment showed initial land clearance and the presence of grazing livestock around the lake in the 10th century (Gauthier et al., 2010). Sedimentary evidence for grazing pressure in the lake catchment culminated in the 12–13th century, resulting in soil erosion rates twice as great as the pre-Landnám background (Massa et al., 2012a). The Norse colonization phase is then followed by a decrease in anthropogenic indicators starting in the early 14th century and their subsequent disappearance in the 14th–15th century (Gauthier et al., 2010; Massa et al., 2012a).

Present-day Igaliku was founded at the end of the 18th century. Agriculture in the area resumed in the 1920s under the incentive of the Danish Government and consists primarily of sheep farming with

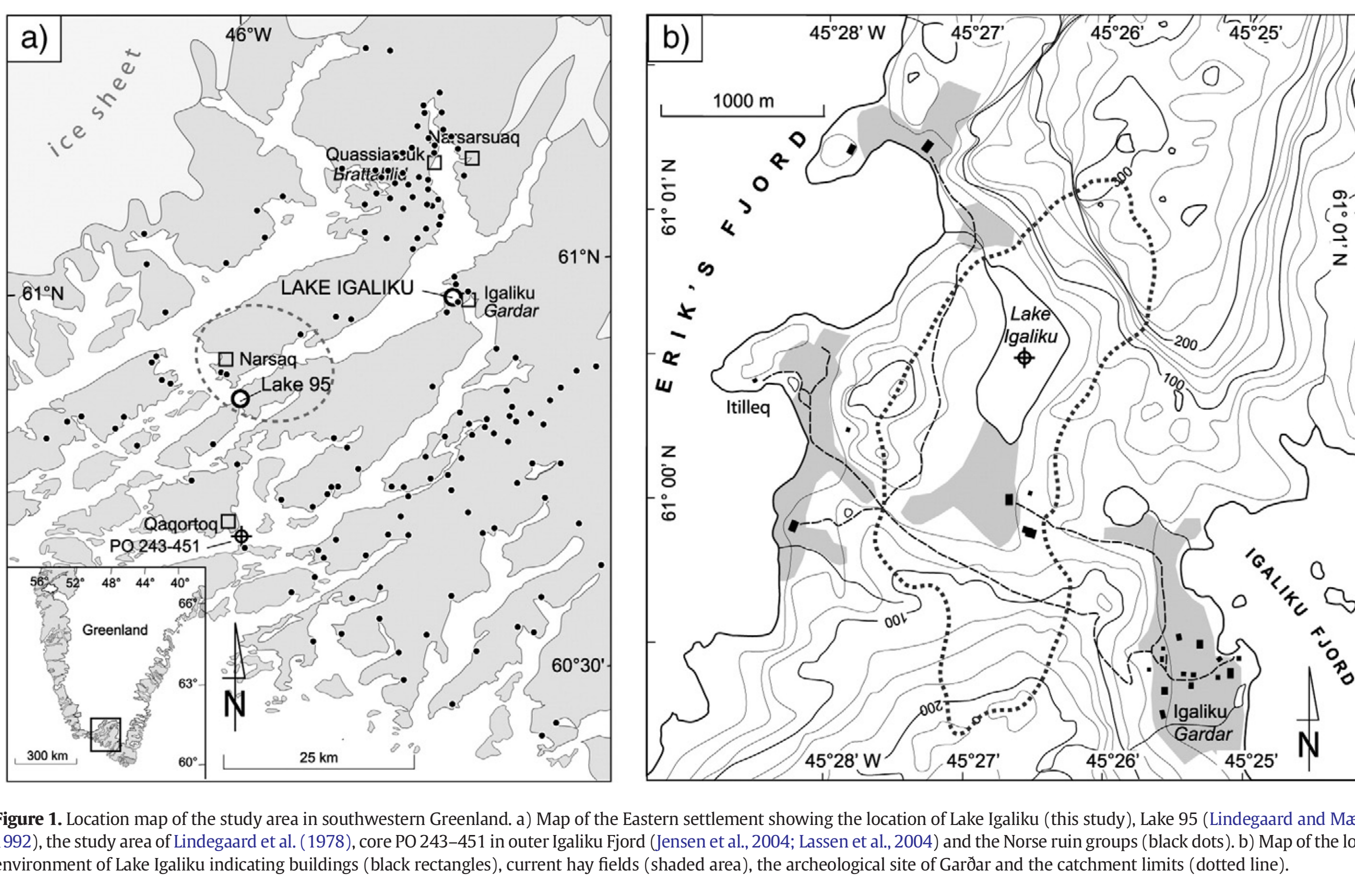

Figure 1. Location map of the study area in southwestern Greenland. a) Map of the Eastern settlement showing the location of Lake Igaliku (this study), Lake 95 (Lindegaard and Mæhl, 1992), the study area of Lindegaard et al. (1978), core PO 243–451 in outer Igaliku Fjord (Jensen et al., 2004; Lassen et al., 2004) and the Norse ruin groups (black dots). b) Map of the local environment of Lake Igaliku indicating buildings (black rectangles), current hay fields (shaded area), the archeological site of Garðar and the catchment limits (dotted line).