Palaeogeography, Palaeoclimatology, Palaeoecology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Regional Holocene climate and landscape changes recorded in the large subarctic lake Torneträsk, N Fennoscandia

Carsten Meyer-Jacob [a,*], Richard Bindler [a], Christian Bigler [a], Melanie J. Leng [b,c], Sally E. Lowick [d], Hendrik Vogel [d]

[a] Department of Ecology and Environmental Science, Umeå University, 901 87 Umeå, Sweden
[b] NERC Isotope Geosciences Facilities, British Geological Survey, Nottingham, NG12 5GG, UK
[c] Centre for Environmental Geochemistry, University of Nottingham, Nottingham, NG7 2RD, UK
[d] Institute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern, Baltzerstrasse 1 +3, 3012 Bern, Switzerland

ARTICLE INFO

Article history:
Received 13 February 2017
Received in revised form 21 July 2017
Accepted 2 August 2017
Available online xxxx

Keywords:
Inorganic geochemistry
Soil erosion
Climate change
Oxygen and silicon isotopes
Holocene
Scandinavia

ABSTRACT

Understanding the response of sensitive Arctic and subarctic landscapes to climate change is essential to determine the risks of ongoing and projected climate warming. However, these responses will not be uniform in terms of timing and magnitude across the landscape because of site-specific differences in ecosystem susceptibility to climate forcing. Here we present a multi-proxy analysis of a sediment record from the 330-km^2 lake Torneträsk to assess the sensitivity of the Fennoscandian subarctic landscape to climate change over the past ~9500 years. By comparing responses of this large-lake system to past climatic and environmental changes with those in small lakes in its catchment, we assessed when the magnitude of change was sufficient to affect an entire region rather than only specific sub-catchments that may be more sensitive to localized environmental changes such as, e.g., tree-line dynamics. Our results show three periods of regional landscape alteration with distinct change in sediment composition: i) landscape development following deglaciation and through the Holocene Thermal Maximum, ~9500–3400 cal yr BP; ii) increased soil erosion during the Little Ice Age (LIA); and iii) rapid change during the past century coincident with ongoing climate change. The gradual landscape development led to successive changes in the lake sediment composition over several millennia, whereas climate cooling during the late Holocene caused a rather abrupt shift occurring within ~100 years. However, this shift at the onset of the LIA (~750 cal yr BP) occurred >2000 years later than the first indications for climate cooling recorded in small lakes in the Torneträsk catchment, suggesting that a critical ecosystem threshold was not crossed until the LIA. In contrast, the ongoing response to recent climate change was immediate, emphasizing the unprecedented scale of ongoing climate changes in subarctic Fennoscandia.

1. Introduction

Landscapes in the Arctic and subarctic are undergoing extensive transformations because of ongoing climate change. In these landscapes, climate change leads to pronounced changes in land cover and vegetation composition (e.g., Zhang et al., 2013) as well as to the degradation of permafrost, which alters hydrology and slope stability (e.g., Hinzman et al., 2005). These dynamics in turn cause climate feedbacks, particularly by affecting carbon cycling and release of greenhouse gases (Pearson et al., 2013; Schuur et al., 2015). However, the scale of this transformation is not uniform across northern landscapes (e.g., Elmendorf et al., 2012; Xu et al., 2013).

Lakes can respond rapidly to changes in climate forcing with regard to their physical (e.g., water temperature, thermal stratification, ice cover duration), chemical (e.g., oxygen levels, carbon and nutrient cycling), and biological (e.g., phenology, food web structure) characteristics (Williamson et al., 2009). In addition to immediate in-lake responses, there are also responses in the aquatic and surrounding terrestrial systems that occur over centuries to millennia. Lakes integrate information on these long-term changes and may archive them in their sediments. Responses to long-term changes, such as variations in vegetation cover, soil development or catchment erosion, are non-linear because of complex forcing-response relationships. Furthermore, lakes may show variable responses to climate changes because of differences in characteristics; for example, small, shallow lakes with a low heat capacity may respond rapidly to small changes and thus present higher-frequency noise in limnological and paleolimnological data (Adrian et al., 2009). With increased lake and watershed size, initial small-scale changes in the watershed are recorded at different scales in these cascading systems and potentially with time lags (cf., Dearing and Jones,

---

* Corresponding author.
E-mail addresses: carsten.meyer-jacob@umu.se (C. Meyer-Jacob), richard.bindler@umu.se (R. Bindler), christian.bigler@umu.se (C. Bigler), mjl@bgs.ac.uk (M.J. Leng), lowick@geo.unibe.ch (S.E. Lowick), hendrik.vogel@geo.unibe.ch (H. Vogel).

http://dx.doi.org/10.1016/j.palaeo.2017.08.001
0031-0182/© 2017 Elsevier B.V. All rights reserved.

Please cite this article as: Meyer-Jacob, C., et al., Regional Holocene climate and landscape changes recorded in the large subarctic lake Torneträsk, N Fennoscandia, Palaeogeogr. Palaeoclimatol. Palaeoecol. (2017), http://dx.doi.org/10.1016/j.palaeo.2017.08.001

2003). This lower sensitivity of larger drainage basins to local changes allows the determination of the timing and character of important environmental tipping points, i.e., changes that are of sufficient magnitude to affect an entire region rather than only specific areas of a watershed that are particularly sensitive to climate/environmental changes, e.g., tree-line lakes.

In northernmost Sweden in the subarctic catchment of the large lake Torneträsk ("Torne Lake" in English; surface area: 330 km^2; watershed: 3350 km^2; Fig. 1), the observed climate change during the past century has thus far led to a mean annual temperature increase of 2.5 °C, a shortened (~40 days) lake ice cover period (Callaghan et al., 2013), a reduced permafrost thickness (Åkerman and Johansson, 2008), and an increase of wet areas in mires due to permafrost degradation (Malmer et al., 2005). The Torneträsk area has been subject to numerous studies in different disciplines focusing on a modern process understanding, including carbon cycling (e.g., Christensen et al., 2007; Karlsson et al., 2010), permafrost dynamics (e.g., Åkerman and Johansson, 2008; Kokfelt et al., 2009), and sediment transport (e.g., Beylich et al., 2006). In addition to these studies on recent processes, sediment records from several small lakes in the catchment have been studied to reconstruct Holocene climate and environmental change with a focus on vegetation development (e.g., Barnekow, 1999, 2000), quantitative climate reconstructions (e.g., Bigler et al., 2002, 2003), sediment transport and erosion (e.g., Snowball and Sandgren, 1996; Rubensdotter and Rosqvist, 2003) and changes in atmospheric circulation patterns (e.g., Hammarlund et al., 2002; Rosqvist et al., 2007; Shemesh et al., 2001) (Fig. 1).

Because of the complexity and multitude of studies of small lakes conducted in the Torneträsk catchment, a study of the lake itself represents an ideal site for investigating the integrated regional climatic and environmental development in northernmost Sweden since the retreat of the Fennoscandian ice sheet. Studies of Torneträsk's sediment record are thus far scarce and have only focused on a general sedimentological description of the lacustrine sediment (Andrén et al., 2002), recent changes in the input of terrestrial organic matter (OM) (Vonk et al., 2012) and on depositional patterns and subaquatic topography (Vogel et al., 2013).

Using a combination of geochemical, isotopic and biological proxies, the aims of this multi-proxy study are twofold. One aim was to survey the surface sediment geochemistry in order to assess spatial variability, how this variability relates to catchment influences, and how signals might vary across this 70-km-long lake. The second and main aim was to analyze a complete sediment sequence from Torneträsk in order to determine the regional climate and environmental development in northernmost Sweden during the Holocene and to assess i) how responses to environmental change are recorded in the large lake system compared to small lakes that have been studied within its catchment, and ii) to what extent the ongoing climate change has already affected the lake ecosystem, and how the scale of any identified changes compares to changes that occurred during past periods of distinct climate change such as the Holocene Thermal Maximum (HTM) or the Little Ice Age (LIA).

2. Regional setting

Torneträsk (68° 29′–68° 11′ N, 20° 01′–18° 36′ E; 341 m a.s.l.) is 70 km long (NW-SE), maximally 10 km wide (SW-NE), has a surface area of 330 km^2 and a watershed of 3350 km^2 (Fig. 1). The lake has an average depth of 53 m and a maximum depth of 168 m (based on bathymetric measurements in 1920/1921, Abisko Research Station; Fig. 2), with an estimated water residence time of c. 8.5 years (Swedish Meteorological and Hydrological Institute (SMHI); https://vattenwebb.smhi.se/). The watershed is drained by several smaller streams and rivers of which the Abiskojåkka, entering the lake west of the village of Abisko, is the largest inlet with an average discharge of 14 $m^3 \cdot s^{-1}$ (Fig. 1). Torneälven ("Torne River" in English) drains Torneträsk to the SE with an average discharge of 65 $m^3 \cdot s^{-1}$ (1999–2013; SMHI; https://vattenwebb.smhi.se/) (Fig. 1). The lake is (ultra)oligotrophic (TN = 195 ± 25 $\mu g \cdot l^{-1}$, TP = 3 ± 2 $\mu g \cdot l^{-1}$, TOC = 1.3 ± 0.5 $mg \cdot l^{-1}$), circumneutral (pH = 7.3 ± 0.1) (environmental monitoring data (MVM); http://www.slu.se/miljodata-MVM), and $\delta^{18}O$ and $\delta^{2}H$ of water samples from Torneträsk were −12.7/−12.8‰ and −92.6/−93.0‰, respectively in August 1999 (Shemesh et al., 2001).

The complex bedrock geology in the Torneträsk area consists of Archean plutonites (mainly granite and syenite) and their metamorphic products that are overthrusted by Caledonian metasediments and amphibolites (Swedish Geological Survey (SGU) database; maps2.sgu.se/kartgenerator/maporder_sv.html). During the retreat of the Weichselian ice sheet, the NW-SE trending Torneträsk depression hosted one/multiple ice-dammed lakes with water levels up to 250 m higher than today as suggested by paleoshoreline and paleodelta deposits (Gretener and Strömquist, 1981; Melander, 1977). The area was largely deglaciated around 9500 cal yr BP (glaciers occupy ~0.5% of the watershed today (SMHI; https://vattenwebb.smhi.se/)), leading to the drainage of the precursor lakes and the likely establishment of the

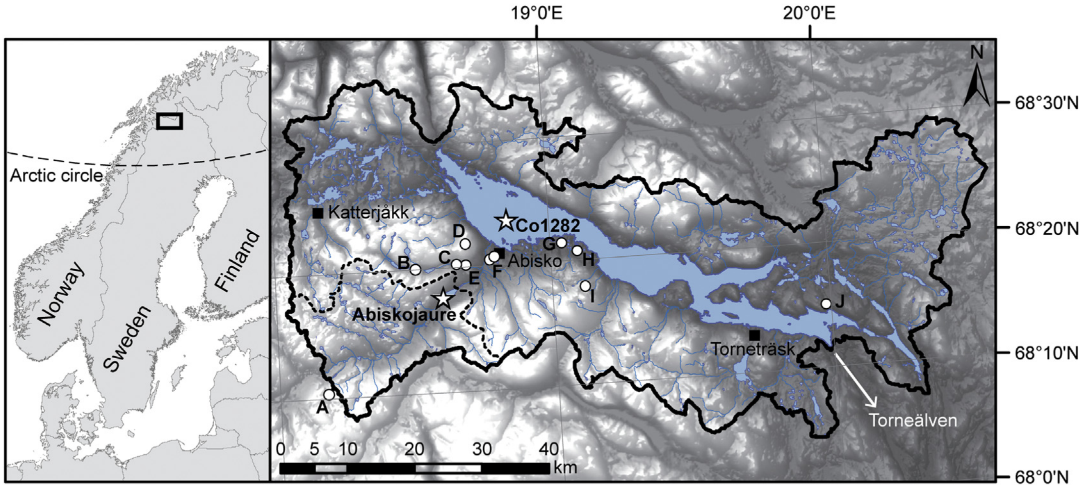

Fig. 1. (left) Map over Fennoscandia showing the location of the study region. (right) Elevation map over the watershed of Torneträsk (black contour line). Dashed contour line defines the watershed of Abiskojaure, filled squares indicate the location of three weather stations (Swedish Meteorological and Hydrological Institute) across the Torneträsk catchment, while open stars mark the sampling sites in Torneträsk (core Co1282) and Abiskojaure. Open circles indicate locations of paleolimnological studies on smaller lakes from the area (A: Vuolep Allakasjaure, B: Kårsa valley lakes, C: Pikkujärvi, D: Lake Njulla, E: Lake Tibetanus, F: Vuolep Njakajaure and Badsjön, G: Villasjön and Inre Harrsjön, H: Vuoskkujávri, I: Lake 850/865, J: Lake Latteluokta. The white arrow highlights the outlet of Torneträsk, Torneälven, in the SE.

Please cite this article as: Meyer-Jacob, C., et al., Regional Holocene climate and landscape changes recorded in the large subarctic lake Torneträsk, N Fennoscandia, Palaeogeogr. Palaeoclimatol. Palaeoecol. (2017), http://dx.doi.org/10.1016/j.palaeo.2017.08.001