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From cold to cool in northernmost Norway: Lateglacial and early Holocene multi-proxy environmental and climate reconstructions from Jansvatnet, Hammerfest

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A B S T R A C T

A multi-proxy palaeoecological study of the lateglacial and early Holocene sediments of Jansvatnet, Hammerfest, northernmost Norway (70°39′ N) showed that cold and arid conditions prevailed in both the lateglacial interstadial and the Younger Dryas. Terrestrial proxies are macrofossils and pollen. Aquatic proxies are plant and invertebrate macrofossils, pollen, diatoms, and chironomids. Mean July temperatures were reconstructed using pollen and chironomid calibration functions and ecological knowledge of the fossil flora and fauna. Lake-water pH was reconstructed using a diatom pH-calibration function. Above sterile basal deglacial silts, biotic activity was detected around 14600 years ago in the interstadial (chronologically equivalent to the Bølling-Allerød in the Greenland Ice-Core Chronology). Catchment vegetation resembled polar desert and ultra-cold stenothermic chironomids lived in the lake. However, diatom assemblages were diverse and dynamic. In the Younger Dryas stadial, conditions deteriorated. In the early Younger Dryas chironomid-inferred air temperatures (CI-Tjul) fell about 1 °C. Pollen-inferred temperatures (PI-Tjul) did not fall and the terrestrial vegetation hardly changed because of the extreme aridity. The lake water was turbid from suspended clay which diminished aquatic life. Later in the Younger Dryas (ca 12400 cal yr BP) reconstructed mean July temperatures fell by a further 3 °C and were close to the minimum to support life, at around 3–4 °C. However, decreased turbidity allowed moss growth on the lake bottom that provided habitats for invertebrates and diatoms. In the last 200 years of the Younger Dryas temperatures increased by 2–3 °C and terrestrial and aquatic organisms responded quickly. At the start of the Holocene a rapid increase of more than 3 °C in PI-Tjul to 9.5 °C initiated the replacement of sparse arctic tundra by low-arctic dwarf-shrub heath. Simultaneously, a further 2 °C increase in CI-Tjul to 10–11 °C reflected a regime shift in the lake. Aquatic macrophytes rapidly replaced the moss carpet, diatom assemblages stabilised and diatom plankton developed, and cold stenotherm chironomids were replaced by cool-temperate taxa. Productivity increased as CI-Tjul reached a steady maximum of around 12 °C and PI-Tjul reached 10.5 °C at about 10000 cal yr BP. At this time, tree-birch arrived and woodland developed over the catchment. Birch could have immigrated from the south up the west coast or from the east along the Barents Sea coast. Acidophilous aquatic taxa increased as diatom-inferred pH gradually decreased from 7.3 to 6.6. After ca 9380 cal yr BP, the density and extent of birch woodland decreased and species of exposed rocky areas increased,

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reflecting increased windiness, precipitation, and possibly a small decrease in July temperatures. Birch now formed the arctic tree-line at Jansvatnet. The lateglacial climatic pattern at Jansvatnet resembles patterns detected elsewhere in northern Norway and Svalbard and in marine records from the Norwegian and Barents Seas but contrasts with patterns in southern Norway.

1. Introduction

The climate of north-west Norway close to the entrance to the Barents Sea is sensitive to shifts in the ocean/atmosphere climate system, both at present and in the past. In the south-western Barents Sea, changes in the strength of the inflowing warm Atlantic water influence sea-surface temperature and the extent of sea ice (Risebrobakken et al., 2010). Terrestrial climate is modulated by the ocean currents, the fluctuations in winter sea-ice extent, and regional wind patterns (Risebrobakken et al., 2010). Today, mean July temperatures across northern Norway (Troms and Finnmark counties) range between 11.5 and 9 °C at sea level. The minimum temperature requirements of tree birch (*Betula pubescens*) fall within this range and hence it reaches its northern limit in this region (Moen, 1998). The tree-line ecotone between northern boreal forest and arctic tundra (*sensu* Moen, 1998) is sensitive to small climate changes.

During the last glacial maximum the Scandinavian ice-sheet covered the land and the Barents Sea. The eastern Norwegian Sea was ice-free in summer but with sea-surface temperatures around 2–3 °C (Meland et al., 2005). Thermohaline circulation and hence ocean-transported heat were diminished. Deglaciation of the northern coast started about 14600 years ago (Romundset et al., 2011) and Atlantic water started to push north (Hald et al., 2007; Aagaard-Sørensen et al., 2010). Following increased solar insolation, summer temperatures on the deglaciated land rose above 0 °C, opening the landscape to colonisation by cold- and arid-adapted plants and animals from earlier ice-free areas along the west coast and from the east in the Kola Peninsula, Pechora, and the Urals. They subsequently survived the cold and arid Younger Dryas climate reversal in unglaciated areas or re-immigrated after the rapid Holocene warming.

Biotic responses to lateglacial climate changes can be tracked through time in lake sediments (Birks and Birks, 2006, 2008). In northern Norway, lateglacial lake-sediment sequences would be expected to occur between the Younger Dryas end-moraine and the Younger Dryas marine limit. However, they are scarce. Only three lateglacial sequences are known, all from Varanger Peninsula (Prentice, 1981, 1982). At the base of the Nordkinn Peninsula, Lake Ifjord contains Younger Dryas sediments (Seppä, 1996; Seppä et al., 2002). Little is known of the biotic responses to lateglacial climate changes in the extreme environment of northern Norway, so an extensive coring reconnaissance was undertaken in 1999 to search for lateglacial sequences. Silt sediments were found at the base of many of the cored lake sediments, but no sediments from the interstadial period were identified. It may be that interstadial conditions were so severe near the Barents Sea coast that lakes remained ice-covered for most of the year and any biotic development was undetectable. Minimal organic sedimentation would make sediments indistinguishable from overlying minerogenic Younger Dryas sediments. Romundset et al. (2011) overcame the problem by finding marine lateglacial sequences below the marine limit where there had been no permanent freezing and the earliest biotic development following deglaciation was dated to 14600 cal yr BP.

Only in the north-west were lateglacial sequences discovered above the marine limit, at Jansvatnet and close by at Rumpetrollvatnet in Hammerfest. A multi-proxy study was undertaken on the Jansvatnet sediments. Jansvatnet lies at the northern limit of birch woodland today (Moen, 1998). It is in a sensitive ecotonal position where small climatic or ocean-current shifts can have large effects on the terrestrial biota. Jansvatnet presents a unique opportunity to discover more about ecosystem history and the responses of aquatic and terrestrial organisms to lateglacial and early Holocene climate changes so far north. Reactions of the biota to climate warming at the start of the Holocene may give some indication of what may occur as present global warming proceeds in the Arctic (e.g. ACIA, 2004) and give a glimpse from the past into the future.

The focus of this paper is the multi-proxy reconstruction of biotic responses to lateglacial and early Holocene climate changes in the most northerly terrestrial lateglacial site known in Europe. First, we use a variety of proxies from Jansvatnet to reconstruct terrestrial (macrofossils, pollen) and aquatic (chironomids, diatoms, macrofossils, pollen) ecosystems through the lateglacial and early Holocene, 14600–9000 cal yr BP. Second, from these proxies we reconstruct quantitatively limnological (lake-water pH) and climate (mean July temperature) variables. Third, we compare the Jansvatnet record with other records in the Scandinavian Arctic to assess its contribution to understanding patterns and processes of climate change during the transition from the last glacial period to the early Holocene.

2. Site

Jansvatnet is a small lake about 300 m by 200 m lying between Hammerfest and Rypefjord on the island of Kvaløya in Finnmark county, North Norway (70°39′ N, 23°40′ E) (Fig. 1). At Hammerfest the mean July temperature is 11.1 °C, mean January temperature is −5.1 °C, and mean annual temperature is 1.7 °C. Mean annual precipitation is 820 mm (D). At 53 m above sea level, the lake is just above the marine limit (48 m) and does not contain marine sediments. It lies in a sheltered south-west facing hollow in a public park. The eastern slopes support open birch woodland with a heath and fern-rich understory up to about 80–100 m altitude. This is one of the northernmost occurrences of birch woodland in Europe. Within the catchment are many exposed acidic-rock outcrops supporting open fjellfield vegetation (Fig. 1d). The south and north-western shores are covered by treeless species-poor *Betula nana* heath or boggy tundra-grassland grazed by reindeer. The main road runs along the south-western shore and there are scattered buildings. Shallow parts of the lake support *Myriophyllum alterniflorum, Potamogeton alpinus, Sparganium hyperboreum,* and *Equisetum fluviatile*.

3. Methods

3.1. Cores and sediments

Two adjacent 6 m long sediment cores were taken from under 9.2 m of water (water surface is zero datum) near the middle of the lake using an 11 cm diameter piston corer (Nesje, 1992) from a raft in 2000. The sediment stratigraphy is shown in Table 1 and Fig. 7. The soft pale clay in Core 1 was disturbed by coring. Therefore, Core 1 was used above the clay and Core 2 for the lower part. With the top of the distinct soft pale clay layer at 1281 cm in Core 1 as