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Air temperature and water level inferences from northeastern Lapland (69°N) since the Little Ice Age

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Abstract: Independent Arctic records of temperature and precipitation from the same proxy archives are rare. Nevertheless, they are important for providing detailed information on long-term climate changes and temperature-precipitation relationships in the context of large-scale atmospheric dynamics. Here, we used chironomid and cladoceran fossil assemblages to reconstruct summer air-temperature and water-level changes, during the past 400 years, in a small lake located in Finnish Lapland. Temperatures remained persistently cold over the Little Ice Age (LIA), but increased in the 20th century. After a cooler phase in the 1970s, the climate rapidly warmed to the record-high temperatures of the most recent decades. The lake-level reconstruction suggested persistently wet conditions for the LIA, followed by a dry period between ~1910 and 1970 CE, when the lake apparently became almost dry. Since the 1980s, the lake level has returned to a similar position as during the LIA. The temperature development was consistent with earlier records, but a significant local feature was found in the lake-level reconstruction – the LIA appears to have been continuously wet, without the generally depicted dry phase during the 18th and 19th centuries. Therefore, the results suggest local precipitation patterns and enforce the concept of spatially divergent LIA conditions.

Key words: Arctic, paleoclimate, precipitation, temperature, Chironomidae, Cladocera.

Introduction

Concurrent with the global climate warming trend, distinct regional differences are evident in the magnitude of warming. Owing to Arctic amplification, northern areas have warmed over twice the rate of the global average (Cohen *et al.* 2014). Complex feedback processes within the atmosphere-cryosphere-ocean system, most importantly – substantial losses in sea ice extent and late-spring snow cover (Overland 2014), control the Arctic amplification (Serreze *et al.* 2009). Due to the observed regional variability in climate trends, records of long-term temperature and precipitation dynamics are needed to better understand the climate-change feedback mechanisms operating in Arctic areas.

The network of paleotemperature records in the Arctic has increased in size during the past centuries (McKay and Kaufman 2014), but precipitation data remain more scattered and fragmented (Screen and Simmonds 2012; Helama *et al.* 2017). The lack of spatiotemporal observational records makes reliable quantification of Arctic hydroclimate changes difficult, especially in a long-term context (Linderholm *et al.* 2018). In general, multi-record reanalysis data show an increasing trend in Arctic precipitation over the 20th century, but changes are not homogenous across seasons or regions (Linderholm *et al.* 2018). Temperature increases have resulted in intensified hydrological cycles (Huntington 2006; Luoto *et al.* 2013), but this has not been well demonstrated based on long-term proxy data, since chronologically synchronized temperature and precipitation records (from same archives) are exceptionally rare. Nonetheless, combining independent proxy records from same sites and samples has shown that in boreal Northern Europe, the temperature-precipitation relationship closely mimics the trends in the North Atlantic Oscillation (NAO) (Luoto and Nevalainen 2018).

Lake bottom sediments collect and archive environmental signals from the lake itself, but also from the catchment and atmosphere (Cohen 2003; Smol 2009). Therefore, chronologically determined sedimentary archives provide important long-term records for paleoclimate research (Fritz 2008). One of the most useful paleotemperature proxies are chironomids (Diptera: Chironomidae), whose fossil head capsules preserve in lake sediments and are often identifiable at the species-type level (Brooks *et al.* 2007). At regional scale, chironomid midges respond closely to prevailing temperature conditions, each taxon having a specific temperature optimum (Engels *et al.* 2014). The response of chironomids to temperature is direct through their metabolic response (water temperature on the larvae and air temperature on the flying adults) for growth and development (Engels *et al.* 2019), with similar taxon-specific temperature optima observed between intra-lake water temperature datasets and multi-lake air temperature datasets (Luoto and Nevalainen 2013; Luoto *et al.* 2014). Chironomid-based paleotemperature reconstructions are typically performed using the transfer function approach (Brooks 2006), applying local or regional calibration models (Lotter *et al.* 1999; Heiri *et al.* 2011).

Although cladocerans (Branchiopoda: Cladocera) also respond strongly to temperature conditions via production of ephippial resting-egg envelopes (Sarmaja-Korjonen 2003, 2004), which can be used for climate reconstructions (Kultti *et al.* 2011; Luoto *et al.* 2015), their species assemblages are distributed within lake basins according to their habitat requirements and ecological niche (Nevalainen 2011, 2012). The planktonic:littoral ratio of cladocerans provides a general indication of water level in lakes, but quantitative methods allow for numerical reconstructions of lake level changes using the species assemblages (Korhola *et al.* 2000, 2005; Kattel *et al.* 2008). Similar to the chironomid-temperature relationship, the species-specific cladoceran-water depth relationship is comparable in both the site-specific intra-lake datasets and the multi-lake regional datasets (Nevalainen *et al.* 2011, 2013). Importantly, reconstructions of past lake-level fluctuations can be considered to reflect changes in local precipitation (Vassiljev 1998; MacDonald *et al.* 2000; Pawłowski *et al.* 2016a, 2016b).

In this study, we use chironomid and cladoceran fossil assemblages to reconstruct past air temperature and water level changes in a lake located in northeastern Finnish Lapland. A small and shallow lake was selected as the study site, since smaller water bodies better reflect air temperature and water depth fluctuations (Cohen 2003; Fritz 2008; Smol 2009). In addition, the chironomid communities of shallow sites respond more strongly to air temperature variation than those of deeper sites, where they reflect hypolimnetic water temperatures rather than air temperature (Luoto *et al.* 2014). In the case of cladocerans, typically higher diversity and wider representation of littoral chydorids in shallow sites provides better environment for estimates of water depth than deeper sites, which typically have lower diversity and are dominated by planktonic taxa (Nevalainen 2011, 2012). We apply the transfer function approach and statistical validations in the quantitative reconstructions and compare the findings against previous temperature and hydroclimatic records. Since independent records of temperature and precipitations from same proxy archives with no chronological mismatch are rare, this study has the potential of providing new insights into climate changes of northernmost continental Europe since the Little Ice Age (LIA).

Material and Methods

Study site. – The study site (Fig. 1A) is located in northeastern Finland (69°05′N, 27°30′E), about 250 km north of the Arctic Circle, at the crossing of north boreal and subarctic ecoregions. The 7 ha catchment exhibits both mixed pine forest and mountain birch woodland elements. The study lake has no official name, but it is called Sylvilampi in accordance with a previous lake survey in the region (Nevalainen *et al.* 2019). The closed basin is small (0.5 ha) and shallow (maximum depth <1 m), and situated at an altitude of 127 m a.s.l. (Fig. 1B).

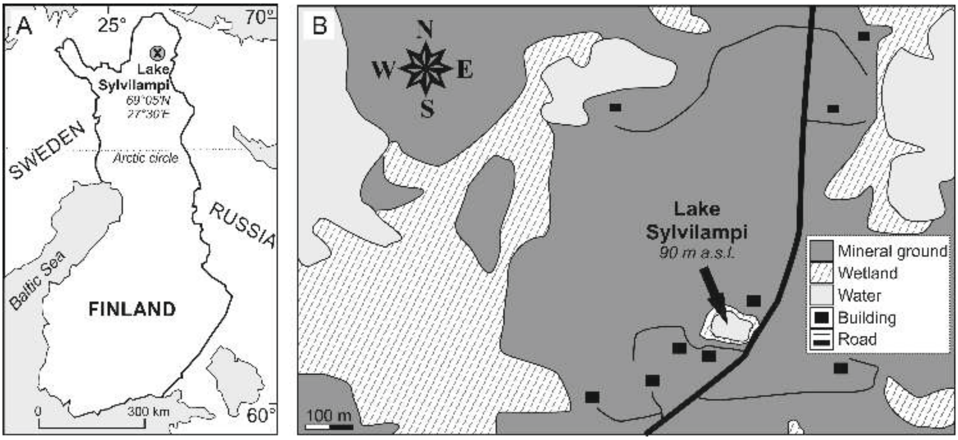

Fig. 1. Location of Lake Sylvilampi (unofficial name) in Finnish Lapland (A) and general catchment characteristics (B). There is no permanent settlement in the catchment.

The lake is classified as oligotrophic but close to mesotrophic, based on a summer total phosphorus measurement (TP = 14.1 $\mu g \cdot l^{-1}$). *Carex* and *Sphagnum* inhabit the limnotelmatic areas of the acidic (pH = 5.6) and humic (dissolved organic carbon, DOC = 6.6 $mg \cdot l^{-1}$) lake (Rantala *et al.* 2016a). There are some small summer cottages located in the catchment, but no permanent settlement exists. The road next to the lake occupies very light traffic, since no significant settlement is located further down its course. The lake has remained close to its pristine state.

Instrumentally measured mean July air temperatures (TJul) at Ivalo Airport (Finnish Meteorological Institute), ~50 km south from the study site, indicate an increasing trend from the beginning of measurements in the late 1950s (Fig. 2A). The last 30-year average TJul (1988–2018) has been 14.4°C, whereas the last 5-year average (2013–2018) has been 15.4°C, with the record highest temperature (19.4°C) occurring in 2018. June to August precipitation measurements from the same meteorological station show that rainfall generally increased from the 1980s onwards but has slightly decreased in the recent years (Fig. 2B). The average June to August precipitation between 1983 and 2013 has been 66 mm.

Sampling and sediments. – A 16-cm sediment sequence was collected from Lake Sylvilampi in summer 2014, using a Limnos gravity corer (Kansanen *et al.* 1991). The captured sediment profile extended to the bottom of the accumulated material, since a hard surface was reached. The sediments were subsampled at 1-cm intervals in the field and stored at 4°C for later analysis. Sediment chronology is available in a paper by Nevalainen *et al.* (2019).

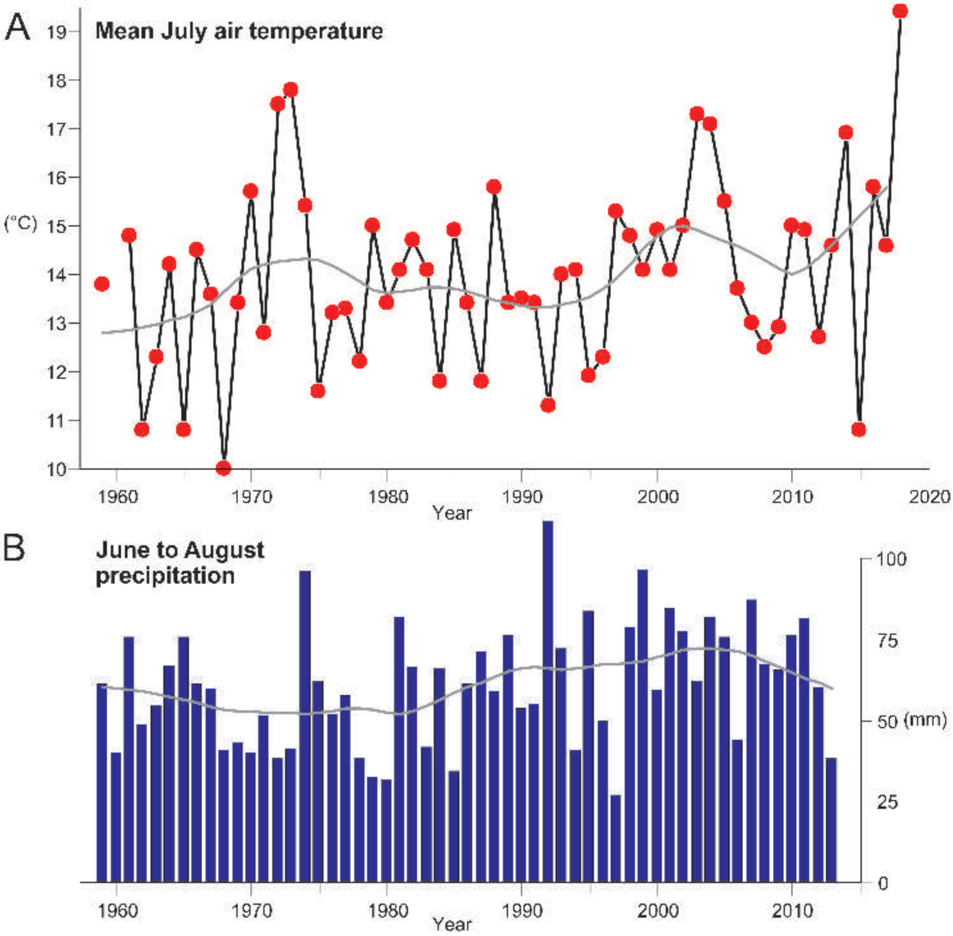

Fig. 2. Meteorological data from Ivalo Airport including (A) mean July air temperature (1959-2018) and (B) June to August precipitation (1959-2013) (Finnish Meteorological Institute). Grey lines represent LOESS smooth (span 0.3).

Fossil assemblage analyses. – For fossil chironomid analysis (Brooks *et al.* 2007), the untreated sediments were sieved through a 100-µm mesh and the residue was scanned, using a Bogorov counting tray, under a stereo microscope at magnification of 25x for chironomid head capsule extraction (with fine forceps) on microscope slides. The head capsules were mounted on Euparal and identified under a light microscope at 100–400x. The target count sum of individuals was set to 50.

For fossil Cladocera analysis, sediments were pretreated by heating them in 10% KOH for 20 min, washing and sieving the deflocculated sediment under running tap water using a 55-µm sieve, and centrifuging the residues at 4000 rpm for 10 min (Szeroczyńska and Sarmaja-Korjonen 2007). Samples were then mounted on microscopic slides and sealed with safranin-stained glycerol gelatin. Cladoceran body parts, including carapaces, headshields, post-abdomens and ephippia, were examined and identified under a light microscope at 100–400x. As a counting sum, 50 individuals (the most abundant body part of each taxon) per sample were set as the target. In low-diversity lakes, 50 individuals are enough for a cladoceran community analysis (Kurek *et al.* 2010). The cladoceran assemblages from Lake Sylvilampi were originally included in a biogeographical study of *Rhynchotalona latens* (Chydoridae) (Nevalainen *et al.* 2019).

Reconstructions and statistical validations. – The chironomid-based mean July air temperature (CI-TJul) reconstruction was performed using the East European calibration model (Luoto *et al.* 2019), which combines a single Polish and two Finnish chironomid datasets (Luoto 2009; Luoto *et al.* 2016). The calibration set had a temperature range of 11.3–20.1°C and it includeed 212 sites and 142 chironomid taxa. The model was constructed using the Weighted Averaging-Partial Least Squares (WA-PLS) technique and had a jackknife cross-validated coefficient of determination (R^2_{jack}) of 0.88 and a root mean squared error of prediction (RMSEP) of 0.88°C.

Cladocera-based lake level reconstructions (ClI-depth) were run using the Finnish water-depth calibration model for shallow lakes (Nevalainen *et al.* 2011). The calibration set water- depth gradient was 6.5 m (0.5–7.0 m) and it consisted of 55 sites and 56 cladoceran taxa. The model used the modern analogue technique (MAT) and has an R^2_{jack} of 0.58 and an RMSEP of 1.09 m.

Estimated standard errors of prediction (eSEP), *i.e.*, sample-specific errors in the reconstructions, were established using bootstrapping cross-validation with 999 iterations. The closest modern analogues of the fossil samples in the calibration sets were assessed using the MAT with squared chi-square distance as a dissimilarity coefficient and a 5 percentile threshold (minDC) for poor/good analogues. To evaluate the trends in primary and secondary environmental responses of chironomids and cladocerans, the Principal Component Analysis (PCA), with square-root transformed relative abundances of taxa, was used. Statistical relationships between the reconstructed CI-TJul, ClI-depth and the PC axis 1 (primary) and PC axis 2 (secondary) scores were assessed using Pearson's product-moment correlation coefficient (R) and adjusted coefficient of determination (R^2_{cor}), and their statistical significance was determined via P-values. Diversities of chironomid and cladoceran communities were estimated using Hill's (1973) N2 effective number of occurrences. The temperature reconstruction was compared with a tree-ring-based June to August temperature record from northern Finland (Matskovsky and Helama 2016) and the water-depth reconstruction with a multi-proxy pan-Arctic hydroclimate index (Linderholm *et al.* 2018).

Results

Fossil assemblages. – Within the sediment profile of Sylvilampi, 24 chironomid taxa were found. *Ablabesmyia monilis*-type, *Polypedilum nubeculosum*-type, *Psectrocladius septentrionalis*-type, *P. sordidellus*-type and *Zalutschia* type B occurred in all the samples. The highest maximum and mean abundances were reached by *P. sordidellus*-type (38.0%, 19.3%), *P. septentrionalis*-type (32.1%, 18.1%) and *Zalutschia* type B (25.9%, 16.1%). The most important changes in the chironomid stratigraphy included decreases in cold-water *Tanytarsus lugens*-type and *P. sordidellus*-type from the bottom towards the top, and the simultaneous increase in warm-water *Procladius* and *Dicrotendipes nervosus*-type (Fig. 3). *P. septentrionalis*-type generally increased from the bottom until 3 cm (~1980 CE), after which it decreased. Also *Zalutschia* type B decreased from 2 cm (1990s) onwards. The chironomid diversity increased towards the present with N2 of 16 at the topmost sample. The chironomid PC axis 1 explained 41.9% and axis 2 explained 26.8% of whole variance. The axis 1 scores showed a progressive increase in values from bottom (-1.1) to top (1.2). The positive axis 2 scores occurred between 15 and 13 cm and between 2 and 0 cm, while the scores were negative between 12 and 3 cm.

Of the 15 cladoceran taxa found, *Alonella nana*, *Chydorus sphaericus*-type and *Rhynchotalona latens* (previously *Unapertura latens*) occurred in all the samples. *A. nana* also had the highest maximum (79.7%) and mean (53.8%) abundances, followed by *R. latens* (50.6%, 18.1%) and *C. sphaericus*-type (18.8%, 8.5%). Shallow-water *A. nana* was the most abundant taxon between 15 and 7 cm (from 17th to 19th century) and between 3 and 0 cm (from ~1980 CE to present), whereas *R. latens*, with the lowest water-depth optimum, dominated between 6 and 4 cm (1900–1970 CE) (Fig. 4). These two taxa constituted at least 50% of the cladoceran community throughout the stratigraphy. In all, the cladoceran assemblages included mostly littoral (shallow water) taxa, while the relative proportion of planktonic (deep water) taxa, such as *Ceriodaphnia* spp. and *Bosmina longispina*, remained under 10% in every sample. The cladoceran diversity was high (N2 > 2.5) between 15 and 4 cm (from the 17th century to the 1970s), but decreased towards the present (N2 = 1.5 at 0 cm). The cladoceran PC axis 1 explained 41.8% and axis 2 explained 25.5% of all variance. The axis 1 scores remained close to 0 until 6–4 cm when they increased (> 0.5). The lowest axis 1 scores (< -0.9) occurred between 3 and 0 cm. Disregarding a slight, but progressive, decreasing trend, axis 2 scores showed very little variation.

Reconstructions. – The CI-TJul varied from 13.4°C to 16.1°C, with the lowest value at 6 cm (~1900 CE) and the highest – at 1 cm (~2000 CE). Between 15 and 3 cm (from the 17th century to the 1980s), the temperatures remained below 15°C, but increased to ~16°C at 2–0 cm (from the 1990s to the present) (Fig. 3). The sample-specific errors remained persistently below 1°C, and

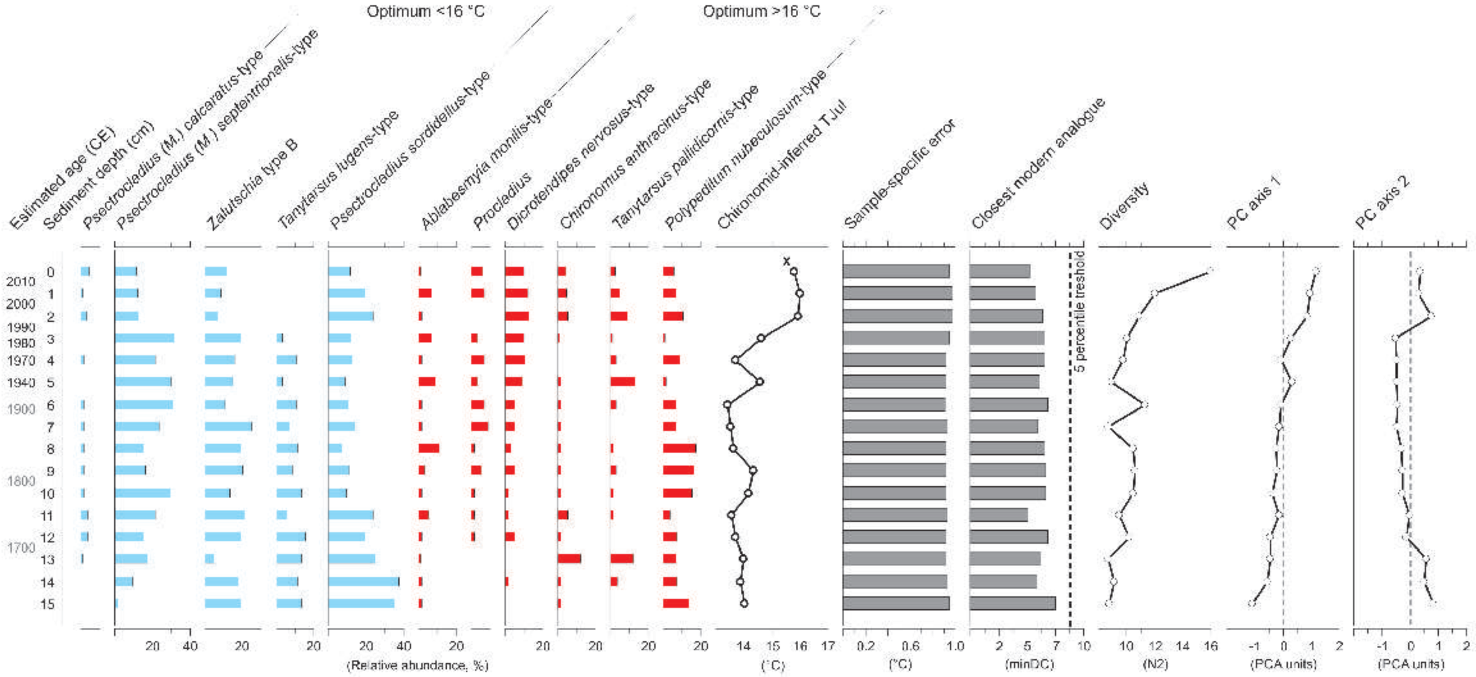

Fig. 3. Relative abundances of most common (N2 > 5) chironomids in Lake Sylvilampi, Finnish Lapland, arranged according to their temperature optima (from coldest to warmest) in the used temperature calibration model (Luoto *et al.* 2019). The chironomid-based mean July air temperature (TJul) reconstruction uses the weighted averaging-partial least squares technique. Also given are sample-specific errors (bootstrapping cross-validation), closest modern analogues (modern analogue technique), N2 diversity index (effective number of occurrences) and principal component (PC) axis 1 and 2 scores. Extrapolated ages are marked in grey and the instrumentally measured modern temperature (5-year average 2013-2018) is marked with an x.

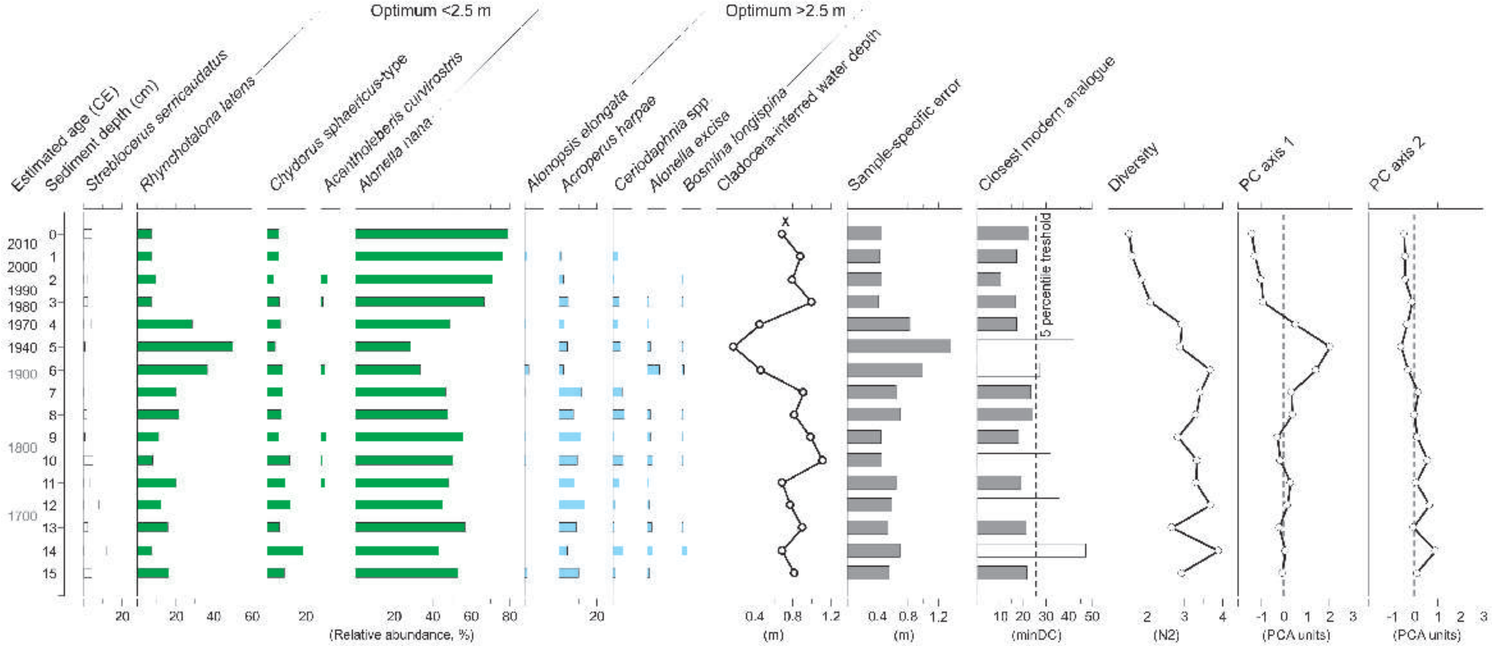

Fig. 4. Relative abundances of most common (N2 > 5) Cladocera in Lake Sylvilampi, Finnish Lapland, arranged according to their water depth optima (from shallowest to deepest) in the used lake level calibration model *(Nevalainen et al. 2011)*. *Streblocerus serricaudatus* is not present in the calibration set, and subsequently does not have estimated optimum for depth. The cladoceran assemblages of Lake Sylvilampi were originally published in Nevalainen et al. 2019. The Cladocera-based water depth reconstruction uses the modern analogue technique. Also given are sample-specific errors (bootstrapping cross-validation), closest modern analogues (modern analogue technique), N2 diversity index (effective number of occurrences) and principal component (PC) axis 1 and 2 scores. Extrapolated ages are marked in grey and the modern measured water depth is marked with an x.

according to MAT, all samples had good modern analogues. The CI-TJul correlated significantly with the chironomid PC axis 1 scores ($R = 0.82$, $R^2_{cor} = 0.65$, $P < 0.001$), but no significant correlation was found with the axis 2 scores ($R = 0.43$, $R^2_{cor} = 0.12$, $P = 0.099$).

The ClI-depth varied between 0.2 and 1.1 m. The lowest values with depth below 0.5 m occurred between 6 and 4 cm (~1900–1970 CE), whereas the highest value was reconstructed at 10 cm (late 18th century) (Fig. 4). In the reconstruction, five samples had poor modern analogues; these occurring at 14, 12, 10, 6 and 5 cm. The sample at 5 cm (1940 CE) also had very high sample-specific error (eSEP = 1.4 m). The Cladocera-inferred water depths correlated significantly with the cladoceran PC axis 1 scores ($R = 0.67$, $R^2_{cor} = 0.45$, $P = 0.004$), but not with the PC axis 2 scores ($R = 0.46$, $R^2_{cor} = 0.15$, $P = 0.076$).

Discussion

Temperature development. – Reliable chironomid-based temperature reconstructions require the presence of temperature indicator taxa, which did occur abundantly throughout the Sylvilampi sediment profile (Fig. 3). Furthermore, in order to avoid unrealistic temperature extrapolations in the WA-PLS method, an adequate chironomid diversity is preferential, because single dominant taxon with extreme (cold or warm) optimum, or response to a confounding environmental factor, can distort the reconstruction (Shala *et al.* 2017; Plikk *et al.* 2019). In Sylvilampi, at least ten taxa were encountered in each of the samples. Of the chironomids in the present record, *Dicrotendipes nervosus*-type was the only taxon that has no significant relationship with temperature in the applied calibration set. It has an intermediate temperature optimum and wide tolerance along the latitudinal gradient (49–70°N) in Eastern Europe (Luoto *et al.* 2019), but most temperature training sets identify it as a warm taxon (Brooks *et al.* 2007). When considering the intermediate optimum of *D. nervosus*-type in the used calibration set (16.6°C) against the northern location of the current downcore site (last 30-year average temperature 14.4°C), it suggests a comparatively warm temperature preference, and hence provides a uniform temperature signal, when compared to other data sets in the Eurasian region (Brooks 2006). Therefore, it may be considered that all the chironomid taxa in the Sylvilampi record have realistic temperature indications, and in all the samples – the fossil assemblages had good modern analogues in the calibration set (Fig. 3).

The temperature reconstruction showed persistently low temperatures between 15 and 6 cm (Figs 3, 5) corresponding to a period from 1620 CE to 1910 CE. This time period matches with the temporal extent of the LIA, which is known to have been a complex and spatially divergent climate event (Mann *et al.* 2009). Typically, the LIA has been described to have occurred between 1550 and 1850 CE in western Scandinavia (Zawiska *et al.* 2017), but in northern and

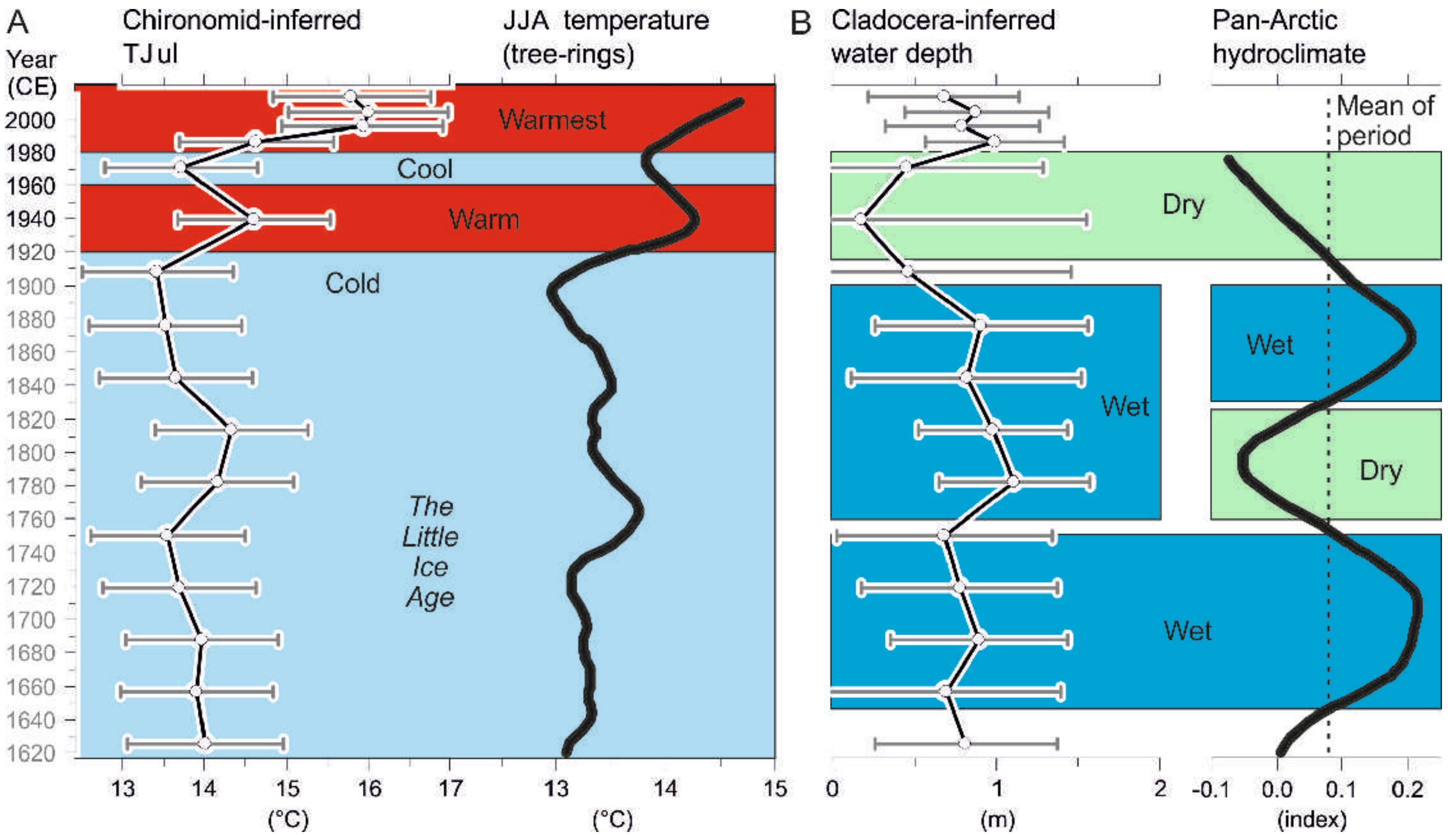

Fig. 5. Chironomid-inferred mean July air temperature (weighted averaging-partial least squares) (A) and Cladocera-inferred water depth (modern analogue technique) (B) reconstructions with sample-specific errors (bootstrapping cross-validation) from Lake Sylvilampi, Finnish Lapland, compared with a tree-ring-based June to August temperature reconstruction from Finnish Lapland (Matskovsky and Helama 2016) and a mean Pan-Arctic hydroclimate index based on 17 proxy-series (Linderholm *et al.* 2018). Extrapolated ages are marked in grey.

eastern Finland it lasted longer, until the beginning of the 20th century (Weckström *et al.* 2006; Luoto and Helama 2010; Rantala *et al.* 2016b). In addition to the delayed ending, the current record agrees with previous evidence (Matskovsky and Helama 2016; Fig. 5) that the LIA was not uniformly cold, but a slightly warmer phase prevailed between the 18th and 19th centuries. It has also been previously shown from two independent sites (lakes Nammajávri and Loažžejávri) that summer temperatures peaked around 1600 CE in northeastern Finland (Rantala *et al.* 2016b; Luoto *et al.* 2017). This, however, represents the initial phases of the current record, and hence cannot be interpreted based on the present data. Parallel to the tree-ring record (Matskovsky and Helama 2016), the Sylvilampi temperature reconstruction suggests that the coldest temperatures of the examined time period occurred at the end of the LIA around 1900 CE. Historical records show that in eastern Finland (64°N) the cold climate caused serious famine following the cold summers, which continued from the 1860s until the beginning of the 20th century (Wilmi 2003). Since these historical writings coincide with the current temperature reconstruction, it appears that similar climate trends prevailed between central eastern and northeastern Finland (~500 km distance between the sites) at this time.

Consistent with the tree-ring record (Matskovsky and Helama 2016; Fig. 5), the temperature reconstruction over the last 100 years also indicated warmer temperatures at ~1940 CE followed by a cooler period at ~1960–1970 CE, after which the temperatures rapidly increased. The warmer phase at ~1940 CE predated the instrumental record and cannot be meteorologically verified, but the observational data do suggest lower temperatures for the 1960s. When comparing the reconstructed temperature of the most recent sample with the cold climax at the end of the LIA, there has been a 2.7°C increase in temperature, which is higher than the 2°C averaged difference between the present and LIA minimum temperatures in southern Finland (Luoto 2013). As the Northern Hemispheric temperature difference between the LIA and the present has generally been ~0.7–1.5°C (Moberg *et al.* 2005; Jansen *et al.* 2007), for our study site this might imply the importance of the Arctic amplification process (Serreze *et al.* 2009). For Scandinavia in general, the climate change predictions for the 21st century suggest that warming rates increase along with latitude and distance from the coast (Hanssen-Bauer *et al.* 2005), which is also implied by the present long-term paleoclimate results.

Lake level changes. – As could be expected from a very shallow site such as Lake Sylvilampi, the cladoceran assemblages were dominated by littoral (Chydoridae) taxa, while the only planktonic taxa, *Ceriodaphnia* spp. and *Bosmina longispina,* occurred with low abundance throughout the core (Fig. 4). Moreover, the occurrence of the taxa in the very shallow study site may be more related to food supply than water depth. All taxa encountered in the stratigraphy, except *Streblocerus serricaudatus*, were present in the water depth calibration model.

Consistent with the characteristics of Lake Sylvilampi, *S. serricaudatus* has been described as a habitant of boggy pools (Fryer 1974). Only in the sample at 14 cm, the abundance of *S. serricaudatus* exceeded 10%, hence the influence derived from its absence from the calibration set and consequent effects to the water depth reconstruction remained relatively minor. Nonetheless, the absence of *S. serricaudatus* from the reconstruction is shown in the MAT statistics as poor analogues for the samples where it was most abundant (14, 12 and 10 cm) (Fig. 4). In addition, although *S. serricaudatus* was rare or absent, poor analogue samples with the largest sample-specific errors occurred during an inferred low lake level phase at 6–5 cm, a period which followed the relatively stable lake level phase in the early part of the record (Fig. 4). During this low Cladocera-inferred lake level phase, *P. sordidellus*-type, which is a shallow water taxon associated with littoral vegetation (Lindegaard 1992; Luoto 2012), was the most abundant chironomid (Fig. 3). Also *T. pallidicornis*-type, which is typically found from shallow littoral areas with varying substrate (Luoto 2010), had its abundance peak at 5 cm (Fig. 3) – confirming that a shallow water level event occurred in the lake between 6 and 4 cm. It could also be argued that in the most recent part (3–0 cm) of the sediment record, the lake level reconstruction is not reliable because of low cladoceran diversity (Fig. 4). However, the inferred values for this period, corresponding to a time period from 1980s to the present, vary between 0.7 and 1.0 m, which equal to the water depth observed during the fieldwork.

Earlier paleoclimatic records from Northern Europe have shown that lake and wetland water tables were higher between 1700 and 1900 CE (Andersson and Schoning 2010; Nevalainen *et al.* 2011), and that is in line with the present reconstruction from Lake Sylvilampi. Since cold climate reduces evaporation (Rouse *et al.* 2008), it is uncertain whether precipitation truly increased during the LIA, or if the increased lake levels were also due to the low air temperatures, and the subsequently lower evapotranspiration. The dry condition during the 20th century inferred from the cladocerans (Fig. 5) is, however, partially confirmed by the meteorological data, which show low summer precipitation during the observational period from the late 1950s to the early 1980s (Fig. 2). The early part (~1910–1970 CE) of the dry phase, depicted by the Sylvilampi lake level reconstructions, is supported by a peat record (humification index) from Sweden (Andersson and Schoning 2010) that indicate a sudden drastic decrease in precipitation during the period. In the present reconstruction, the lower lake level between ~1910 and 1970 CE (6–4 cm) is driven by high abundance of *Rhynchotalona latens,* which has the lowest water depth optimum in the calibration model (Fig. 3). According to a biogeographical investigation, *R. latens* is a specialized taxon and has a preference for acidic, mesotrophic, humic and shallow lakes with highly organic sediments (Nevalainen *et al.* 2019). Hence, it may be speculated that Lake Sylvilampi was a very typical habitat for the species during the dry conditions of the 20th century, because the latent species has been described from small northern ponds bordered with *Sphagnum* and rich in submerged vegetation

(Van Damme and Nevalainen 2019). More specifically, lower lake level and/or temporal drying would have induced *R. latens* to undergo intensive gamogenesis and diapauses for survival because of changes in the physical environment (*e.g.*, drying, high water temperature in the shallow water) or biotic interactions (*e.g.*, high population density in the shallow water) (Nevalainen *et al.* 2019).

Following the dry conditions, the lake level became elevated in Lake Sylvilampi in the 1980s and has since remained roughly at the same level. The increase in reconstructed lake level is supported by the instrumental precipitation trends that show highest precipitation during the 1990s and 2000s (Fig. 2). The recently elevated lake level in Lake Sylvilampi is therefore in line with the global-change scenarios for Finland projecting major increase in precipitation and surface runoff owing to the ongoing climate change (Carter *et al.* 2004; Jylhä *et al.* 2004). However, the hydroclimatic impacts are not uniform within Finland due to regional differences in climate conditions and watershed properties (Veijalainen *et al.* 2010), subsequently emphasizing the need for site-specific baseline studies.

Conclusions

Our chironomid-based temperature reconstruction from Lake Sylvilampi showed persistently low values during the LIA. Temperatures increased in the 20th century followed by a short-lived cooler phase in the 1970s. The record-high temperatures occurred in the most recent decades. Our cladoceran-based lake level reconstruction suggested high precipitation during the LIA. A dry period was reconstructed between ~1910 and 1970 CE when the lake became almost dry. Since the 1980s, the lake levels became again elevated suggesting increased precipitation. The recent part of the reconstructed climate oscillations were verified by the meteorological data available from the late 1950s. The temperature reconstruction followed generally established patterns, but the lake level reconstruction indicated a distinct local feature during the 18th and 19th centuries by the absence of agenerally described dry phase. These findings therefore suggest local precipitation patterns and complex spatiotemporal Arctic hydroclimate development.

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