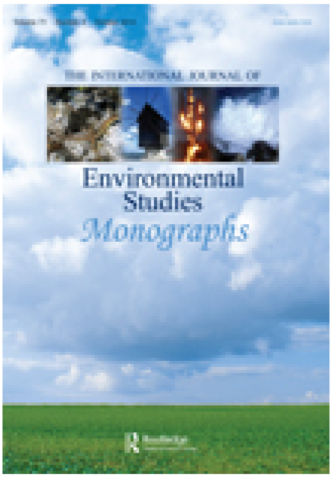

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Reconstruction of summer temperatures in East Siberia (Russia) for the last 850 years, inferred from records in lake sediments of non-biting midges (Diptera: Chironomidae)

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Reconstruction of summer temperatures in East Siberia (Russia) for the last 850 years, inferred from records in lake sediments of non-biting midges (Diptera: Chironomidae)

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We analysed a 42-cm-long sediment record from Lake Mountain located in East Siberia (Russia) for the reconstruction of summer temperature for the last 850 years. The high latitude of East Siberia at 52°N is probably sensitive to variation in insolation and solar activity. According to our reconstruction, clear decrease in summer temperatures occurred in East Siberia after ca. 1400 and we linked this temperature drop with the beginning of the Little Ice Age. The coldest summer occurred about ca. 1570–1700 and 1830–1900.

Keywords: Little Ice Age; Siberia; Chironomid; Sediments

1. Introduction

Lakes respond sensitively to environmental changes and these changes are often reflected in the physical, geochemical and biological features of the sediments accumulating in lakes. Hence, sedimentary research plays a key role in deciphering the effects of increasing environmental pressure on aquatic ecosystems as sediments collect and unify environmental signals of both local and regional changes [1,2]. Understanding the variation in lake ecosystems, be it as a result of natural or anthropogenic causes, is of utmost importance if we are to fully comprehend how these ecosystems function and how they can be restored and protected [3,4]. Many studies have focused on the Late Holocene climatic changes in Europe, Fennoscandia and Canada [5]. Yet information on fluctuations of East Siberian climate during the Late Holocene and in particular the last few centuries is still scarce. It is evident that small lakes with small watersheds exist in a sensitive state of equilibrium with climate and are therefore good indicators of climate change with the minimal time lag. Therefore, the slightest changes in climate can affect the bio-productivity of lakes and water-saturated soil in the catchment area [6,7].

Chironomid records are sensitive to summer air temperatures [8,9], and the time lag between changes of air temperatures and chironomid taxa is probably minimal. Among various palaeolimnological methods, chironomid analysis of lake sediments is one of the

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most promising biological methods for reconstructing past temperatures [10–13]. Temperature reconstruction based on chironomid records relies on the empirical relationship between the taxonomic composition of chironomid assemblages in recently deposited lake sediments and air or lake surface water temperature during the summer months [14–16]. But, their ability to reconstruct Holocene temperature changes in East Siberia *quantitatively* remains uncertain [17–20] and our investigations were intended to fill this gap.

East Siberia is very sensitive to moisture regimes because it is located in a margin area, where moisture from the North Atlantic is strongly depleted, and the penetration of the East Asian monsoon is weak and rare [21,22]. In addition, the high latitude of the study area at 52°N is probably sensitive to variation in insolation and solar activity. Therefore, even minor shifts of the global climate may cause drastic climate changes within the study area.

In the present study, we used lake sediment sequences to investigate changes in the landscape of East Siberia (Russia) during the past 850 years. Records of this period bear critical information about significant climate changes, including the transition from the Little Ice Age (LIA) to the Recent Warming (RW) and the beginning of anthropogenic global warming. We analysed pollen, diatom, chironomid, geochemical and mineralogical records from Lake Mountain, situated near Lake Baikal and Lake Khovsgol (Northern Mongolia). We interpret these records in terms of the changing summer temperature.

2. Regional setting

Lake Mountain is located in the western part of East Siberia (Russia) at the East Sayan Ridge, approximately 200 km to the south shore of Lake Baikal (figure 1). Lake Mountain (51°56′N, 100°45′E) is a small freshwater lake situated at 2098 m above sea level and is approximately 0.14 km^2. The climate in the Eastern Sayan region is continental, as reflected in the large differences of temperature (figure 1). According to monthly precipitation and

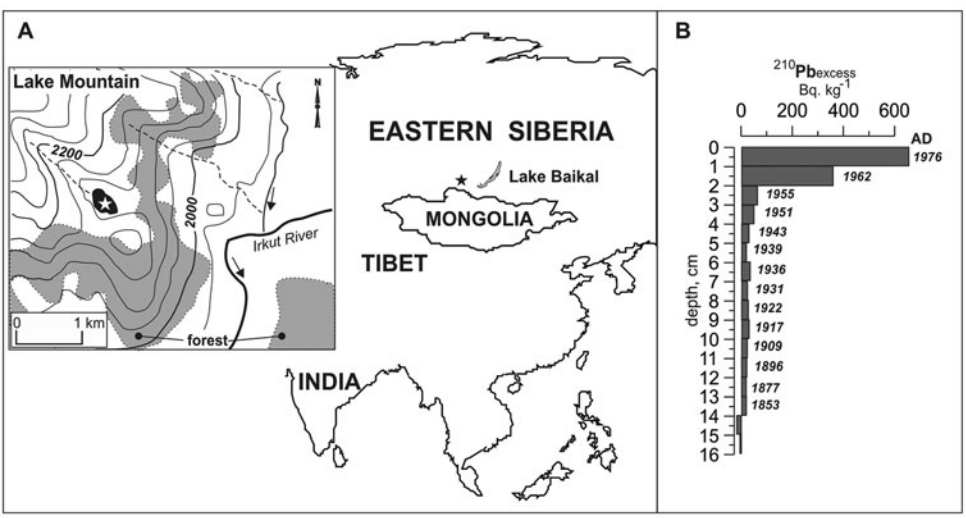

Figure 1. The locations of Lake Mountain (*asterisk*)-panel A, and the depth-age model of the cores based on radioactive isotopes ^{210}Pb-panel B.

temperature data representing the 1900–2010 interval, the climate is characterised by the mean January −28 °C and mean July 12 °C temperatures (figure 1). The annual precipitation ranges from 220 to 380 mm, with the precipitation largely (60–75%) accumulating during the summer months (NOAA data-set [23] and grid model [24]).

3. Methods

3.1. Sampling

A 42.5-cm-long sediment record (LM-01/10) was taken from the central part of Lake Mountain at 14 m water depth using the Uwitec Corer sampler in July 2010.

3.2. Lithology

Water content (WC) was determined by weighing wet sediment and the residue after drying at 60 °C, and the sampling resolution was 1 cm.

3.3. Dating

Dating of the LM-01/10 core was based on ^{210}Pb and ^{137}Cs chronology. Measurement of ^{238}U, ^{234}Th, ^{226}Ra, ^{137}Cs and ^{210}Pb content in the studied samples was carried out using a high-resolution semiconductor gamma spectrometry technique. We calculated the depth-age relationship for the uppermost 15 cm using the constant rate of supply (CRS) model [25].

Excess ^{210}Pb concentrations were calculated by ^{226}Ra (figure 2).

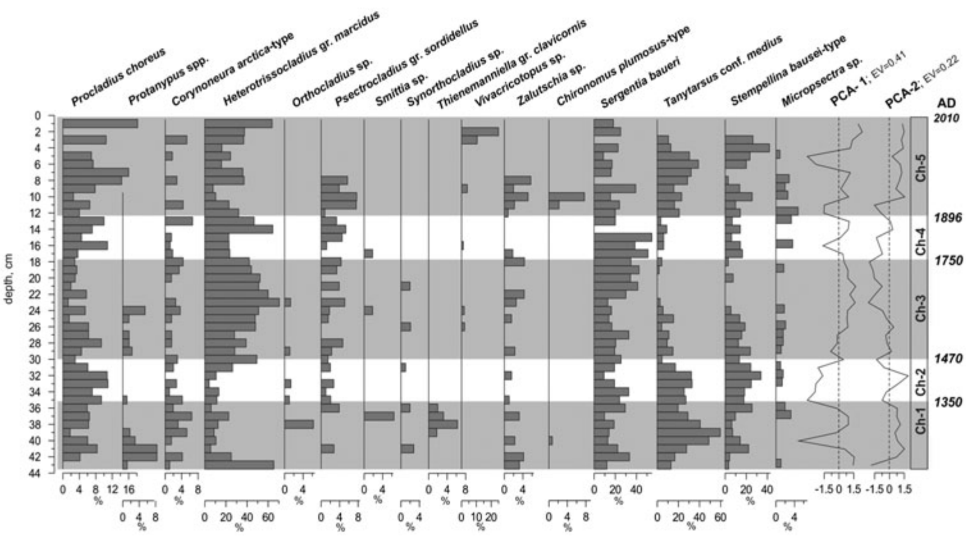

Figure 2. Biostratigraphical record of selected chironomid taxa plotted as percentages. PCA 1 and 2 are plots of component scores for the first two principal components.

3.4. Chironomid analysis

Samples of 1 cm^3 used for chironomid analysis were immersed in concentrate HF; 24 h later, the acid was washed out and then the samples were washed through a 100-µm sieve with a sampling resolution of 1 cm. The remains of chironomid head capsules were identified by following the method of Pankratova and Makarchenko [26–30]. The distribution of modern chironomid assemblages in the Baikal area was taken from Linevich [31] and Erbaeva and Safronov [32].

3.5. Statistical analyses

Statistical analyses were performed using a principal component analysis (PCA) then redistributed using the varimax rotation method. Cluster analysis was performed using Ward's method with standardised z-scores. Quantitative transfer functions of July air temperature based on chironomid analyses were developed using weighted-averaging partial-least-squares (WA-PLS) calibration techniques. Transfer functions were developed in C2 version 1.7.4 [33].

4. Results and discussion

4.1. Lithology

The LM-01/10 core was composed of fine, light brown silty clay, an average WC of 60–70 and a pH of 5.9–6.3. The top of the core (0–1.5 cm) was well oxidised. Based on these lithologic features, we assumed that the interval from 0 to 42.5 cm was formed under lake conditions.

4.2. Dating

Excess ^{210}Pb concentrations were negative below a depth of 14 cm (figure 1). According to the CRS model, the upper part (0–14 cm) of the core was formed after 1853. There were no markers of a hiatus or a change of sedimentation type below 14 cm. If the calculated sediment accumulation ration for the last seven dated points is extrapolated to the layer of 42 cm, for this purpose, the layer in 42 cm bss was formed approximately at 1160 (figure 1).

4.4. Chironomid record

A total of 18 taxa of the subfamilies: *Diamesinae*, *Tanypodinae*, *Orthocladiinae* and *Chrinominae* were identified. The most widespread taxa were *Procladius* gr. *choreus, Heterotrissocladius* gr. *marcidus*, *Sergentia baueri*, *Tanytarsus* conf. *medius* and *Stempellina bausei*-type (figure 2). Percentages of other chironomid taxa (*Protanypus* spp., *Corynoneura arctica*-type, *Orthocladius* sp., *Psectrocladius* gr. *sordidellus, Smittia* sp., *Synortocladius* sp., *Thienemanniella* gr. *clavicornis*, *Vivacriocotopus* sp., *Zalutschia* sp., *Chironomus plumosus*-type, *Paracladopelma camptolabis*-type, *Micropsectra* sp., *Shangomyia* sp.) often comprised less than 6%.

We divided the chironomid records into five zones (Ch 1–5). Zone Ch-1 (43–35 cm bss., ca. 1160–1350) was dominated by *T.* conf. *medius* (30–60% abundance). *P.* gr. *choreus,* *Protanypus* spp., and *St. baueri*-type also were abundant. Zone Ch-2 (35–30 cm bss., ca. 1350–1470) *T.* conf. *medius* and *St. baueri*-type remained abundant in this zone. *P.* gr. *choreus*, *St. bausei*-type and *T.* gr. *clavicornis* increased in relative abundance. Zone Ch-3 (30–18 cm bss, ca. 1470–1750) *H.* gr. *marcidus* sharply increased in abundance to highest values at between ca. 1610 and 1660, while *P.* gr. *choreus*, *St. bausei*-type and *T.* conf. *medius* declined. Zone Ch-4 (18–12 cm bss, ca. 1750–1896) *S. baueri*-type remained abundant, *P.* gr. *choreus* and *T.* conf. *medius* moderately increased, while *H.* gr. *marcidus* decreased. Zone Ch-5 (12–0 cm bss, 1896–2010) the abundances of *P.* gr. *choreus, H.* gr. *marcidus*, *S. baueri*, *T.* conf. *medius* and *S. bausei*-type showed frequent fluctuations.

4.5. Summer air temperature reconstruction

In present time, Siberian regional mean July air temperatures (T_{July}) were reconstructed using a modern chironomid-based temperature calibration training set from Yakutia and north-eastern Russia [18,20,34]. Unfortunately, a similar calibration training set has not yet been tested for the southern part of East Siberia.

Our temperature calibration training set was performed using WA-PLS, when the chironomid composition of each sample from within the upper part of the LM-01/10 formed after 1900 was linked with the regional T_{July} of the relevant time span. The data-set of the regional T_{July} was obtained from instrumental (weather stations Mondy and Il'chir [23]) and grid model (temperature data representing the 1900–2010 [24]).

Parameters of WA-PLS were the r^2 (based on leave one-out cross-validation) – 0.97, RMSEP – 0.13 °C and maximum bias −0.2 °C. The found range (from +12 to +14 °C) of the T_{July} was similar to that reconstructed for other Holocene records from this area [17].

We compared our records with regional climate records from Asia and Europe and to proxy global climate forcing factors (the temperature anomalies of the Northern Hemisphere and the total solar irradiance).

According to our estimates, a clear decrease in summer temperatures occurred in East Siberia after ca. 1400, when the T_{July} was similar to the modern (1900–1950) during 1160–1400 (figure 3). Temperature reconstructions for China [35] and West Siberia [36] also suggest a warm condition during ca. 1160–1400 (figure 3). In addition, the level of total solar irradiation (TSI) was also high at the span [37]. Based on these results, we assumed that the LIA in East Siberia began after 1400. This estimate agreed well with the global temperature record [38] but incompletely coincided with some regional reconstructions from Europe and North America [39,40].

The second episode of high regional summer temperatures was occurred ca. 1750–1825 (figure 3). The similar strong increase in summer temperature at the end of the seventeenth/beginning of the eighteenth century has been observed in Europe [41,42]. In addition, the North Atlantic Oscillation (NAO) index of summer months was high at the span [43]. But, this episode appeared only weakly in temperature records of China, although the level of the TSI was high (figure 3). It is very likely that the summer temperature rise at the second episode in East Siberia was mostly induced by the NAO.

According to our reconstruction, the coldest summer T_{July} occurred ca. 1570–1700 and 1830–1900. The beginning of the decrease in summer temperature after 1570 was somewhat unexpected, because the level of the TSI was relatively high and the Maunder minimum occurred later; and also European summer temperatures did not show contrasting changes ca. 1600–1700 (figure 3). But, empirical reconstructions (the model ECHO-G) of

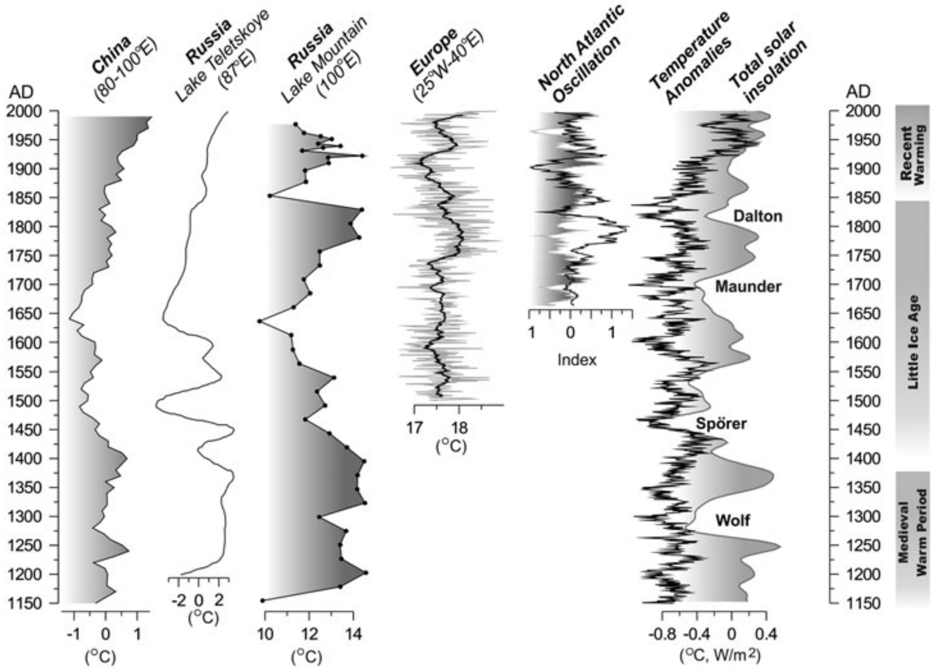

Figure 3. Relationships between regional records from Central Asia and global record from the Northern Hemisphere and total solar insolation. China temperature reconstruction [35,48]; temperature reconstruction inferred: Teletskoe Lake sediments (Altai region, Western Siberia, Russian) adapted from [36]; summer surface temperature fields for Europe [42,48]; the seasonal NAO with running average over 10 points [41,48], *black curve* – the summer NAO, *grey shaded* – the winter NAO; temperature anomalies in the Northern Hemisphere [48,49]; total solar irradiance [37,48].

the NH temperature evidenced that annual temperature dramatically decreased after ca. 1550 [44] as well as in West Siberia [36] and China [35,45]. Central Asian temperature records clearly evidenced that in the last 850 years, the regional minimum summer temperature occurred in 1650 (figure 3).

According to many reconstructions of global surface temperatures for the NH, a transition from the LIA to the RW was characterised by a sharp increase in annual temperature that occurred ca. 1850–1860 [46,47]. Our temperature reconstruction showed that temperature increase was not intense, however, in East Siberia until the 1900s. The Dalton minimum was not strong and long in comparison with other periods of low solar activity (e.g. Maunder, Spörer and Wolf minima). The decrease of the T_{July} following the Dalton minimum was significant but not so notable in China, West Siberia and Europe (figure 3). It is likely explained by a contrasting response of Lake Mountain under climate changes due to its high altitude position.

5. Conclusion

Using chironomid records in sediment core from Lake Mountain (East Siberia), we reconstructed changes of regional summer temperatures for the last 850 years. We compared our obtained records with regional climate records from Asia and Europe and to proxy global climate forcing factors (the temperature anomalies of the NH and the total solar irradiance).

Mean July air temperatures were reconstructed using a modern chironomid-based temperature calibration. According to our reconstruction, a clear decrease in summer temperatures occurred in East Siberia after ca. 1400, while the T_{July} similar to the modern (1900–1950) were during 1160–1400. We assumed that a climate condition linked with the LIA begun to form in East Siberia after 1400. The coldest T_{July} occurred in ca. 1570–1700 and 1830–1900.

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