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# A first chironomid-based summer temperature reconstruction (13–5 ka BP) around 49°N in inland Europe compared with local lake development

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ABSTRACT

Temperature reconstructions for the end of the Pleistocene and the first half of the Holocene based on biotic proxies are rare for inland Europe around 49°N. We analysed a 7 m long sequence of lake deposits in the Vihorlat Mts in eastern Slovakia (820 m a.s.l.). Chironomid head capsules were used to reconstruct mean July temperature ($T_{July}$), other proxies (diatoms, green algae, pollen, geochemistry) were used to reconstruct local environmental changes that might have affected the climate reconstruction, such as epilimnetic total phosphorus concentrations (TP), lake level changes and development of surrounding vegetation. During the Younger Dryas (YD), temperature fluctuated between 7 and 11 °C, with distinct, decadal to centennial scale variations, that agree with other palaeoclimate records in Europe such as $\delta^{18}O$ content in stalagmites or Greenland ice cores. The results indicate that the site was somewhat colder than expected from the general south-to-north YD temperature gradient within Europe, possibly because of north-facing exposition. The warmer phases of the YD were characterised by low water level or even complete desiccation of the lake (12,200–12,400 cal yr BP). At the Late-Glacial/Holocene transition $T_{July}$ steeply increased from from 11 to 15.5 °C (11,700–11,400 cal yr BP) – the highest $T_{July}$ for entire sequence. This rapid climate change was reflected by all proxies as a compositional change and increasing species diversity. The open woodlands of *Pinus*, *Betula*, *Larix* and *Picea* were replaced by broad-leaved temperate forests dominated by *Betula*, later by *Ulmus* and finally by *Corylus* (ca 9700 cal yr BP). At the same time, input of eroded coarse-grained material into the lake decreased and organic matter (LOI) and biogenic silica increased. The Early-Holocene climate was rather stable till 8700 cal yr BP, with temporary decrease in $T_{July}$ around 11,200 cal yr BP. The lake was productive with a well-developed littoral, as indicated by both diatoms and chironomids. A distinct decline of $T_{July}$ to 10 °C between 8700 and 8000 cal yr BP was associated with decreasing chironomid diversity and increasing climate moistening indicated by pollen. Tychoplanktonic and phosphorus-demanding diatoms increased which might be explained by hydrological and land-cover changes. Later, a gradual warming started after 7000 cal yr BP and representation of macrophytes, periphytic diatoms and littoral chironomids increased. Our results suggest that the Holocene thermal maximum was taking place unusually early in the Holocene at our study site, but its timing might be affected by topography and mesoclimate. We further demonstrated that temperature changes had coincided with variations in local hydrology.



## 1. Introduction

Recent climate changes have stimulated an intense research on past climatic variations and their impact on both biotic and abiotic ecosystem processes. Quaternary climate changes have been reconstructed using isotope composition in long ice-core or marine

*Abbreviations:* LOI, loss-on-ignition; LG, Late Glacial; $T_{July}$, mean July temperature; TP, epilimnetic total phosphorus; YD, Younger Dryas.

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sequences (e.g. Blockley et al., 2012; Lowe et al., 2008), or, for Europe, by climate model runs driven by changes in past climate forcing factors such as variations in the North Atlantic thermohaline circulation (e.g. Renssen et al., 2012). Climatic changes, recent or pre-historic, are, however, never uniform across different regions (e.g. Heiri et al., 2014a) and spatial variability in climate dynamics may affect large-scale edaphic processes and species distribution. Regional and local climate can substantially deviate from the global models (Mayewski et al., 2004; Feurdean et al., 2014) because of specific topography and landscape settings. Fossil remains of different organisms like pollen, macrofossils, diatoms or chironomids are often used as climate proxies in local and regional reconstructions (e.g. Davis et al., 2003; Buczkó et al., 2013; Heiri et al., 2014a; Väliranta et al., 2014). Generally, they have shown that the Holocene (since ca 11,650 cal yr BP, Walker et al., 2009) is a warm period with relatively stable climatic conditions compared to Pleistocene. At the end of the Late Glacial (LG), summer temperature in Europe increased, partially as a consequence of orbitally-forced summer insolation, which in the northern Hemisphere was the highest in the Early Holocene (Laskar et al., 2004), partially due to changes in other climate forcing and amplifying factors such as greenhouse gas concentrations, ocean current changes and melting of large continental ice sheets (e.g. Clark et al., 2001; Renssen and Isarin, 2001; Menviel et al., 2011). Nevertheless, in Europe there was some variation in climate during the Holocene, even if with lower amplitude than observed in the late Pleistocene. A review of 50 globally-distributed palaeoclimatical records has shown that Holocene climate variations have been larger and more frequent than is commonly recognized (Mayewski et al., 2004). Several periods of rapid climate change (RCC) were revealed, from which two took place in the Early and Middle Holocene (9000–8000 cal yr BP, 6000–5000 cal yr BP). Most of the climate change events in these globally distributed records were characterised by polar cooling, tropical aridity, and major atmospheric circulation changes. Several abrupt short-term oscillations during the Holocene were also recorded by both, oxygen isotopes in ice-sheet cores (Blockley et al., 2012) and biotic proxies (e.g. Magny et al., 2003; Rosén et al., 2001; Davis et al., 2003; Tóth et al., 2012, 2015). The so called 8.2 ka event was the most pronounced temperature change within the Early and Middle Holocene, which was reflected by a decrease in *Corylus* pollen in the fossil record of North Europe (Seppä et al., 2005; Rasmussen et al., 2008) and less frequently also in Central Europe (Tinner and Lotter, 2001; Dudová et al., 2014). Contrary, chironomid-based reconstructions captured this event rarely (Płóciennik et al., 2011; but see Seppä et al., 2007 and Heiri et al., 2003). It is hence likely that this short-term North Atlantic cooling triggered by Laurentide ice-sheet collapse (Wiersma and Renssen, 2006) influenced regional and local summer temperatures and some types of ecosystems only locally and moreover, it appears that some biotic proxies do not consistently reflect this short-term climate oscillation.

A widely used biotic proxy for temperature reconstruction are fossil chironomids in lake sediment records. Chironomids have a rather short life-cycle and relatively high dissemination ability and therefore show a rapid response to changing environment (Brooks et al., 2007). There are numerous stenotopic species within the chironomids which can provide reliable reconstructions of the past environment. Identification is usually possible at the level of genera or species morphotypes, often with known ecological preferences. In the last 15 years, several calibration data-sets were developed for July air temperature ($T_{July}$) reconstruction in Eurasia (e.g. Brooks and Birks, 2001; Nazarova et al., 2011; Holmes et al., 2011; Heiri et al., 2011, 2014a). In East-Central Europe, there is a gap in knowledge on chironomid-inferred climate from the LG and Holocene periods. Further, even if chironomids are very good indicators of changes in July temperatures, some autogenic processes not triggered by climate can influence chironomid species turnover and thus distort the climate reconstruction. Typically, there is a general positive correlation between temperature and productivity, but lake productivity can increase independently of temperature because of changing nutrient concentrations and it may be difficult to separate these two influences (Velle et al., 2010). Interpretation of quantitative reconstructions should be therefore done with caution and other biotic or abiotic proxies can help to separate potential independent effects of productivity, oxygen and water level changes from climate influence (e.g. Heiri and Lotter, 2005). Geochemical analyses may serve as a proxy for catchment erosion and diatoms and green algae as reliable proxies of trophic conditions (Battarbee et al., 2001). Regional vegetation composition, reconstructed by means of fossil pollen, can characterise lake catchments in terms of potential intensity of erosion, hydrology or biogeochemistry and in addition may indicate coarse-scale climatic changes as well (Davis et al., 2003; Mauri et al., 2015). In this study we covered all these proxies to provide the first chironomid-based temperature reconstruction for inland Europe around 49°N, covering the end of the Pleistocene and the first half of the Holocene, and to compare it with reconstructed local development of the sedimentary environment.

The study site in the Vihorlat Mts (49°N) is situated between a more southerly located site with a chironomid inferred temperature reconstruction in the Eastern Carpathians (Retezat Mts., 45°N; Tóth et al., 2012, 2015) and a more northerly located site in the Polish lowland (52°N; Płóciennik et al., 2011). According to a review by Heiri et al. (2014a), there is a rather high number of sites where July air temperatures are reconstructed based on chironomids in the Alps, British islands and NW Europe, but data are almost missing for the latitude 47–52°N in East-Central Europe. Tátosová et al. (2006) and Hošek et al. (2014) provided some data on fossil chironomid assemblages, but without quantitative $T_{July}$ reconstruction. Thus, this study fills a gap in our knowledge about past climate in East-Central Europe. Moreover, the position of the study site is transitional between oceanic and continental climate influences and thus shifts in atmospheric circulation and pressure changes, e.g. associated with variations in the predominance of North Atlantic oscillation states, may substantially have influence local climate. Combining different proxies, we aim to separate the influence of past climate changes in the study region from independent local processes like autogenic changes in productivity and lake depth. The main aims of our study were: 1) to reconstruct mean July temperatures ($T_{July}$) based on chironomid assemblages; 2) to reconstruct local environmental conditions and processes like lake productivity and water level changes using diatoms and green algae to control for undesired local effects in climate reconstruction and 3) to reconstruct changes in the lake surrounding using pollen and geochemical methods to detect influence of changing vegetation cover and extent of erosion.

## 2. Material and methods

### 2.1. Study site and sediment sampling

The study site named Hypkaňa is located in the westernmost part of the Eastern Carpathians, in the Vihorlat Mts in eastern Slovakia (East-Central Europe; 820 m a.s.l.; 48°54.787′ N, 22°09.814′ E; see Fig. 1). The geological bedrock is formed by neogenic andezite. The recent climate of the region is characterised by mean annual temperatures of 4–6 °C (mean in January −5–−6 °C, mean in July 14–16 °C) and mean annual precipitation of 1000–1200 mm (http://geo.enviroportal.sk/atlassr). The daily mean temperature (long time series of air temperature, 1961–1990)