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Northern Russian chironomid-based modern summer temperature data set and inference models

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ABSTRACT

West and East Siberian data sets and 55 new sites were merged based on the high taxonomic similarity, and the strong relationship between mean July air temperature and the distribution of chironomid taxa in both data sets compared with other environmental parameters. Multivariate statistical analysis of chironomid and environmental data from the combined data set consisting of 268 lakes, located in northern Russia, suggests that mean July air temperature explains the greatest amount of variance in chironomid distribution compared with other measured variables (latitude, longitude, altitude, water depth, lake surface area, pH, conductivity, mean January air temperature, mean July air temperature, and continentality). We established two robust inference models to reconstruct mean summer air temperatures from subfossil chironomids based on ecological and geographical approaches. The North Russian 2-component WA-PLS model ($RMSEP_{Jack} = 1.35$ °C, $r^2_{Jack} = 0.87$) can be recommended for application in palaeoclimatic studies in northern Russia. Based on distinctive chironomid fauna and climatic regimes of Kamchatka the Far East 2-component WAPLS model ($RMSEP_{Jack} = 1.3$ °C, $r^2_{Jack} = 0.81$) has potentially better applicability in Kamchatka.

1. Introduction

Biotic proxies from lake sediments provide a powerful means of quantifying past climate change in terrestrial contexts. In addition, analysis of biotic remains from lake sediments provides an indication of the rate and magnitude of the response of animals and plants to past climate change and how they may respond in the future. Climatic inferences from palaeorecords are based on modern or near-modern analogues (training sets) from which the empirical reconstruction models (i.e. the transfer function) are established. By using inference models, which link the present distribution and abundance of chironomids to contemporary climate, past climates can be quantified from fossil chironomid assemblages (Kienast et al., 2011; Self et al., 2011). Chironomids (Insecta: Diptera) are well-proven to be among the most reliable quantitative proxies of mean July air temperature (Brooks, 2006). They are a diverse and nearly ubiquitous family of holometabolous two-winged flies and play vital roles in freshwater ecosystems as primary consumers (Coffman and Ferrington, 1996). The abundance and distribution of most chironomid taxa are temperature-dependent (Walker et al., 1991), reflecting the effect of air and water temperatures on all stages of their life cycles (Oliver, 1971) and they respond rapidly to climate change by virtue of the winged adult stage. The larval head capsules preserve well in lake sediment deposits and the subfossils are readily identifiable in most cases at least to species morphotype (Brooks et al., 2007).

Chironomid based inference models for reconstructing mean July air temperature have been developed successfully for Western Europe (Olander et al., 1999; Brooks and Birks, 2001), North America (Walker et al., 1997; Barley et al., 2006), Africa (Eggermont et al., 2007), New Zealand (Woodward and Shulmeister, 2006) and Tasmania (Rees et al., 2008).

Recently, data on the distribution and abundance of chironomids in lakes along environmental gradients in eastern and western Siberia were used to develop modern chironomid-based calibration data sets (training sets) and quantitative transfer functions for reconstructing mean July air temperature (T July), water depth (WD) and continentality (CI) in eastern (ES) and western Siberia (WS) (Nazarova et al., 2011; Self et al., 2011). Numerical analysis showed that T July is the most significant variable explaining contemporary chironomid distribution and abundance in both data sets. These data sets and transfer functions

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have provided a new tool for quantitative assessment of the past environment in north-eastern Eurasia and were applied in several studies of Holocene palaeoclimate in Siberia (Jones et al., 2011; Kienast et al., 2011; Self et al., 2011; Mackay et al., 2012; Nazarova, 2012; Nazarova et al., 2013a, 2013b; Engels et al., 2014). Climate inference models have limited application outside the regions in which they have been developed, so the new Russian models are an improvement over the Swedish and Norwegian inference models, which have been used previously for chironomid-inferred temperature reconstructions in northern Russia. Solovieva et al. (2005) reconstructed T July in north-east European Russia using a chironomid July air temperature-inference model based on a modern training set of 153 Norwegian lakes (Brooks and Birks, 2001 and unpublished data), supplemented with data from lakes within the study area. The chironomid temperature-inference model developed for northern Sweden (Larocque et al., 2001) has also been used for temperature reconstructions in the Lena River Delta (Andreev et al., 2004), the Kola Peninsula (Ilyashuk et al., 2005) and the Polar Urals (Solovieva et al., 2005).

In this paper we present the results of the work we have done to reanalyse and standardise the taxonomy between our already published chironomid calibration sets from East Siberia (Nazarova et al., 2011) and West Siberia (Self et al., 2011) with the addition of new regions to the data set: Bunge Land (Laptev Sea), 31 lakes from Kolyma River region, 10 lakes from Indigirka River region and 13 lakes from Kamchatka (Fig. 1). Following taxonomic standardisation we have merged the data sets. This has the advantage of extending the geographical and environmental gradients and increasing the representation of taxa in the calibration set. This can be expected to further improve the performance and applicability of the chironomid-temperature inference models by providing better estimates of the environmental optimum of taxa and increasing the probability of analogues between present and past assemblages.

The main objectives of our investigation are to compare the faunal composition of the WS and ES data sets, to examine the environmental factors which influence chironomid distribution and abundance in the combined data set, to identify which climate variable has the most potential for development of a chironomid-based inference model and to develop chironomid inference models for quantifying past regional climate and environmental changes in northern and north-eastern Russia.

2. Study regions

Study sites included in this investigation span wide latitudinal and longitudinal ranges in northern Russia: from Komi Republic in the West (50.50 E, part of the WS) to Kamchatka in the East (163.15 E, new data) and from Novosibirsk Islands in the Laptev Sea in the North (75.40 N, part of the ES) to southern Kamchatka (53.03 N, new data) in the South (Fig. 1).

The most western part of the data set includes the Komi Republic (region Komi, part of WS, Fig. 1) and Bolshezemelskaya tundra (region Pechora, part of WS, Fig. 1), a large lowland plain situated to the west of the Ural Mountains within the zone of discontinuous–continuous permafrost (Fig. 1). Climate is severe with an eight-month winter period when mean monthly temperatures are below 0 °C. Mean July air temperatures are about 12.8 °C (New et al., 2002). Annual precipitation varies between 370 and 395 mm (Mukhin et al., 1964; Solovieva et al., 2005, 2008).

The next region, east, included in the data set is the Putorana Plateau, a mountainous area at the north-western edge of the Central Siberian Plateau and to the south of the Taymyr Peninsula (region Putoran, part of WS, Fig. 1). The climate is continental with short warm summers and long, cold winters. Most of the territory is covered with conifer forests. Investigated lakes here crossed the latitudinal tree line from

Fig. 1. Map of Russia showing the location of the sampled lakes.