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Early Holocene vegetation and climate dynamics in the central part of the East European Plain (Russia)

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ABSTRACT

This paper presents vegetation and climate reconstructions for the forest zone in the central part of the East European Plain, Russia, for the time period 10,000–7900 cal. BP. Reconstructions were based on pollen records from three key regions located in taiga, mixed coniferous-broadleaved and broadleaved forest zones. Results showed that the considered period was characterized by relatively low air temperatures and high precipitation compared with modern conditions. Analysis of the long-term pattern of the mean annual temperature for all three regions reveal two synchronous significant cooling periods observed 9300–9100 cal. BP and 8500–8100 cal. BP as well as rapid growth of the air temperature in 8100–7800 cal. BP, when the annual temperatures increased by 3 °C during about 300 years. The cooling phase of 8500–8100 cal. BP could correspond to the distinct "8.2 ka event" widely recorded across Europe. Periods of climate warming are coincided with periods of precipitation rise whereas the cool phases are characterized by its decrease. The ratio of actual evapotranspiration and precipitation amount selected as indicator of surface moistening conditions decreased significantly in period of cooling phases (down to 0.27) and can be used as a clear indicator of ground surface overwatering and strengthening of mire formation processes.

1. Introduction

Despite a large number of Holocene climatic reconstructions that are available from a wide range of archives and proxies in Europe (Davis et al., 2003; Barber et al., 2004; Mayewski et al., 2004; Allen et al., 2007; Wohlfarth et al., 2007; Kylander et al., 2013), the climate of the Boreal and early Atlantic phases of the Holocene (approximately 10,000–7800 cal. BP – according to the North European scheme proposed by Mangerud et al. (1974) and modified for the East European Plain by Khotinski (1977)) for the forest zone of European Russia are still very poorly investigated, especially with regard to climate history. Existing regional paleoenvironmental studies focused primarily on vegetation and climate reconstructions for the Late Glacial or the entire Holocene, but the Boreal period has only been described as a phase of relatively warm and dry climate with broadly distributed birch forests. Quantitative climatic characteristics for this period have been presented in Khotinski and Klimanov (1997), Velichko et al. (2001), and Novenko et al. (2009a). Climatic reconstruction from these studies agree relatively well with reconstructions for Northern and Central Europe, which together show a gradual increase in air temperature during the period (Seppä and Birks, 2001; Davis et al., 2003; Barber et al., 2004; Seppä and Poska, 2004; Allen et al., 2007), as well as strong climate fluctuations, such as the distinct "8.2 ka event" widely recorded in the North Atlantic and northern Europe at 8500–8000 cal BP (Alley et al., 1997; Baldini et al., 2002; Alley and Ágústsdóttir, 2005; Thomas et al., 2007).

Information about hydroclimatic conditions in the forest zone of European Russia for this period is also relatively sparse. According to Khotinski (1977), the climate was relatively dry across the East European Plain during the Boreal phase of the Holocene. Other studies, however, have indicated that the climate was more humid during this period. In particular, multiple studies in the boreal zone of European Russia and Siberia (Neustadt, 1984; Kremenetski et al., 2003; MacDonald et al., 2006), based radiocarbon dating of peat strata, showed that the Boreal phase between 10,000 and 8000 cal. BP was a period mire formation and its intensive development. The possible links among mire development, peat accumulation rates and past variations in moisture conditions are increasingly attracting the attention of the scientific community, who have employed various paleoenvironmental methods (e.g. analyses of pollen, plant

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macrofossil, testate amoebae, peat humification and organic bulk density) to describe their interactions (Borgmark, 2005; Barber and Langdon, 2007; Väliranta et al., 2012; Kylander et al., 2013). Surface moisture conditions are mainly determined by the different ratios between precipitation (P), potential evaporation (PET) and actual evapotranspiration (ET). PET is defined as evaporation rate from wet or open water surfaces and quantified usually by the different modifications of the Penman (Penman, 1948), Priestley-Taylor (Priestley and Taylor, 1972) and Thornthwaite (Thornthwaite, 1948; Thornthwaite and Mather, 1957) equations. ET quantifies the actual amount of water that is directly evaporated wet surfaces and transpired by plants. Existing methods for estimating ET from proxy data are usually based on relatively simple approaches that consider ET as a function of PET (e.g. derived from climatic variables reconstructed from pollen and plant macrofossil data) and parameters characterizing the surface wetness (e.g. Prentice et al., 1996; Ward et al., 2007). The clear advantage of the method is the small number of required input parameters. Its disadvantage is ignoring the natural variability of biophysical properties of different vegetation types controlling the plant transpiration (e.g. Olchev and Novenko, 2011, 2012) that can significantly reduce an accuracy of ET estimations.

The main aim of the present study was to contribute further to our understanding of early Holocene climate dynamics (Boreal – early Atlantic phases, 10,000 -7800 cal. BP) in the forest zone of the East European Plain of Russia by reconstructing hydroclimatic conditions, including PET and ET. Three previously published pollen records from Kostroma (south taiga), Tver (mixed coniferous-broadleaved forests) and Tula (broadleaved forests) regions were selected for the study. By including sites from different forest zones, we were able to explore variation in vegetation, thermal and moisture conditions in European Russia during the Boreal and early Atlantic phases of the Holocene.

2. Study area

The three study sites were situated in key geographical zones and are characterized by differences in vegetation, climate, geomorphological structure and soils (Fig. 1). These differences allowed us to reconstruct and analyze past climate dynamics under contrasting natural conditions.

Our mixed conifer-broadleaf site was located in the Central Forest State Natural Biosphere Reserve (CFSNBR), which is situated in the Tver region in the southern part of the Valday upland, about 360 km northwest from Moscow. This territory is located at the margin of the Weichselian ice sheet and is characterised by slightly hilly relief with elevations of 220–250 m a.s.l. The highest moraine ridge in the south part of the CFSNBR (up to 280 m a.s.l.) is also the main watershed divide of the East European Plain between the Caspian and the Baltic Sea basins.

The area has a moderate continental climate with relatively mild winters and warm summers. Meteorological observations carried out in the CFSNBR show that the current mean annual temperature is around −3.8 °C, with temperatures ranging from −10.0 °C in January to 17.0 °C in July. Annual precipitation does not exceed 700 mm (Desherevskaya et al., 2010).

Vegetation in the CFSNBR is composed mainly of primary forests and characterised by minimal human disturbance. *Picea abies* (Norway spruce) is the dominant species in forest stands. Broadleaved tree species are relatively sparse, with *Betula pubescens*, *Betula verrucosa* (birch) and *Populus tremula* (aspen) occupy mainly the windthrow, old clear-cut, abandoned and forest fire sites. River valleys are occupied by *Alnus glutinosa* (black alder) communities.

The pollen records used for vegetation and climate reconstructions were derived from an 8 m deep borehole located in the central part of a relatively large (about 617 ha) mire, Staroselsky Moch (56°17′N, 32°02′ E). The peat bog occupies the series of depressions in the upper part of the watershed area of the Mezha (Daugava river basin) and Tudovka (Upper Volga basin). The lowermost radiocarbon age of the peat deposits is 9730 ± 100 cal BP. Pollen and plant macrofossil analysis and radiocarbon dating of this borehole have been presented in detail in Novenko et al. (2009b, 2014a).

Our southern taiga site, Galich Lake (58°24′ N, 42°17′ E), is located about 100 km northeast of Kostroma city, in the Upper Volga basin (Fig. 1). The lake has oval form, and is elongated from the west to the east. The area of the lake is 75.4 km^2. Its length is about 17 km, the maximum width 6.4 km, and the maximum depth 5 m. The lake depression is situated at the southern margin of the Galich-Chukhloma Upland, a chain of rolling hills branching from the south-western end of the large upland, Severnye Uvaly. The Middle Pleistocene glacial accumulative relief of the territory was transformed considerably by subsequent fluvial processes. The climate is moderate continental with mean annual temperature about 3.5 °C and the January and July temperatures of −12.0 °C and 18.0 °C, respectively. Total annual precipitation amounts to 570 mm (http://www.meteo.ru). The region belongs to the southern taiga sub-zone with forests composed mainly of spruce (*P. abies*) with admixture of birch (*Betula alba*), aspen (*P. tremula*), and alder (*Alnus incana*).

The Galich-1 borehole was located in a wetland on the eastern bank of the lake (Velichko et al., 2001). The organic-rich deposits include 2 main units: the lower layer is brown-grey clay (thickness 2.6 m) and the upper one is lake gyttija (thickness 9.3 m). The lowermost radiocarbon data is 9387 ± 50 cal. BP. Pollen, diatom and geochemical data for this borehole were published by Velichko et al. (2001).

The third area that was selected for the study is located in the Upper Oka River basin (Tula region) in the north-west of the Central Russian Upland (Fig. 1). Modern relief of the territory is a gentle undulating plain with a predominance of absolute elevation of 210–240 m on watersheds, dissected by well developed gullies and ravines. Thickness of quaternary deposits varies from a few dozens of meters at watersheds to more than 60 m in deepest parts of the Oka River valley. In the areas adjacent to the valley of Oka, the moraine deposits of the Middle Pleistocene glaciations are covered with a thick sequence of fluvioglacial sediments.

The region is characterized by a temperate continental climate: mean annual air temperature is +5.5 °C, the mean January and July temperatures are −9.7 °C and +19 °C, respectively. Precipitation is about 600 mm per year (http://www.meteo.ru). The forests are composed of spruce (*P. abies*), lime (*Tilia cordata*), oak (*Quercus robur*) and maple (*Acer platanoides*), with pine (*Pinus sylvestris*) often occurring on sandy soils.

Vegetation and climate reconstructions were performed using pollen, plant macrofossils and radiocarbon data from the Klukva mire (53°50′ N, 36°15′ E), which is a small hummock-ridge bog (~1 ha) formed in a karst-suffosion depression (Volkova, 2011). The organic deposits (250 cm of peat and 30 cm of gyttija) are underlain by fluvioglacial sands. According to radiocarbon data, the accumulation of organic sediments started in the depression at 9370 ± 115 cal. BP. The results of multiproxy studies of the Klukva mire were presented in detail in Novenko et al. (2015).

3. Methods

Our reconstructions of vegetation and climatic changes were based on previously published pollen records from the Staroselsky moch, Klukva mires, and Galich Lake (Velichko et al., 2001; Novenko et al., 2009b, 2014a,b). The core chronologies were determined by radiocarbon dating, which was performed in the Radiocarbon Laboratory of the Institute of Geography of the Russian