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## DYNAMICS OF ECOSYSTEMS AND THEIR COMPONENTS

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# DYNAMICS OF LANDSCAPES AND CLIMATE IN CENTRAL AND EASTERN EUROPE IN THE HOLOCENE: PALEOGRAPHIC ASPECTS FOR PROGNOSIS OF POSSIBLE ENVIRONMENTAL CHANGES[1]

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The paper presents a review of modern studies of the Holocene landscape and climatic changes. A large amount of paleobotanical data and paleoclimatic reconstructions for the forest zone of Central and Eastern Europe in a frame of latitudinal transect between N52° and N58° were summarized, and compared with the published materials of paleoecological and paleographical researches for the same regions. The author analyzed the expected climatic changes according to the scenarios of representative paths of greenhouse gases concentration, which were compiled by the Intergovernmental Panel on Climate Change. The obtained data allowed us to determine 3 main stages of the Holocene paleoenvironmental changes. 1) Fast warming in the early Holocene (11.7-8.0 ka BP), which included series of climate oscillations. During this period the broadleaf forests replaced the birch and pine-birch ones that were spread in the periglacial formations in the early Holocene. Expansion of broadleaf species in Eastern Europe occured 2 thousand years later than in Central Europe. 2) The Holocene Thermal Maximum (8.0-5.7 ka BP) without any abrupt and short-term climatic changes. During this period a continuous zone of broadleaf forests occupied Central and Eastern Europe. 3) Progressive cooling of the second half of the Holocene (5.7 ka BP − present) with quasiharmonic temperature and precipitation fluctuations. Regional differentiation of landscape cover became more prominent. Beech and hornbeam started to expanse into the eastern regions, while spruce spread through the western ones. The Holocene climatic reconstruction throughout the latitudinal transect in Central and Eastern Europe could be used as the different scenarios of possible climatic changes in the current century, the author can expect that temperatures growth, especially during summer, will eventually lead to climate aridization as a result of changes in precipitations/evaporation ratio, and will probably become there as of of increasing wildfires and weather extremes due to the uneven precipitation.

*Keywords:* Holocene, paleoclimatic reconstructions, ecosystems dynamic, paleoclimatic data, paleogeography, Central Europe, European Russia.
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For a long time the assessment of reaction of landscape components to the global climatic changes has been one of the most important and fundamental scientific issues in need of comprehensive study. Considering that current tendencies of climate change are primarily shown in the fast air temperature growth (IPCC, 2013), a retrospective analysis of landscape and climate conditions of Central and Eastern Europe during the Holocene can be a very useful and efficient for the adequate understanding of modern processes of environmental transformation under the influence of global warming, as well as for determination of its main evolutional trends (Velichko, 2012; Bradley, 2008). It is especially interesting to analyze the abrupt and short-term climate

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fluctuations when instability of climate system was more prominent.

First generalization of palynological data on the postglacial stage of nature evolution in Europe, north to the Alps was performed by F. Firbas (1949), M.I. Neyshtadt (1957) and V.P. Grichuk (1969, 1982). A significant input to the studies of flora and vegetation in the Late Glacial and Holocene periods was made by N.A. Khotinski (1977). The articles on climatic conditions of the Holocene on the global and macro-regional scale were written by A.A. Velichko et al. (a series of atlases-monographs "Dynamics of Landscape Complexes ..." (2002), "Paleoclimate and Paleolandscapes ..." (2009), "Climates and Landscapes of North Eurasia ..." (2010), by O.N. Solomina (2010), O.K. Borisova (2014) and some foreign researchers (Davis et al., 2003; Mayewski et al., 2004; Wanner et al., 2008; Mann et al., 2009; Mauri et al., 2015; Christiansen, Ljungqvist, 2017; PAGES 2k Consortium, 2013, 2017). A vast amount of works, the most significant of which the author will address below, was written on the subject of vegetation and climate reconstruction in the Holocene at the regional scale, where reconstruction was based on palynological data of the soil profiles of alluvial, lake and bog sediments in Central and West Europe.

In this article the author generalizes paleographic data for the Holocene of Central and West Europe, for the territory in the belt of latitudinal transect in forest area, between N52° and N58°. The diversity of physiographical conditions and provincial differences of the modern vegetation along the studied latitudinal profile allow us to analyze the geographical patterns and regional features of the way that vegetation of Central and West Europe reacts to climatic changes nowadays, as well as in the last eras. The Holocene landscapes and climate dynamics revealed from paleobotanical data and paleoclimatic reconstructions obtained by different methods, were compared to the materials of testate ameobae, geomorphological, isotope-geochemical and other proxy that were published for the same territory.

The age of the lower Holocene boundary was 11.7 ka BP, determined by the changes of isotope-oxygen ice composition in the NGRIP borehole in Greenland (Walker et al., 2019; Head, 2019). To study vegetation and climate dynamics of the Holocene, the Russian researchers usually use the Blytt-Sernander periodization scheme, which was originally created for North Europe and later modified by N.A. Khotinski (1977) for European part of Russia. The foreign regional modifications of the scheme were widely used until the 1990s and have almost fallen out of use today, so now researchers usually use the terms of absolute age to reconstruct a sequence of Holocene events. According to the Blytt-Sernander classification, the Holocene consists of 5 climate periods: Preboreal (11.7-10.5 ka BP), Boreal (10.5-8.8 ka BP), Atlantic (8.8-5.3 ka BP), Subboreal (5.3-2.6 ka BP) and Subatlantic (2.6 ka BP – present). On the basis of the studied ice cores and speleothems, the International Commission on Stratigraphy divides the Holocene into 3 periods: Greenlandian − 11700-8236 ka BP to 2000 CE, Northgrippian (mid) − 8236-4250 ka BP to 2000 CE, and Meghalayan (late) − 4250 ka BP to present (Head, 2019; Walker et al., 2019). However, the boundaries of sub-eras, especially between the Mid- and Late Holocene, were a subject of serious discussions between the scientists. In this article to analyze a sequence of the Holocene events, the author mostly uses the data of absolute date determination in comparison to the accepted periodization methods, which are considered to be chronological sub-divisions rather than climatic and stratigraphic.

## 11.7-8.0 ka BP (Early Holocene, Preboreal, Boreal and Early Atlantic Periods)

There are not many landscape-climate reconstructions for the Preboreal period of the Holocene. This period is mostly considered to be a unified span of birch and pine-birch forests development. Despite the very close composition of pollen spectrums, the vegetation along the studied latitudinal transect shows the signs of sectorial differentiation. In the Early Holocene the forest communities of its western area included elm, while in the later phase it also included oak, alder and hazel (Fig. 1; Litt et al., 2001; de Klerk, 2008). The Latvian profiles showed the particles of hazel and elm pollen in the spectrum from 11.0 ka BP, while alder and oak became a constant component of spore-pollen spectrums from 10.1 ka BP (Heikkilä et al., 2009). Meanwhile, in the western areas vegetation composition kept the fractions of periglacial flora (Khotinski, 1977). Single pollen grains of deciduous species appeared in the spectrums of the East European Plain profiles only after 9.7 ka BP (Fig. 2).

Glaciological, palynological and isotope-geochemical studies of the profiles on the continental and marine sediments in North Europe, which were carried out with a high temporal resolution (Bjorck et al., 1996), and changes of isotope-oxygen composition of the Greenland ice cores (Thomas et al., 2007), show that the Preboreal period had some phases of temperature drop (Fig. 3). The first drop was named a “Preboreal oscillation” and reconstructed for the period of 11.3-11.15 ka BP. The second one, a so-called “10.2 ka BP event”, happened right between the Preboreal and Boreal periods. According to the changes of $K^+$ composition in the GISP2 ice core in Greenland (Mayewski et al., 2004), acting as an indicator of the Siberian High intensity, and $Na^+$, reflecting the depth of the Icelandic Low development, the westerlies weakened during this period, while the Siberian High increased (Fig. 3).

Short-term landscape-climatic changes during the Preboreal period were registered after detailed studies of some profiles on lake sediments in Netherlands (Bos et al., 2007) and Switzerland (Lotter et al., 1992). Paleo-environmental changes in the northwest of the East European Plain connected by Preboreal oscillation were found in the profiles of Medvedevskoye and Pastorskoye Lakes in Karelia (Subbeto et al., 2003). In the eastern part of the studied area on the Polovetsko-Kupanskoye bog profile, the Preboreal consists of 2 phases: temperature rise or a “Polovtsian warming” on its early stage, and temperature drop in its second half, also called a “Pereslavsky cooling” according to N.A. Khotinski (1977).

Boreal sediments of the Holocene were found in numerous soil profiles in Central and Eastern Europe. The palynological data showed that at 10.5-8.8 ka BP the birch-pine and oak-pine forests with elm and hazel undergrowth were widespread in the territory of modern Germany, Poland and the Baltic states (Fig. 1; Jahns, 2000, 2007; Bos, Urz, 2003; Heikillä, Seppä, 2004; Seppä, Poska, 2004; Lamentowicz et al., 2008; Gałka et al., 2013). Researches of T. Giesecke et al. (2011) was based on large factual materials and showed that culmination of hazel pollen fraction in the Early Holocene was almost same both for Western and Central Europe at 10.5-8.0 ka BP. In the east the increase of deciduous species pollen was slightly delayed. For example, in the profiles of Mezhuzhol and Staroye Lakes in Belarus, the sum of pollen of broadleaf species at 10.5-10.0 ka BP did not exceed 5%, and grew up to 20% at 9.5 ka BP (Zernitskaya, Novenko, 2016; Zernitskaya et al., 2019).

According to the results obtained after some profiles study in the central regions of the East European Plain, its vast territories were covered with sparse pine-birch forests (Khotinski, 1977; Velichko et al., 2001; Khotinski, Kilmanov, 1997; Krementsky et al., 2000; Wohlfarth et al., 2007). In the south, on the Central Russian Upland, the pine-birch forests with some deciduous species were widespread (Fig. 2; Kilmanov, Serebryanaya, 1986; Novenko et al., 2015).

Climate reconstructions of Central Europe showed that during the Boreal the average air temperature in January did not exceed -2°C, and the average June temperature was never lower than 15°C (Zagwijn, 1994). According to those reconstructions that were based on the ratio of beetle species, the summer temperatures of Northern Europe were about 17-19°C, and even higher in Central Europe (Coope, 1998).

Reconstructions based on the palynological data taken from Mezhuzhol Lake profile in Northern Belarus (Zernitskaya, Novenko, 2016) showed that the average annual, winter and summer air temperatures were 4°, -8° and 16°C respectively at 10.5-9.5 ka BP, which was 2°C lower than nowadays; at 9.5-8.5 ka BP the winter and annual temperatures grew significantly and were about -6.5° and 6.0°C, while the summer temperatures were close to the current ones, about 18°C.

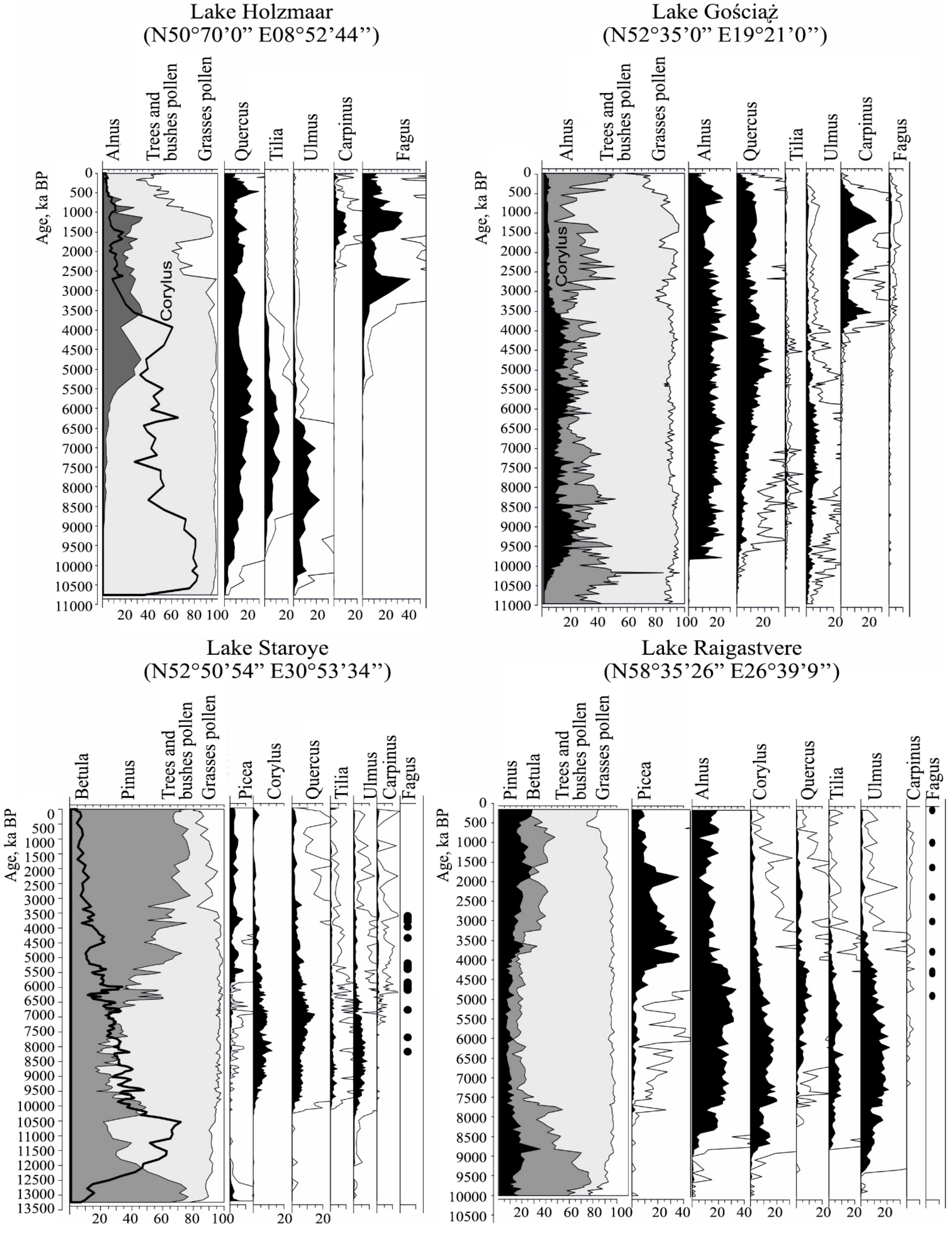

**Fig. 1.** Changes in pollen content of the main forest-forming tree species in the diagrams for the lake sediments from the Central and Eastern Europe profiles. The short diagrams were made on the basis of the “European Pollen Database” (2007).

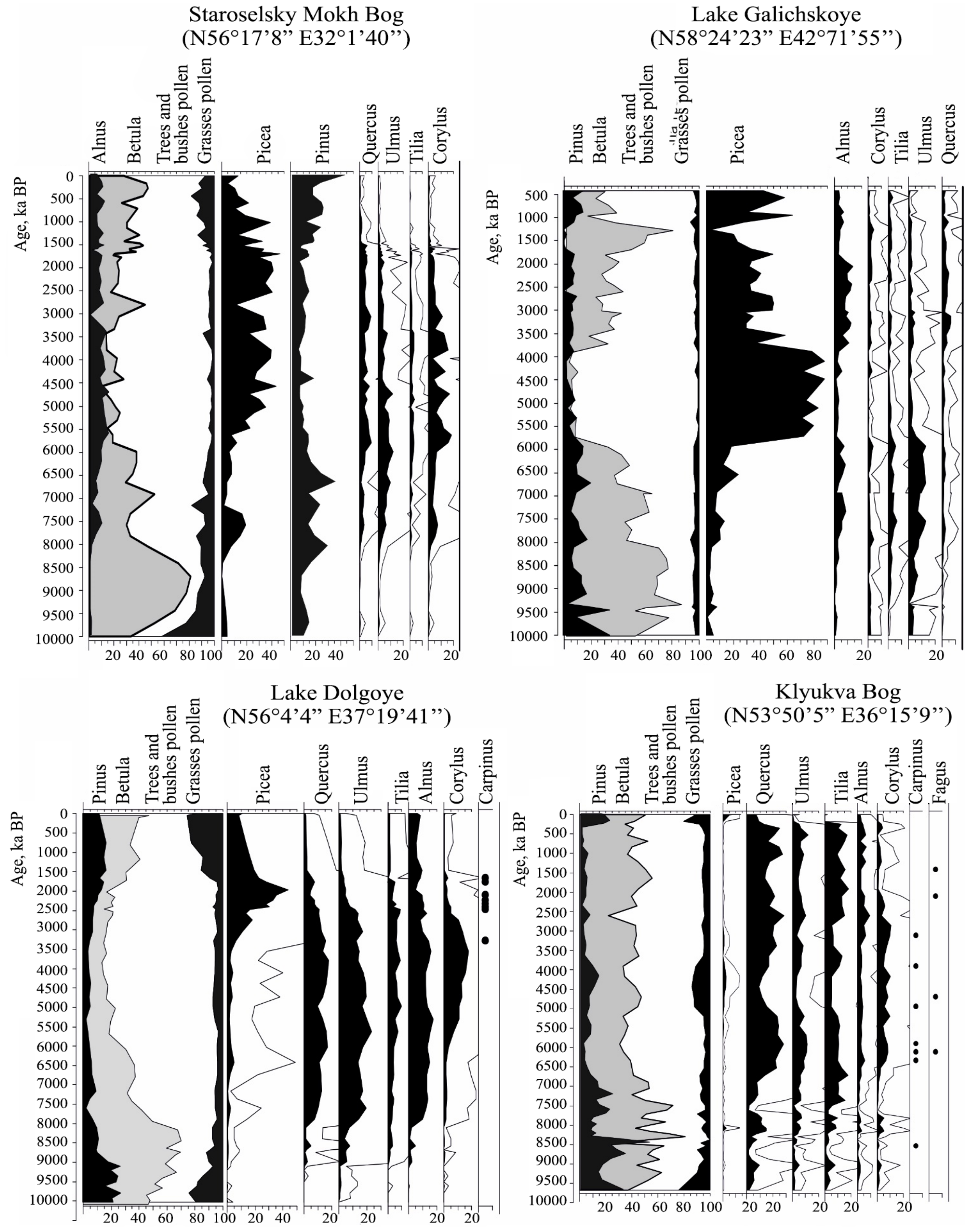

**Fig. 2.** Changes in pollen content of the main forest-forming tree species in the diagrams for the East European Plain profiles, recorded on the basis of O.K. Borisova, K.V. Kremenetsky and E.M. Zelikson researches on Dolgoye Lake and with the help of “European Pollen Database” (2007), other profiles were made on the basis of the author’s records.

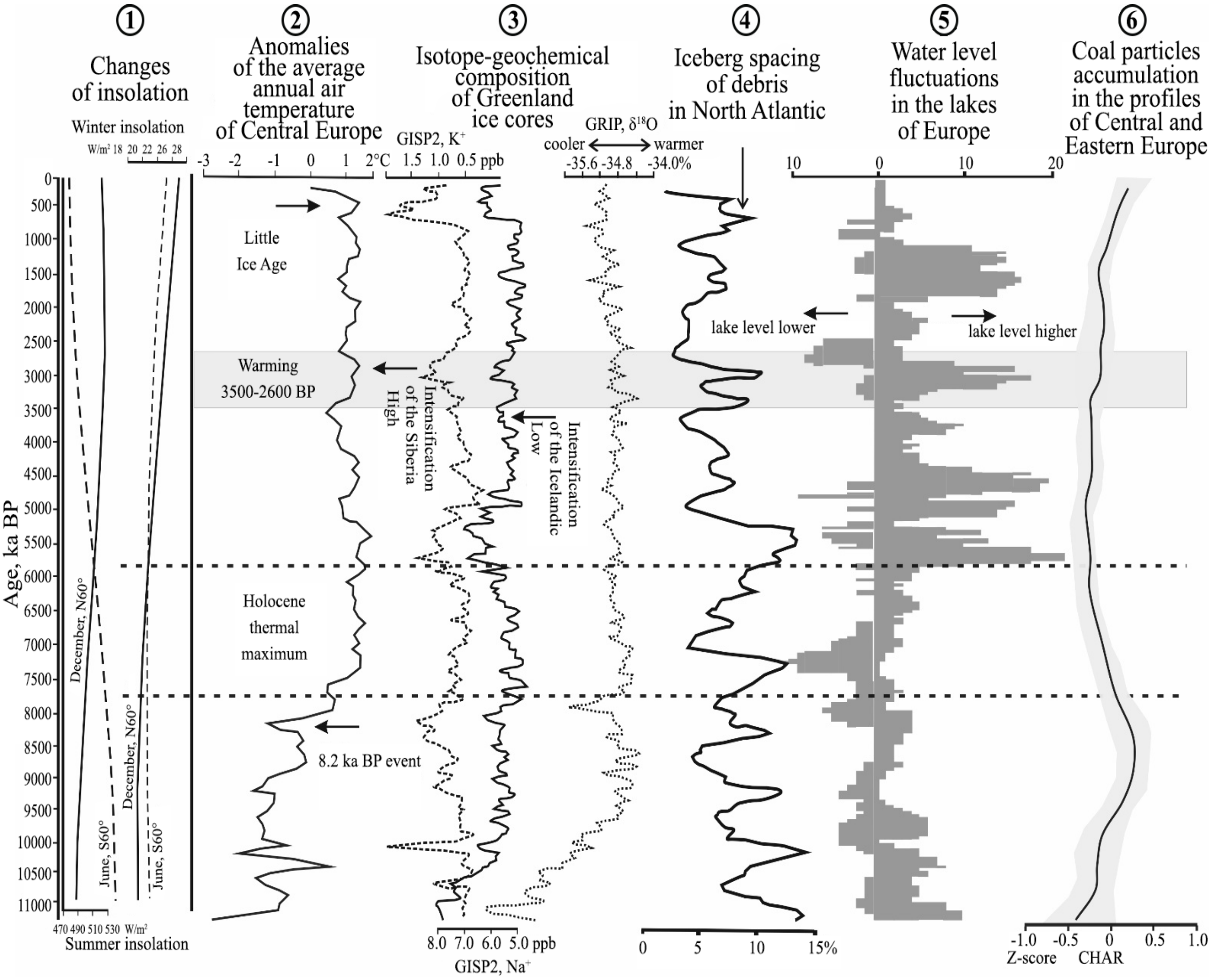

**Fig. 3.** The main landscape and climatic changes in Europe during the Holocene. *Legend:* 1 – winter and summer insolation values at 60°N and 60°S latitude (Berger, Loutre, 1991); 2 – reconstruction of the mean annual temperature in Europe during the Holocene, expressed as deviations from current values (Davis et al., 2003); 3 – change of the isotope-geochemical composition of ice cores GRIP and GISP2 in Greenland: the content of the cation $K^+$ and cation $Na^+$ GISP2 ice core (Mayewski et al., 2004), changes in $\delta^{18}O$ in ice core GRIP (Johnsen et al., 1992); 4 – change in the intensity of ice-rafted debris in the North Atlantic, expressed as a percentage of petrological markers (Bond et al., 1993); 5 – fluctuations in the level of lakes in France and Switzerland, the number of radiocarbon dates of higher and lower lake-level events in successive 50 years intervals (Magny, 2004); 6 – changes in micro- and macro-charcoal accumulation rates (CHAR) in lake and peat deposits in Central and Eastern Europe expressed as Z-score of CHAR (Feurdean et al., 2020).

Fast warming and relatively warm climate conditions in the Boreal period were also determined for the coastal territory of the Baltic Sea. For example, Latvian summer temperatures at 10.0 ka BP were about 17°C (i.e. 1°C lower than modern indices), but they increased by 1.5°C at 9.0 ka BP (Heikkilä, Seppä, 2010). All temperature indices were lower than the modern ones in the central regions of the East European Plain at 10.1-7.9 ka BP (Khotinski, Kilmanov, 1997; Novenko, Olchev, 2015).

Reconstructions of paleo-temperatures obtained from various natural archives, make it possible to find a short-term and abrupt climate cold snap, or the so-called “8.2 ka BP event” (Borzenkova et al., 2017; Alley et al., 1997; Thomas et al., 2007; Daley et al., 2011). According to our results, the average annual temperature in the Upper Volga basin in 8.1-8.5 ka BP dropped by 2-3°C (Novenko, Olchev, 2015). Reconstructions based on the palynological data from the profiles of Estonia (Seppä, Poska, 2004), Finland (Heikkilä, Seppä, 2003) and Southern Sweden (Antonsson, Seppä, 2007), showed that the average annual temperatures decreased by 1.5-2.0°C during the "8.2 ka BP event". Reconstructions made on the basis of diatom analysis data showed that the summer temperatures dropped by 0.75-1.0°C in the north of Finland (Korhola et al., 2000). B.A.S. Davis et al. (2003) generalized a large number of pollen diagrams and climate reconstructions and reconstructed a decrease by 1°C in the average annual temperature for Europe at 8.2 ka BP (Fig. 1). The reason for this significant temperature drop, which was reconstructed in Europe at 8.4-8.0 ka BP, as well as for the previous Preboreal cold snaps that we already studied, was a weakening of thermohaline circulation in the North Atlantic region (Teller et al., 2002). During a cold snap at 8.2 ka BP these changes could be the result of a release of large fresh water masses into the ocean from the large periglacial Agassiz Lake in North America (Borzenkova et al., 2017; Keigwin, Boyle, 2000).

Reconstructions of the annual sum of precipitation and quantitative characteristics of climate humidity are a difficult task, and their results for the Early Holocene in Europe can be found only in a small amount of works (Barber et al., 2004; Harrison et al., 1996; Allen et al., 2007). Since the studies of A. Blitt at the end of the XIX century, a common opinion stated that the Boreal climate of the Holocene was dry, which was later noted in many other studies and then made it to climatic stratigraphic schemes of the Holocene (Khotinski, 1977).

Climate humidity data for the East European Plain proved that temporal and spatial dynamics of precipitation amount are complicated. According to our studies, the average annual amount at 9.5 ka BP was lower than the modern values of the Upper Volga basin and in Valday Upland, and higher in the northwest of the Central Russian Upland (Fig. 4). An almost simultaneous increase of precipitation in the entire territory of the central regions of European Russia was reconstructed for the period of 9.1-8.5 ka BP, when precipitation was 100-200 mm higher than nowadays (Novenko, Olchev, 2015).

Reconstructions of the wildfires changes in the Holocene showed an increased frequency of fires in different regions during the Boreal period (Zernitskaya et al., 2019; Novenko et al., 2016), which may indicate that summer precipitation was uneven and fire hazardous meteorological conditions were recurrent. Once the data on concentration of micro and macro coal particles in the lake and bog sediments from 117 profiles of Central and Eastern Europe was generalized (Feurdean et al., 2020), we determined the maximal accumulation speed of these particles in the Holocene, between 9.0 and 8.0 ka BP for the entire macro-region (Fig. 3). This indicated that wildfires were frequent and severe.

Data on lakes level fluctuations can be an indirect source of information on climate humidity. The studies of some lakes in Switzerland and the French Alps (Magny, 2010) resulted in a complex humidity dynamics in the Early Holocene and were based on 180 radiocarbon, dendrochronological, and archaeological dating. The phases of increased water level in the lakes were revealed for the periods of 10.3-10.0 and 9.55-9.15 ka BP, between which the level was significantly lower than nowadays. The studies that took place in southern Sweden (Harrison, Digerfeldt, 1993) showed an extremely low water level in the lakes at approximately 10.5-9.7 ka BP, however, then it changed into a quick level rise.

## 8.0-5.7 ka BP (Mid-Holocene, Mid- and Late Atlantic Period)

Many works on the subject of vegetation and climatic changes in the Holocene showed that Europe was at its highest heat availability (Khotinski, 1977; Dynamics of Landscape Components ..., 2002; Paleoclimate and Paleolandscapes ..., 2009; Zagwijn, 1994; Davis et al., 2003; Mauri et al., 2015; Borisova, 2019) and relatively stable climate conditions (Borisova, 2014;

Mayewski et al., 2004) at 8.0-5.7 ka BP. In the Russian literary works this period is called the Holocene climatic optimum (Khotinski, 1977). In the foreign works it is usually called the Mid-Holocene thermal maximum.

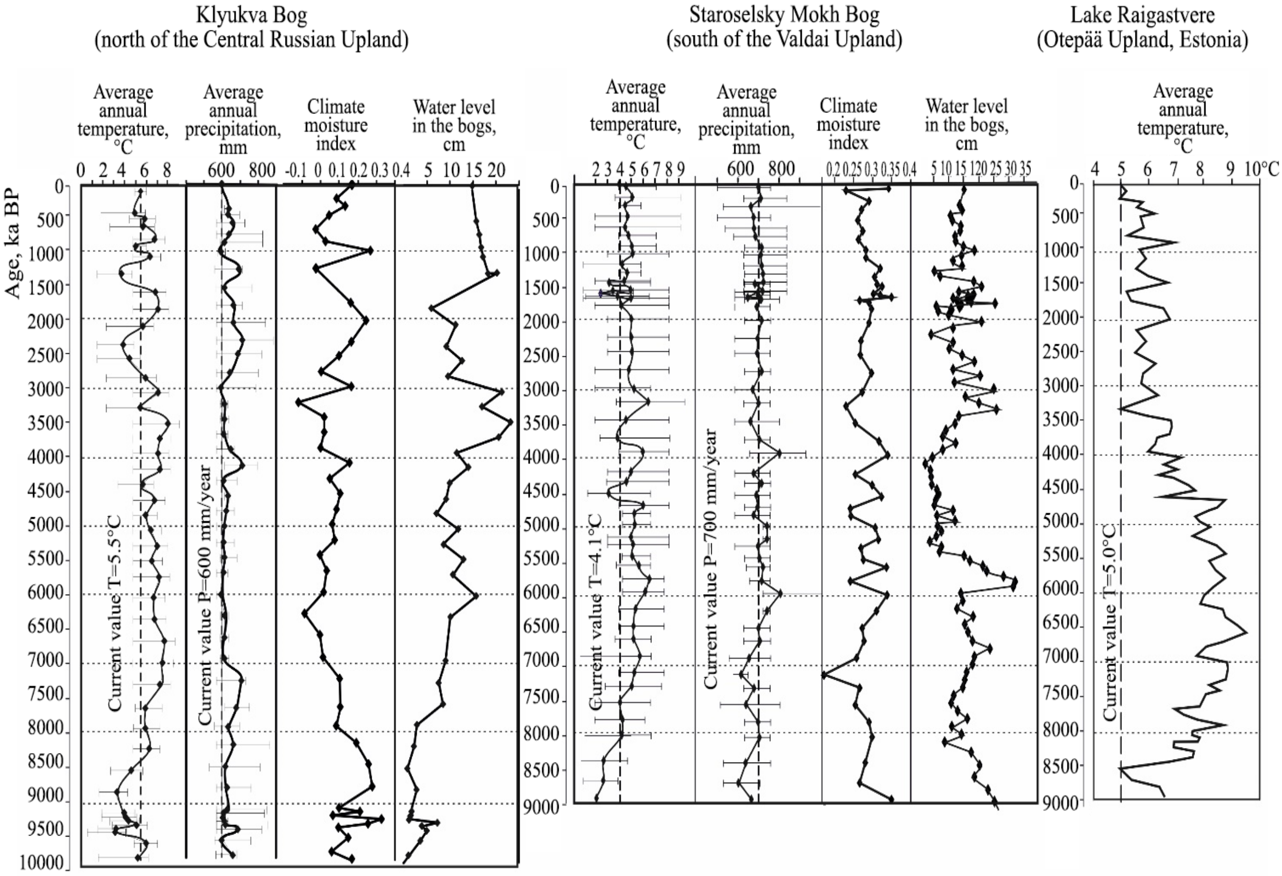

**Fig. 4.** Climatic changes in the East European Plain during the Holocene. Paleoclimatic reconstructions by data from the Klukva bog (Novenko et al., 2019), Staroselsky Mokh bog (Novenko et al., 2018) and Lake Raigastvere (Seppä, Poska, 2004).

At 8.0-5.7 ka BP Central and Eastern Europe had a unified zone of deciduous forests (Fig. 1, 2). Oak, linden, elm and alder forests with sparse yew and holly were growing in the northeastern Atlantic part of Europe. Oak forests were extremely developed in Germany, Southern Sweden, Denmark and Poland, supplanting pine formations (Latalowa, Nalepka, 1987; Jahns, 2000, 2007; Kalis et al., 2003; Lamentowicz et al., 2008; Kulesza et al., 2012; Gałka et al., 2013). Elm, linden, alder and hazel played a major role in those forests. Spruce and fir were part of the tree stand in the Hercynian mountains (Black Forest, Thuringian Basin, Bohemian Massif; Harmata, 1987).

In the Baltic states the mixed oak-elm-linden forests with a lot of alder were very widespread. In the north and east of Belarus oak forests were prevailing, while in the west deciduous forests were mixed with pine-deciduous ones. According to some works written on the subject of vegetation development in European Russia in the Holocene (Khotinski, 1977; Velichko et al., 2001; Sapelko et al., 2014; Ershova, Krenke, 2014; Novenko, 2016; Nizovtsev et al., 2020; Kremenetski et al., 2000; Nosova et al., 2019; Tarasov et al., 2019; Miagkaia, Ershova, 2020), the central regions of the East European Plain were covered with deciduous forests of oak, elm and linden with hazel undergrowth. In the lands of Belarusian Polesia, Prinemanye and Meshchera Polesia Lowlands the pine forests were growing along with some deciduous species and alder

(Bolikhovskaya, 1988; Zernitskaya et al., 2019, 2010; Novenko et al., 2016).

Many literary sources were written on the subject of reconstructions of the Atlantic climate conditions of the Holocene on a global scale (Guiot et al., 1993; Cheddadi et al., 1997; Tarasov et al., 1999; Davis et al., 2003, Mayewski et al., 2004; Wu et al., 2007; Mauri et al., 2015), as well as on a regional one (Korhola et al., 2000; Heikkilä, Seppä, 2003; Seppä, Poska, 2004; Antonsson, Seppä, 2007; Borisova, 2019). While analyzing the existing data on the paloclimate conditions at 8.0-5.7 ka BP in Central and Eastern Europe, we can conclude that climate became warmer and the temperature gradient weakened from east to west. For example, the reconstructions performed by W.H. Zagwijn (1994) with the method of indicator species, on the basis of the data taken from 136 profiles throughout Europe, showed that the summer and winter temperatures of Germany and Western Poland were very close to the modern ones ($T_I$=-1…0°C; $T_{VII}$=19°C). Reconstructions of paleotemperatures by the "Best Modern Analogue technique" on the basis of profile data obtained from Lednitza Lake in Central Poland (Barber et al., 2004) determined that the average January temperature was about 0°C, which is 2°C higher than nowadays.

The reconstructions obtained with the help of transfer function on the basis of the palynological data that was taken from the profiles of Raigastvere (Fig. 4), Viitna and Ruila lakes in Estonia, show that the average annual temperatures in the Mid-Holocene grew up to 8-9°C, which is 3-3.5°C higher than the modern temperatures (Seppä, Poska, 2004). The reconstructions of summer temperatures by the same method based on data from Kuryanovas Lake in Latvia, indicate that summer temperatures grew up to 19-20°C, i.e. 2-3°C higher than they are today (Heikillä, Seppä, 2010). When paleotemperature data (Seppä, Poska, 2004), based on 36 reconstructions of the average annual temperature and temperature of July, estimated for individual profiles of Scandinavia and the Baltic states, was generalized, it was determined that at 8.0-4.8 ka BP there was an obvious maximum of climate heat availability, when the annual air temperatures were exceeding the modern ones by 2°C in general.

A significant climate warming at 8.5-5.7 ka BP was also registered in Northern Belarus. The average annual temperatures increased by 2-4°C in comparison to the modern ones, and the winter temperatures grew significantly (Zernitskaya, Novenko, 2016).

The reconstructions of climatic characteristics in the eastern part of the studied latitudinal transect, were based on the palynological data of the Staroselsky Mokh bog (Fig. 4) and revealed that conditions of heat availability in the south of the Valdai Upland at 7.5-6.5 ka BP were close to the modern ones; while at 6.5-5.9 ka BP the average annual temperature was 6°C, exceeding the modern ones by 2°C. According to the reconstruction carried out by O.K. Borisova (2019) on the basis of the analysis of ecological confinement and geographic distribution of fossil flora from the Atlantic sediments of the Holocene, the heat availability in the Upper Volga Basin was significantly higher for the entire period of 7.6-5.9 ka BP. The average January temperature exceeded the modern values by 6°C, and the average July temperature was close to the modern ones (17°C). As our reconstructions demonstrate, based on palynological data from the Klyukva bog (Fig. 4), in the northwest of the Central Russian Upland a significant warming was registered for the period of 7.5-5.7 ka BP, when the average annual temperature was 3°C higher than nowadays.

Generalization of palynological data from more than 5000 profiles of Europe (Davis et al., 2003; Mauri et al., 2015) made it possible to determine 6 regional types of paleoclimatic changes. These calculations showed that the maximal heat availability in the Atlantic period was very prominent in Northern Europe and Fennoscandia, mostly due to the growth of summer temperatures. In Central Europe the thermal maximum of the Mid-Holocene was weaker, and the positive anomalies of average annual temperatures did not exceed 1°C (Fig. 3). The same results were obtained by the researchers of the BIOME600 Project (Wu et al., 2007) and by R. Cheddadi et al. (1997), who used the data of the bioclimatic modeling on the basis of the palynological materials around the world. However, according to these model calculations, climate warming in the northern and Atlantic regions of Europe took place both during the summer and winter periods. It is worth noting that during the climatic changes analysis in the said works only a small amount of data from the regions east of Poland was took into account.

Reconstructions of quantitative values of climatic characteristics of the Northern Hemisphere were carried out by A.A. Velichko et al. (Paloclimates and Paleolandscapes …, 2009) on the basis of the data of 400 spore-pollen diagrams. They showed that the most positive deviations of average annual air temperature were common for the circumpolar regions. In the mid-latitude Europe belt the average annual temperature was higher than the modern one by 1-2°C. The reconstructions obtained by P.E. Tarasov et al. (1999) for the chronological profile 6000 $^{14}$C BP (about 6.8 ka BP) for the territory of the former USSR and Mongolia showed the same result, with the average annual temperatures exceeding the modern ones by 2°C in European Russia.

There are not many quantitative estimations of the average annual precipitation in the Holocene. Mostly, they consist of indirect data on climate humidity changes for various regions. According to the reconstruction of the annual precipitation sum deviating from the modern values in the Northern Hemisphere at approximately 6.8-6.3 ka BP (6.0-5.5 ka $^{14}$C years ago), calculated by A.A. Velichko et al. (Paleoclimates and Paleolandscapes ..., 2009), the average annual precipitation in Central Europe was close to the modern values, while in Eastern Europe it decreased by 25 mm per year in the studied transect. Similar results were obtained for the same area by G. Guiot et al. (1993). Their calculations of the difference between precipitation and potential evaporation showed that the climate was slightly drier in Central Europe at about 6.8 ka BP (6000 $^{14}$C BP), and the humidity conditions were close to the modern ones in the territory of the East European Plain, with the exception of the eastern part of European Russia.

The characteristics of climate humidity changes which we obtained for the territory of the East European Plain, showed that the annual precipitation in Northern Belarus (Zernitskaya, Novenko, 2016), in the west of European Russia on the Ilmen Lowland (Nososva et al., 2019), and in the northwest of the Central Russian Upland (Klyukva bog) was close to the modern values, which, together with the summer temperatures rise, could possibly cause the drying of the climate due to increased evaporation. In the south of the Valdai Upland, according to the reconstruction based on the data from the Staroselsky Mokh bog, the annual precipitation at 7.5-6.8 ka BP was lower by 50-75 mm than now, while humidity conditions at 6.8-6.1 ka BP were close to the modern ones. Reconstructions made by V.A. Klimanov on the basis of the data from the Polovetsko-Kupansky bog, also showed that the average annual precipitation decreased by 25-50 mm in the Yaroslavl Volga Region during the entire Atlantic period of the Holocene (Khotinski, Klimanov, 1997). According to O.K. Borisova (2019), the annual precipitation was about 600 mm per year for the same territory, which is close to the modern values.

To characterize the humidity conditions during the Holocene, we used the climate moisture index (CMI). It is based on the ratio of annual precipitation and potential evaporation or volatility (Olchev et al., 2020). The required potential evaporation is calculated with the help of the Priestley-Taylor equation, using the data on vegetation and temperature changes, which was reconstructed from palynological data obtained from the Staroselsky Mokh and Klyukva bogs. The calculations showed that evaporation rate on the Valdai Upland was almost equal to the amount of precipitation at 7.0-5.5 ka BP, while in the north of the Central Russian Upland it exceeded them (Fig. 4), indicating there were relatively dry climatic conditions (Novenko et al., 2018, 2019).

One of the indirect indicators of humidity decrease in the Mid-Holocene is the data on the lake level changes. Generally, in Central Europe the decrease happened about 7.0 ka $^{14}$C years ago (Magny, 2004). However, the lakes levels in some regions, i.e. Southern Sweden, could significantly drop as well as rise (Harrison, Digerfeldt, 1993). The research on the river bends morphology, carried out by A.Yu. Sidorchuk et al. (2012), proves that level of the rivers dropped during the same time period in the East European Plain. Formation of small river paleobeds and soil horizons in the floodplains in the northern and central parts of the East European Plain indicates that in the Holocene water discharge that was forming the riverbeds significantly decreased for a long period, and the floodplains were waterlogged (Sidorchuk et al., 2018).

Another approach to the humidity conditions assessment is the reconstruction of the changes of the bog waters level by the rhizopoda data. These calculations used a transition function on the basis of the species composition changes in the testate amoebae communities from the Tukhola bog in Northern Poland (Lamentowicz et al., 2008). They identified an extremely dry period at 7.15-6.8 ka BP, which correlated well with the data on the level fluctuations in the lakes of the same region (Ralska-Jasiewiczowa, 1989). The researches in the south of the Valdai Upland allowed us to determine 2 periods at 7.0-6.2 and 6.0-5.5 ka BP, when the surface humidity decreased in the Staroselsky Mokh bog (Fig. 4), which was apparently due to the dry summer (Novenko et al., 2018). The similar results were obtained after a rhisopodic analysis of the Klyukva bog on the Central Russian Upland (Novenko et al., 2019), where the period of decreased water level in the bogs was registered between 6.8 and 5.5 ka BP (Fig. 4).

## 5.7 ka BP – present (Mid-Late Holocene, Subboreal and Subatlantic Periods)

Landscape-climatic reconstructions in the various regions worldwide are very convincing to demonstrate that after 5.7-5.5 ka BP the global warming of the Holocene thermal maximum changed to a cold snap (Khotinski, 1977; Borisova, 2014; Davis et al., 2003; Wanner et al., 2008; Mauri et al., 2015), which was apparently caused by a decrease of solar radiation during summer (Fig. 3; Berger, Loutre, 1991). During the same period the mountain glaciers started to advance widely, indicating the beginning of the “neoglacial” (Wanner et al., 2008; Solomina et al., 2008), and the westerlies intensified (Fig. 3; Mayewski et al., 2004). It was discovered that the amount of mineral particles in the North Atlantic marine sediments increased again due to iceberg spacing (Fig. 3), and the psychrophilic species of planktonic foraminifera appeared (Bond et al., 2001). The global cooling trend in the Late Holocene can be clearly traced by the change in the isotopic-oxygen composition of the Greenland glacial cores (Mayewski et al., 2004; Vinther et al., 2006).

The second half of the Holocene had a complex dynamics of plant communities in Central and Eastern Europe due to climatic changes and anthropogenic factor, the impact of which had intensified in the last millennium. Starting at 5.7 ka BP, in the eastern part of the studied latitudinal transect the area of oak and pine-oak forests decreased, while hornbeam and beech spread and strengthen their roles as the dominants of the forest communities (Fig. 1). The spread of beech forests was slightly delayed from west to east. Thus, the rise of its curve in Eastern and Central Germany, in the Rhine, Weser and Saale basins was at 3.7-3.9 ka BP; but in Western Germany, in the Elba and Oder basins as well as in Western Poland beech became the main forest-forming species only at 2.8-2.6 ka BP (Jahns, 2000; Lamentowicz et al., 2008; Gałka et al., 2013). In Central and Eastern Poland (Ralska-Jasiewiczowa et al., 2003) hornbeam and pine with a significant amount of oak were the main forest-forming species. The formation of hornbeam forests started at about 3.5 ka BP after it gradually replaced oak and linden.

The second half of the Holocene in the territory of Northern and Central Belarus (Belorussian Lakeland), in Estonia, Latvia and Lithuania, was characterized by the spreading spruce (Zernitskaya et al., 2010; Seppä, Poska, 2004; Zernitskaya, Mikhailov, 2009; Niinemets, Saarse, 2009). The researchers of these regions distinguish several consistent phases of increase and decrease in the fraction of spruce and deciduous species of forest communities starting from about 5.7 ka BP. The hornbeam pollen was found everywhere in the spore-pollen spectrum from the profiles in the territory adjacent to the Baltic Sea. However, its content did not exceed 1-2%.

In the center of the East European Plain the reconstruction of vegetation cover happened due to an increase of spruce abundance, which occurred transgressively from north to south (Fig. 2). On the Valdai Upland and in the Upper Volga basin the formation of spruce-deciduous forests (the "upper maximum of spruce") happened at 5.5 ka BP (Klimanov et al., 1995; Velichko et al., 2001; Klimenko, Klimanov, 2003; Novenko, 2016). In the Vyatka-Kama territory the amount of fir in forest communities increased (Lychagina et al., 2016). On the Smolensk-Moscow Upland the increase of spruce fraction began around 2.7-2.5. ka BP, although it was already presented there in small amounts (Kremenetski et al., 2000; Ershova, Krenke, 2014; Nizovtsev et al., 2020; Miagkaia, Ershova, 2020). In the south, in the basin of the Upper Oka of the Central Russian Upland deciduous forests of oak, elm and linden were preserved throughout the Holocene. Spruce grew on the edge of its habitat and began to enter forest cenoses at 2.5 ka BP in the ecotopes with favorable conditions.

In the area of psammophytic-pine-forest landscapes of Polesie, pine and deciduous-pine forests remained a part of vegetation cover until 2.7 ka BP. In Belarusian Polesia during the 2.7-1.0 ka BP the amount of hornbeam pollen in the spectrum increased up to 10%, which indicated the distribution of mixed pine-deciduous forests with oak and hornbeam, with addition of linden, elm, spruce, and possibly beech as well (Zernitskaya et al., 2010, 2019). In the east, in the forest belt of European Russia, the participation of deciduous pollen decreased, the hornbeam pollen was found sporadically, and the fraction of pine, birch and grasses increased (Bolikhovskaya, 1988; Novenko et al., 2016, 2018).

From 5.7 ka BP the main tendency of climatic changes was showing in decreasing heat availability and increasing climate humidity (Dynamics of Landscape Components …, 2002; Borisova, 2014). The reconstructions of paleotemperatures changes in Central Europe were obtained by B. Davis et al. (2003) on the basis of palynological data showed that unlike in Northern Europe, where the cold snap of the last 5 millennia was especially pronounced, the average temperature drop for January, July and the entire year in the mid-latitude Europe was not higher than 2°C.

Since the reconstruction possibilities of paleoclimatic characteristics in the eastern part of the studied latitudinal transect are limited due to the distorted spore-pollen spectrums, which are the result of anthropogenic factor impact, some works usually use different sources of paleographic information to restore the conditions of the past. Considering a large amount of data on the structure of peat deposits, stage of peat humufication and results of rhisopodic analysis of the sediments from the upper bogs of the United Kingdom, Ireland, Netherlands, Northern Germany, Denmark and Sweden, we can define the phases of cold snaps and climate humidity at about 4.4-4.0, 2.8-2.2, 1.8-1.7, 1.4-1.3 and 1.1-1.0 ka BP, as well as climate fluctuations during the last millennium (Charman, Hendon, 2000; Barber et al., 2004; Lücke et al., 2003). On the basis of the paleobotanical analysis of the bog sediments in Netherlands, B. Van Geel (1978) discovered a significant cold snap and increase of precipitation at about 2.6 ka BP.

The indirect indication of cooling and climate humidification can be the data on the periods of increased flood level, obtained in Poland on the basis of the geomorphological researches. L. Starkel et al. (2013) determined the 3 periods of the second half of the Holocene: 6350-6300, 4825-4775 and 3230-1950 ka BP. The reconstructions of the water level in the upper bogs ecosystems in Northern Poland on the basis of peat decomposition data and species ratio in the testate amoebae communities made it possible to discover a humid phase at 2.75-2.4 ka BP and a dry phase at 2.25-2.1 ka BP (Lamentowicz et al., 2008). According to the results obtained after a study of the composition and radiocarbon dating of alluvial sediments in the East European Plain (Panin, Matlakhova, 2015), the increase of river flow in the Early Subboreal (about 5.7 ka BP) and Early Subatlantic periods (about 2.6 ka BP) was discovered.

In the northwest of the East European Plain, in the Baltic states, according to climatic reconstructions based on palynological data from Kuryanovas Lake in Latvia (Heikkilä, Seppä, 2010) and Raigastvere, Viitna, and Ruila lakes in Estonia (Seppä, Poska, 2004), the average July temperature and the average annual temperature from 5.7 ka BP up to the present time decreased by 3-3.5°C. In the general cooling trend the periods of warming at about 3.6 and 2.0 ka BP, of cooling at 2.5 ka BP, and an abrupt and deep decrease of heat availability of the Little Ice Age can be distinguished (Fig. 4).

Climatic reconstructions made on the basis of the data from North Belarus (Zernitskaya, Novenko, 2016) and European Russia on the Ilmen Lowland (Nosova et al., 2019) and Valdai Upland (Novenko et al., 2018), showed that at about 5.7 ka BP the average annual air temperatures decreased by 2-3°C (Fig. 4), and precipitation values were close to the modern ones, while at about 4.5 ka BP their amount increased up to 800 mm/year, i.e. they were 100 mm higher than now. In the south of forest zone of the Central Russian Upland (on the Klyukva bog) the average annual temperatures dropped by 1-2°C and reached the modern values, and precipitation was about 600 mm/year (Fig. 4). The cold snap and increased humidity that happened at 4.5 ka BP can be compared quite conditionally to the "4.2 ka BP event".

The "4.2 ka BP event" is not fully studied yet. There are very few works in Europe with climatic reconstruction and paleoenvironment changes being the center of attention. Moreover, the reconstructions from various natural archives are contradictory, and the climatic signals that were identified in them are asynchronous (Roland et al., 2014; Pleskot et al., 2020). Generally, for Northern Eurasia there was a hypothesis about an increased temperature amplitude between the seasons during the "4.2 ka BP event" (Perşoiu et al., 2019). A decrease in winter temperatures is considered to be due to the weakening Icelandic minimum (Bradley, Bakke, 2019).

The climatic reconstructions that we obtained from the profiles of Mezhuzhol Lake (Zernitskaya, Novenko, 2016) and the Staroselsky Mokh and Klyukva bogs made it possible to distinguish a warm and extremely dry phase between 3.5 and 2.5 ka BP. During this period the average annual and summer air temperatures exceeded the modern ones by 1-2°C, while the amount of precipitation was close to the modern ones or just slightly lower (Fig. 4). According to the data from the Staroselsky Mokh and Klyukva bogs profiles, for this period a low CMI index, as well as the lowest water level for the entire Holocene was reconstructed, which indicates there was a significant drop of surface humidity of bog ecosystems during summer, apparently, due to a change in the precipitation/evaporation balance (Novenko et al., 2018, 2019). The warming at 3.5 ka BP was also recorded in the climatic reconstructions for the Yaroslavl Volga region, based on the palynological materials of the Polovetsko-Kupan bog and Galich Lake (Klimanov et al., 1995; Velichko et al., 2001), according to which all temperature indices exceeded the modern ones by 1.5°C. The increased $K^+$ content in the GISP2 ice core in Greenland during the said period (Fig. 3; Mayevski et al., 2004) indicates that the impact of the Siberian High intensified, which probably caused an increased frequency of anicyclonic situations in the East European Plain, causing droughts in summer and creating conditions for wildfires. The studies of the changes in fire regimes in the East European Plain during the Holocene were based on calculations of coal micro- and macroparticles concentration in sediments, and showed that frequency and intensity of forest wildfires at 3.5-2.5 ka BP increased for different regions (Novenko et al., 2016, 2019).

The warming was gradually replaced with a cold snap in the Early Subatlantic period (at about 2.6-2.5 ka BP). The cooling can be clearly traced by the paleobotanical data (Davis et al. 2003; Mauri et al., 2015) and isotope-oxygen composition of Greenland ice cores (Thomas et al., 2007). It was also accompanied by a simultaneous growth of glaciers around all European mountainous countries (Wanner et al., 2008; Solomina et al., 2008). The cold snap was not monotonous and had a series of warm and cool phases. During the first millennium AD many researchers distinguish the Roman Warm Period (2.0-1.7 ka BP) and the Dark Ages Cold Period (1.7-1.2 ka BP; Buntgen et al., 2011; Helama et al., 2017; Gouw-Bouman et al., 2019).

The review of 114 articles on the subject of the Dark Ages Cold Period around the world was carried out by S. Helama et al. (2017). It showed that European climate was more cool and humid than it is nowadays. At 1.7-1.5 ka BP the mountain glaciation increased (Solomina et al., 2008), the lakes level rose (Magny, 2004), and the amount of forests grew in the forest-steppe zone (Novenko, 2016). However, the reconstructions obtained for the East European Plain by the informational-statistical method and based on the data from the Usvyatsky Mokh bog (Daugava River) prove there was a climate warming and drying between 1700 and 1500 BP (Kozharinov et al., 2003); the calculations on the basis of the data from the Polovetsko-Kupanskoye bog in the Yaroslavl Volga Region show there was a warming and an increase of precipitation during the same period (Klimanov et al., 1995). The reconstructions that we obtained by the "method of better analogues" generally showed a growth of heat availability and decrease of humidity during the Roman Warm Period, followed by a cold snap and increasing precipitation. Unfortunately, in the studied profiles the said time periods are represented by a small amount of samples, which makes it difficult to reconstruct.

Landscape-climatic changes in the last millennium are studied thoroughly and widely with the help of different methods (Klimanov et al., 1995; Mann et al., 2009; Wanner et al., 2008; Christiansen, Ljungqvist, 2017; Pages 2k Consortium, 2013, 2017). As the result, 2 main climatic phases were classified: *Medieval Climate Anomaly* (950-1250 AD) and *Little Ice Age* (1400-1850 AD).

Paleoclimatic reconstructions that were made using various nature archives characterize the Medieval Climate Anomaly as a warm and relatively dry period (Goosse et al., 2005). There is a data on repeating summer droughts in some European regions (Büntgen et al., 2010) and on decreasing river flow during the same period (Panin, Matlakhova, 2015), although the results of some paleoclimatic researches indicate that the average annual precipitation sum increased (Davis et al., 2003).

According to paleoclimatic reconstructions based on the palynological data for Raigastvere Lake, the average annual air temperature during the Medieval Climate Anomaly in the Baltic states exceeded the modern ones by 1°C (Seppa, Poska, 2004). In the spore-pollen spectrum from the sediments of some profiles from the central regions of European Russia (Khotinski, 1977; Klimanov et al., 1995), which are part of the Medieval Climate Anomaly, an increase of the deciduous species (oak, linden, elm) fraction was registered. Reconstructions of paleotemperatures for the south of the Valdai Upland showed an increase in the average annual temperatures by 1.5°C. The calculations carried out by V.A. Klimanov et al. (1995) for the Yaroslavl Volga region, showed that all temperature characteristics during the Medieval Climate Anomaly were close to the modern ones, while the amount of precipitation was 25-50 mm lower.

An abrupt and deep drop of heat availability during the Little Ice Age was registered everywhere in the studied territory as well as in the entire Northern Hemisphere (Christiansen, Ljungqvist, 2017). It is possible that temperature decrease in the Little Ice Age was the most significant one among all climate oscillations of the Holocene, with the exception of "8.2 ka BP event".

During that period the anomalies of summer, winter and average annual air temperatures in Central Europe were 1°C (Davis et al., 2003; Mauri et al., 2015). The reconstructions carried out by K. Barber et al. (2004) on the basis of palynological data of the profile from Lednitsa Lake in Eastern Poland revealed a more significant winter cold snap, when the average January temperatures and average annual ones were lower by 2.5°C than the modern ones. For Baltic territory a significant increase of heat availability was determined on the basis of some profiles. The average annual temperatures were lower by 2°C than the modern ones (Seppa, Poska, 2004).

On the Valdai Upland the average January temperature during the Little Ice Age declined by 3°C (down to –12°C), while the average annual temperature decreased by 2°C, and the temperature of June did not change significantly. The share of thermophilic elements in the spore-pollen spectrums of that period abruptly dropped and became almost absent, although the role of spruce pollen increased. In the spectrums of the Polovetsko-Kupanskoe Bog that period resulted in degradation of deciduous species and a significant increase of dwarf birch. V.A. Klimanov et al. (1995) wrote that aside from a winter temperatures drop, this cold snap had a summer temperatures and average annual temperatures drop as well. The deviation of the average annual ones from the modern ones was 2°C.

Climatic changes during the Little Ice Age had a great effect on a fluvial sedimentation both in Central and Eastern Europe. The increasing frequency and level of spring floods, as well as formation of secondary down-cuttings in the ravines and gullies prove the climate humidity growth during that period (Sidorchuk et al., 2018; Panin, Matlakhova, 2015).

## The main patterns of climate dynamics in Central and Eastern Europe in the Holocene and the expected landscape-climatic changes

According to the concept of asymmetry of the main climate trend during the interglacial period (Velichko, 2012), the average annual air temperature was growing fast in Northern Eurasia during the Early Holocene and gradually declining during its second half. The estimations showed that the warming trend from the Late Glacial period to the Holocene optimum was 0.5° for 1000 years, while for the second half of the warm period this trend did not exceed 0.3° for 1000 years (Borisova, 2014). However, it should be noted that the said reconstructions of peleotemperatures for Central and Eastern Europe in the Holocene demonstrate that declining heat availability for the period which came after thermal maximum, has not yet reached the Early Holocene level (Davis et al., 2003; Novenko et al., 2018, 2019).

The data studied above made it possible for us to determine 3 main stages of the changes in the Holocene climatic regime: rapid warming in the Early Holocene (11.7-8.0 ka BP), complicated by oscillations; Holocene thermal maximum (8.0-5.7 ka BP), without any short-term and abrupt climatic changes; directed temperature drop in the second half of the Holocene (5.7 ka BP − present), with quasi-harmonic fluctuations of air temperature and precipitation.

The analysis of landscape-climatic reconstructions for Central and Eastern Europe showed that the periods of cold snaps, separated with climate warming, generally match the global periods (Mayewski et al., 2004). The time differences between beginning and end of the warm and cold periods in different regions are about 100-200 years, which falls within the admissible error of radiocarbon dates and may also depend on constructing errors of the age/depth models for specific profiles which were used for reconstructions.

A “critical point” of climatic changes related to “8.2 ka BP event”, which the International Commission on Stratigraphy suggests considering as a border between the Early and Mid-Holocene (Walker et al., 2019; Head, 2019) in Central and Eastern Europe, is a turning point of climate system transition from the warming in the Early Holocene to the thermal maximum. Climatic changes related to “4.2 ka BP event”, which is considered to be a border between the Mid- and Late Holocene (Head, 2019), is not seen as clearly in our materials as the cold snap at 5.7 ka BP. Starting from 5.7 ka BP, the direction of climatic trend was changing in Central and Eastern Europe, and sectorial differentiation of vegetation cover was increasing. Beech and hornbeam expanded throughout the western regions, while spruce was spreading in the east.

According to the last estimations of the Intergovernmental Panel on Climate Change (IPCC, 2013), based on the results of the Coupled Model Intercomparison Project, Phase 5, by the 4 main scenarios of representative trajectories of green gasses concentrations (RCP2.6; RCP4.5; RCP6.0, RCP8.5), the rise of average global temperature by the end of the current century will start at 0.3°C (RCP2.6 is the most gentle scenario) and go up to 4.8°C (RCP8.5 is the most harsh scenario). The amount of precipitation will grow by 6% (RCP2.6) up to 12% (RCP8.5). When estimating the increase of average annual air temperature in Central and Eastern Europe by the end of the XXI century, the said scenarios make us to assume that it will rise by 2.0-2.5°C according to the gentle scenario and by 6.0-7.0°C according to the harsh one. The increase of average annual precipitation will start from 7% (RCP2.6) up to 15% (RCP8.5; IPCC, 2013).

Using the method of paleoanalogues that was offered by M.I. Budyko (1980) and is widely used A.A. Velichko et al. (2012; Climates and Landscapes of Northern Eurasia ..., 2010) to predict the possible dynamics of landscapes and climate with the help of paleogeographic data, we can suggest some conditions to be considered as possible trajectories of environment changes during climate warming in case of RCP2.6 and RCP4.5 scenarios coming true. First, the conditions for the Holocene thermal maximum (8.0-5.7 ka BP), when the average annual temperatures in the studied region exceeded the modern ones by 2-3°C; second, the conditions for the warming periods during 3.5-2.5 ka BP, 2.0-1.7 ka BP (Roman warming) and the Medieval climatic anomaly, when the average annual temperatures deviated from the modern ones by 1.0 and 2.0°C. The RCP6.0 and RCP8.5 scenarios suggest a greater temperatures deviation than it was previously determined for the Holocene. The paleoanalogues of these conditions should be sought in the conditions of earlier interglacial periods.

Considering the landscape-climatic reconstructions for the Holocene of Central and Eastern Europe, the internal structure of geosystems can be expected to change, especially in the eastern area of the studied transect, as well as the frequency of wildfires caused by natural causes to grow, and the frequency of catastrophes due to uneven precipitation to increase. However, even the most abrupt transformations of landscape components in the Holocene took hundreds and thousands years to happen, while the expected climate warming in the XXI century may take less than a hundred years. The adaptive mechanisms of geosystems are relatively inert, so it is obvious that forecast should take into account some response delay of landscape components to the process of climate warming.

## REFERENCES

*Allen J.R.M., Long A.J., Chris J., Pearson D.G., Huntley B.* 2007. Holocene climate variability in northernmost Europe // Quaternary Science Reviews. Vol. 26. P. 1432-1453.

*Alley R.B., Mayewski P.A., Sowers T., Stuiver M., Taylor K.C., Clark P.U.* 1997. Holocene climatic instability: a prominent, widespread event 8200 yr ago // Geology. Vol. 25. P. 483-486.

*Antonsson K., Seppä H.* 2007. Holocene temperatures in Bohuslän, southwest Sweden: a quantitative reconstruction from fossil pollen Data // Boreas. Vol. 36. P. 400-410.

*Barber K., Zolitschka B., Tarasov P., Lotter A.F.* 2004. Atlantic to Urals − the Holocene climatic record of mid-latitude Europe // Past Climate Variability through Europe and Africa / Eds. R.W. Battarbee, F. Gasse, C.E. Stickley. Kluwer Academic Publishers, Dordrecht, The Netherlands. P. 417-442.

*Berger A., Loutre M.F.* 1991. Insolation values for the climate of the last 10 million years // Quaternary Science Reviews. Vol. 10. P. 297-317.

*Björck S., Kromer B., Johnsen S., Bennike O., Hammarlund D., Lehmdahl G., Possnert G., Rasmussen T.L., Wohlfarth B., Hammer C.U., Spurk M.* 1996. Synchronised terrestrial-atmospheric deglacial records around the North Atlantic // Science. Vol. 274. P. 1155-1160.

*Bolikhovskaya N.S.* 1988. On the History of Vegetation and Climate of the Moscow Meshchera in the Holocene // Holocene Paleoclimates of the European Territory of the USSR. Moscow: Nauka. P. 76-85. [in Russian; *Болиховская Н.С.* 1988. К истории растительности и климата Подмосковной Мещеры в голоцене // Палеоклиматы голоцена Европейской территории СССР. М.: Наука. С. 76-85.]

*Bond G., Broecker W., Johnsen S., McManus J., Labeyrie L., Jouzel J., Bonani G.* 1993. Correlations between climate records from North Atlantic sediments and Greenland ice // Nature. Vol. 365. P. 143-147.

*Bond G., Kromer B., Beer J. Muscheler R., Evans M., Showers W., Hoffmann S.* 2001. Persistent solar influence on North Atlantic climate during the Holocene // Science. Vol. 294. P. 2130-

2136.

*Borisova O.K.* 2014. Landscape and Climatic Changes in the Holocene // News of RAN. Geographic Series. No. 2. Pp. 5-20. [in Russian; *Борисова О.К.* 2014. Ландшафтно-климатические изменения в голоцене // Известия РАН. Серия географическая. № 2. С. 5-20.]

*Borisova O.* 2019. Environmental and climatic conditions of human occupation in the central east European plain during the middle Holocene: Reconstruction from palaeofloristic data // Quaternary International. Vol. 516. P. 42-57.

*Borzenkova I.I., Borisova O.K., Zhiltsova E.L., Sapelko T.V.* 2017. Cold Episode about 8200 Years Ago in Northern Europe: An Analysis of Empirical Data and Possible Causes // Ice and Snow. Vol. 57. No. 1. P. 117-132. [in Russian; *Борзенкова И.И., Борисова О.К., Жильцова Е.Л., Сапелко Т.В.* 2017. Холодный эпизод около 8200 лет назад в Северной Европе: анализ эмпирических данных и возможных причин // Лед и снег. Т. 57. № 1. С. 117-132.]

*Bos J.A.A., Urz R.* 2003. Late Glacial and early Holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early Mesolithic people − pollen and macrofossil evidence // Vegetation History Archaeobotany. Vol. 12. P. 19-36.

*Bos J.A.A., van Geel B., van der Plicht J., Bohncke S.J.P.* 2007. Preboreal climate oscillations in Europe: Wiggle-match dating and synthesis of Dutch high-resolution multi-proxy records // Quaternary Science Reviews. Vol. 26. P. 1927-1950.

*Bradley R.S.* 2008. Holocene perspectives on future climate change // Natural climate variability and global warming: A Holocene perspective / Eds: R.W. Battarbee, H.A. Binney. Chichester: J. Wiley & Sons. P. 254-268.

*Bradley R.S., Bakke J.* 2019. Is there evidence for a 4.2 ka BP event in the northern North Atlantic region? // Climate in the Past. Vol. 15. P. 1665-1676.

*Budyko M.I.* 1980. Climate of the Past and the Future. Leningrad: Hydrometeoizdat. 352 p. [in Russian; *Будыко М.И.* 1980. Климат в прошлом и будущем. Л.: Гидрометеоиздат. 352 с.]

*Büntgen U., Tegel W., Nicolussi K., McCormick M., Frank D., Trouet V., Kaplan J.O., Herzig F., Heussner K.-U., Wanner H., Luterbacher J., Esper J.* 2011. 2500 years of European climate variability and human susceptibility // Science. Vol. 331. P. 578-582.

*Büntgen U., Trouet V., Frank D., Leuschner H.H., Friedrichs D., Luterbacher J., Esper J.* 2010. Tree ring indicators of German summer drought over the last millennium // Quaternary Science Reviews. Vol. 29. P. 1005-1016.

*Charman D.J., Hendon D.* 2000. Long-term changes in soil water tables over the past 4500 years: relationships with climate and North Atlantic atmospheric circulation and sea surface temperature // Climatic Change. Vol. 47. P. 45-59.

*Cheddadi R., Yu G., Guiot J., Harrison S.P., Prentice I.C.* 1997. The climate of Europe 6000 years ago // Climate Dynamics. Vol. 13. P. 1-9.

*Christiansen B., Ljungqvist F.C.* 2017. Challenges and perspectives for large-scale temperature reconstructions of the past two millennia // Reviews of Geophysics. Vol. 55. No. 1. P. 40-96.

Climates and Landscapes of Northern Eurasia in the Context of Global Warming. Retrospective Analysis and Scenarios. Atlas-monograph. 2010. Moscow: GEOS. 220 p. [in Russian; Климаты и ландшафты Северной Евразии в условиях глобального потепления. Ретроспективный анализ и сценарии. Атлас-монография. 2010. М.: ГЕОС. 220 с.]

*Coope G.R., Lemdahl G., Lowe J.J., Walkling A.* 1998. Temperature gradients in northern Europe during the last glacial-Holocene transition (14-9 $^{14}$C kyr BP) interpreted from coleopteran assemblages // Journal of Quaternary Science. Vol. 13. No. 5. P. 419-433.

*Daley T.J., Thomas E.R., Holmes K., Street-Perrott F.A., Chapman M.R., Tindall J.C., Valdes P.J., Loader NJ., Marshall J.D., Wolff E.W., Hopley P.J., Atkinson T., Barber K.E., Fisher EH., Robertson I., Hughes P.D.M., Roberts C.N.*. 2011. The 8200yr BP cold event in stable isotope records from the North Atlantic region // Global and Planetary Change. Vol. 79. P. 288-302.

*Davis B.A.S., Brewer S., Stevenson A.C., Guiot J.* 2003. The temperature of Europe during the Holocene reconstructed from pollen data // Quaternary Science Reviews. Vol. 22. P. 1701-1716.

*De Klerk P.* 2008. Patterns in vegetation and sedimentation during the Weichselian Late-glacial in north-eastern Germany // Journal of Biogeography. Vol. 35. P. 1308-1322.

Dynamics of Landscape Components and Inland Sea Basins of Northern Eurasia over the Past 130,000 Years (General Paleogeography). Atlas-monograph. 2002. Moscow: GEOS. 232 p. [in Russian; Динамика ландшафтных компонентов и внутренних морских бассейнов Северной Евразии за последние 130000 лет (общая палеогеография). Атлас-монография. 2002. М.: ГЕОС. 232 с.].

European Pollen Database. 2007 [Available at http://www.europeanpollendatabase.net (Date of Access 03.06.2020)].

*Feurdean A., Vannière B., Finsinger W. et al.* 2020. Fire hazard modulation by long-term dynamics in land cover and dominant forest type in eastern and central Europe // Biogeosciences. Vol. 17. P. 1213-1230.

*Firbas F.* 1949. Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen. Bd. 1. Jena: Fischer. 326 p.

*Gałka M., Miotk-Szpiganowicz G., Goslar T., Jęśko M., van der Knaap W.O., Lamentowicz M.* 2013. Palaeohydrology, fires and vegetation succession in the southern Baltic during the last 7500 years reconstructed from a raised bog based on multi-proxy data // Palaeogeography, Palaeoclimatology, Palaeoecology. Vol. 370. P. 209-221.

*Giesecke T., Bennett K.D., Birks H.J.B., Bjune A.E., Bozilova E., Feurdean A., Finsinger W., Froyd C., Pokorny P., Rosch M., Seppa H., Tonkov S., Valsecchi V., Wolters S.* 2011. The pace of Holocene vegetation change e testing for synchronous developments // Quaternary Science Reviews. Vol. 30. P. 2805-2814.

*Goosse H., Renssen H., Timmermann A., Bradley R.S.* 2005. Internal and forced climate variability during the last millennium: a model-data comparison using ensemble simulations // Quaternary Science Reviews. Vol. 24. P. 1345-1360.

*Gouw-Bouman M.T.I.J., van Asch N., Engels S., Hoek W.Z.* 2019. Late Holocene ecological shifts and chironomid-inferred summer temperature changes reconstructed from Lake Uddelermeer, the Netherlands // Palaeogeography, Palaeoclimatology, Palaeoecology. Vol. 535. P. 109366.

*Grichuk V.P.* 1969. Experience of Reconstruction of Some Climatic Elements in the Northern Hemisphere during the Atlantic Period of the Holocene // Holocene. Moscow: Nauka. P. 41-57. [in Russian; *Гричук В.П.* 1969. Опыт реконструкции некоторых элементов климатов северного полушария в атлантический период голоцена // Голоцен. М.: Наука. С. 41-57.]

*Grichuk V.P.* 1989. History of Flora and Vegetation of the East European Plain in the Pleistocene. Moscow: Nauka. 183 p. [in Russian; *Гричук В.П.* 1989. История флоры и растительности Русской равнины в плейстоцене. М.: Наука. 183 с.]

*Guiot J., Harrison S.P., Prentice C.* 1993. Reconstruction of Holocene precipitation in Europe using pollen and lake level data // Quaternary Research. Vol. 49. P. 139-149.

*Harmata K.* 1987. Late-glacial and Holocene history of vegetation at Roztoki and Tarnowiec near Jasło (Jasło-Sanok Depression) // Acta Palaeobotanica. Vol. 27. No. 1. P. 43-65.

*Harrison S.P., Digerfeld G.* 1993. European lakes as palaeoclimatic indicators // Quaternary Science Reviews. Vol. 12. P. 233-248.

*Head M.J.* 2019. Formal subdivision of the Quaternary System/Period: Present status and future directions // Quaternary International. Vol. 500. P. 32-51.

*Heikkilä M., Fontana S., Seppä H.* 2009. Rapid Lateglacial tree population dynamics and ecosystem changes in the eastern Baltic region // Journal of Quaternary Science. Vol. 24. P. 802-815.

*Heikkilä M., Seppä H.* 2003. A 11,000 yr palaeotemperature reconstruction from southern boreal zone in Finland // Quaternary Science Reviews. Vol. 22. P. 541-554.

*Heikkilä M., Seppä H.* 2010. Holocene climate dynamics in Latvia, eastern Baltic region: a pollen-based summer temperature reconstruction and regional comparison // Boreas. Vol. 39. P. 705-719.

*Helama S., Jones P.D., Briffa K.R.* 2017. Dark Ages Cold Period: A literature review and directions for future research // The Holocene. Vol. 27. P. 1600-1606.

IPCC. 2013. Climate change 2013. The Physical Science Basis. Cambridge: Cambridge University Press. 1535 p.

*Jahns S.* 2000. Late-glacial and Holocene woodland dynamics and land-use history of the Lower Oder valley, north-eastern Germany, based on two, AMS $^{14}$C-dated, pollen profiles // Vegetation History and Archaeobotany. Vol. 9. P. 111-123.

*Jahns S.* 2007. Palynological investigations into the Late Pleistocene and Holocene history of vegetation and settlement at the Löddigsee, Mecklenburg, Germany // Vegetation History Archaeobotany. Vol. 16. P. 157-169.

*Johnsen S., Clausen H., Dansgaard W., Fuhrer K., Gundestrup N., Hammer C., Iversen P., Jouzel J., Stauffer B., Steffensen J.* 1992. Irregular glacial interstadials recorded in a new Greenland ice core // Nature. Vol. 359. P. 311-313.

*Kalis A.J., Merkt J., Wunderlich J.* 2003. Environmental changes during the Holocene climatic optimum in central Europe - human impact and natural causes // Quaternary Science Reviews. Vol. 22. P. 33-79.

*Keigwin L.D., Boyle E.A.* 2000. Detecting Holocene changes in thermohaline circulation // Proceedings of the National Academy of Sciences. Vol. 4. P. 1343-1346.

*Khotinski N.A.* 1977. Holocene of Northern Eurasia. Moscow: Nauka. 200 p. [in Russian; *Хотинский Н.А.* 1977. Голоцен Северной Евразии. М.: Наука. 200 с.]

*Khotinski N.A., Klimanov V.A.* 1997. Allerod, Younger Dryas and Early Holocene Palaeo-Environmental Stratigraphy // Quaternary International. Vol. 41/42. P. 67-70.

*Klimanov V.A., Khotinski N.A., Blagoveshchenskaya N.V.* 1995. Climate Fluctuations over the Historical Period in the Center of the East European Plain // News of RAN. Geographic Series. No. 1. P. 89-96. [in Russian; *Климанов В.А., Хотинский Н.А., Благовещенская Н.В.* 1995. Колебания климата за исторический период в центре русской равнины // Известия РАН. Серия географическая. № 1. С. 89-96.]

*Klimanov V.A., Serebryanaya T.A.* 1986. Changes in Vegetation and Climate on the Central Russian Upland in the Holocene // News of AN SSSR. Geographic Series. No. 2. P. 93-101. [in Russian; *Климанов В.А., Серебряная Т.А.* 1986. Изменения растительности и климата на Среднерусской возвышенности в голоцене // Известия АН СССР. Серия географическая. № 2. С. 93-101.]

*Klimenko V.V., Klimanov V.A.* 2003. Cold Climate of the Early Sub-Atlantic Era in the Northern Hemisphere // Reports of the Academy of Sciences. Vol. 391. No. 3. P. 393-397. [in Russian; *Клименко В.В., Климанов В.А.* 2003. Холодный климат ранней субатлантической эпохи в Северном полушарии // Доклады Академии наук. Т. 391. № 3. С. 393-397.]

*Korhola A., Weckström J., Holmström L., Erästö P.* 2000. A quantitative Holocene climatic record from diatoms in northern Fennoscandia // Quaternary Research. Vol. 54. P. 284-294.

*Kozharinov A.V., Sirin A.A., Klimenko V.V., Klimanov V.A., Malyasova E.S., Sleptsov A.M.* 2003. Dynamics of Vegetation Cover and Climate of the Daugava Lowland (Tver Region) for the Last 5 Thousand Years // Botanical Journal. Vol. 88. No. 3. P. 90-97. [in Russian; *Кожаринов А.В., Сирин А.А., Клименко В.В., Климанов В.А., Малясова Е.С., Слепцов А.М.* 2003. Динамика растительного покрова и климата Западнодвинской низины (Тверская область) за последние 5 тысяч лет // Ботанический журнал. Т. 88. № 3. С. 90-97.]

*Krementski K.V., Borisova O.K., Zelikson E.M.* 2000. The Late Glacial and Holocene history of vegetation in the Moscow region // Paleontological Journal. Vol. 34. No. 1. P. 67-74.

*Kulesza P., Suchora M., Irena A., Pidek I.A., Dobrowolski R., Alexandrowicz W.P.* 2012. The Holocene palaeoenvironmental changes reflected in the multi-proxy studies of Lake Słone sediments (SE Poland) // Palaeogeography, Palaeoclimatology, Palaeoecology. Vol. 363. P. 79-98.

*Lamentowicz M., Obremska M., Mitchell E.A.D.* 2008. Autogenic succession, land-use change, and climatic influences on the Holocene development of a kettle-hole mire in Northern Poland // Review of Palaeobotany and Palynology. Vol. 151. P. 21-40.

*Latalowa M., Nalepka D.* 1987. A study of the Late-Glacial and Holocene vegetational history of the Wolbrom area (Silesian-Cracovian Upland − S. Poland) // Acta Palaeobotanica. Vol. 27. No. 1. P. 75-115.

*Litt T., Brauer A., Goslar T., Merkt J., Bałaga K., Müller H., Ralska-Jasiewiczowa M., Stebich M., Negendank J.F.W.* 2001. Correlation and synchronisation of Lateglacial continental sequences in northern central Europe based on annually laminated lacustrine sediments // Quaternary Science Reviews. Vol. 20. P. 1233-1249.

*Lotter A.F., Eicher U., Birks, H.J.B., Siegenthaler U.* 1992. Late Glacial climatic oscillations as recorded in Swiss lake sediments // Journal of Quaternary Science. Vol. 7. P. 187-204.

*Lücke A., Schleser G. H., Zolitschka B., Negendank J.F.W.* 2003. A Lateglacial and Holocene organic carbon isotope record of lacustrine palaeoproductivity and climatic change derived from varved lake sediments of Lake Holzmaar, Germany // Quaternary Science Reviews. Vol. 22. P. 569-580.

*Lychagina E.L., Zaretskaya N.E., Chernov A.V., Lapteva E.G., Trofimova S.S., Zinoviev E.V.* 2016. Paleoecological Studies in the Area of Lake Chashkinskoye (Middle Urals) // 7th Bersov's Readings. Materials of the All-Russian Scientific-Practical Conference with International Participation. Yekaterinburg. Pp. 294-302. [in Russian; *Лычагина Е.Л., Зарецкая Н.Е., Чернов А.В., Лаптева Е.Г., Трофимова С.С., Зиновьев Е.В.* 2016. Палеоэкологические исследования в районе Чашкинского озера (Среднее Предуралье) // Седьмые Берсовские чтения. Материалы всероссийской научно-практической конференции с международным участием. Екатеринбург. С. 294-302.]

*Magny M.* 2004. Holocene climate variability as reflected by mid-European lake-level fluctuations andits probable impact on prehistoric human settlements // Quaternary International. Vol. 113. P. 65-79.

*Mann M.E., Zhang Z., Rutherford S., Bradley R.S., Hughes M.K., Shindell D., Ammann C., Faluvegi G., Ni F.* 2009. Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly // Science. Vol. 326. P. 1256-1260.

*Mauri A., Davis B.A.S., Collins P.M., Kaplan J.O.* 2015. The climate of Europe during the Holocene: a gridded pollen-based reconstruction and its multi-proxy evaluation // Quaternary Science Reviews. Vol. 112. P. 109-127.

*Mayewski P.A., Rohling E.E., Stager J.C. et al.* 2004. Holocene climate variability // Quaternary Research. Vol. 62. Pp. 243-255.

*Miagkaia A., Ershova E.* 2020. A 10 000-year pollen and plant macrofossil record from the Losiny Ostrov National Park (Moscow, Russia) // IOP Conference Series: Earth and Environmental Science. Vol. 438. P. 012018 (1-9).

*Neishtadt M.I.* 1957. History of Forests and Paleogeography of the USSR in the Holocene. Moscow: Nauka. 404 p. [in Russian; *Нейштадт М.И.* 1957. История лесов и палеогеография СССР в голоцене. М.: Наука. 404 с.]

*Niinemets E., Saarse L.* 2009. Holocene vegetation and land-use dynamics of south-eastern Estonia // Quaternary International. Vol. 207. P. 104-116.

*Nizovtsev V.A., Novenko E.Yu., Erman N.M., Mazei N.G., Matasov V.M., Lavrova N.B., Filimonova L.V.* 2020. Evolution of Landscapes of the Middle Protva Basin in the Holocene // Bulletin of Moscow University. Series 5: Geography. No. 1. P. 73-86. [in Russian; *Низовцев В.А., Новенко Е.Ю., Эрман Н.М., Мазей Н.Г., Матасов В.М., Лаврова Н.Б., Филимонова*

*Л.В.* 2020. Эволюция ландшафтов бассейна Средней Протвы в голоцене // Вестник Московского университета. Серия 5: География. № 1. С. 73-86.]

*Nosova M.B., Novenko E.Yu., Severova E.E., Volkova O.A.* 2019. Vegetation and climate changes within and around the Polistovo-Lovatskaya mire system (Pskov Oblast, North-Western Russia) during the past 10,500 years // Vegetation History and Archaeobotany. Vol. 28. P. 123-140.

*Novenko E.Yu.* 2016. Changes in Vegetation and Climate of Central and Eastern Europe in the Late Pleistocene and Holocene in the Interglacial and Transitional Stages of Climatic Macrocycles. Moscow: GEOS. 228 p. [in Russian; *Новенко Е.Ю.* 2016. Изменения растительности и климата Центральной и Восточной Европы в позднем плейстоцене и голоцене в межледниковые и переходные этапы климатических макроциклов. М.: ГЕОС. 228 с.]

*Novenko E., Tsyganov A., Volkova E., Kupriyanov D.A., Mironenko I.V., Babeshko K.V., Utkina A.S., Popov V., Mazei Y.A.* 2016. Mid- and Late Holocene vegetation dynamics and fire history in the boreal forest of European Russia: A case study from Meshchera Lowlands // Palaeogeography, Palaeoclimatology, Palaeoecology. Vol. 459. P. 570-584.

*Novenko E.Y., Tsyganov A.N., Olchev A.V.* 2018. Palaeoecological data as a tool to predict possible future vegetation changes in the boreal forest zone of European Russia: a case study from the Central Forest Biosphere Reserve // IOP Conference Series: Earth and Environmental Science. Vol. 107. P. 012104 (1-6).

*Novenko E.Yu., Olchev A.V.* 2015. Early Holocene vegetation and climate dynamics in the central part of the East European Plain (Russia) // Quaternary International. Vol. 388. P. 12-22.

*Novenko E.Yu., Tsyganov A.N., Babeshko K.V., Payne R.J., Li J., Mazei Y.A., Olchev A.V.* 2019. Climatic moisture conditions in the north-west of the Mid-Russian Upland during the Holocene // Geography, Environment, Sustainability. Vol. 12. P. 188-202.

*Novenko E., Tsyganov A., Volkova E., Mazei N.G., Volkova E.M., Chernyshov V.A., Kupriyanov D.A., Mazei Y.A.* 2015. The Holocene palaeoenvironmental history of Central European Russia reconstructed from pollen, plant macrofossil and testate amoeba analyses of the Klukva peatland, Tula region // Quaternary Research. Vol. 83. P. 459-468.

*Olchev A.V., Getmanova E.R., Novenko E.Y.* 2020. A modeling approach for reconstruction of annual land surface evapotranspiration using palaeoecological data // IOP Conference Series: Earth and Environmental Science. Vol. 438. P. 012021.

PAGES 2k Consortium. 2013. Continental-scale temperature variability during the past two millennia // Nature Geoscience. Vol. 6. P. 339-346.

PAGES 2k Consortium. 2017. A global multiproxy database for temperature reconstructions of the Common Era // Scientific Data. Vol. 4 (170088). P. 1-33.

Paleoclimates and Paleolandscapes of the Extratropical Area of Northern Eurasia. Late Pleistocene-Holocene. Atlas-monograph. 2009. Moscow: GEOS. 120 p. [in Russian; Палеоклиматы и палеоландшафты внетропического пространства Северной Евразии. Поздний плейстоцен-голоцен. Атлас-монография. 2009. М.: ГЕОС. 120 с.]

*Panin A., Matlakhova E.* 2015. Fluvial chronology in the East European plain over the last 20 ka and its palaeohydrological implications // Catena. Vol. 130. P. 46-61.

*Perşoiu A., Ionita M., Weiss H.* 2019. Atmospheric blocking induced by the strengthened Siberian High led to drying in west Asia during the 4.2 ka BP event – a hypothesis // Climate in the Past. Vol. 15. P. 781-793.

*Pleskot K., Apolinarska K., Kołaczek P., Suchora M., Fojutowski M., Joniak T., Kotrys B., Kramkowski M., Słowiński M., Woźniak M., Lamentowicz M.* 2020. Searching for the 4.2 ka climate event at Lake Spore, Poland // CATENA. Vol. 191. P. 104565 (1-14).

*Ralska-Jasiewiczowa M.* 1989. Environmental changes recorded in lakes and mires of Poland during the last 13,000 years // Acta Palaeobotanica. Vol. 29. P. 1-120.

*Ralska-Jasiewiczowa M., Nalepka D., Goslar T.* 2003. Some problems of forest transformation at the transition to the oligocratic/Homo sapiens phase of the Holocene interglacial in northern lowlands of central Europe // Vegetation History and Archaeobotany. Vol. 12. P. 233-247.

*Roland T.P., Caseldine C.J., Charman D.J., Turney C.S.M., Amesbury M.J.* 2014. Was there a '4.2 ka event' in Great Britain and Ireland? Evidence from the peatland record // Quaternary Science Reviews. Vol. 83. P. 11-27.

*Sapelko T.V., Kuznetsov D.D., Korneenkova N.Yu., Denisenkov V.P., Ludikova A.V.* 2014. Paleolimnology of the Inner Lakes of the Putsaari Island (Lake Ladoga) // News of the Russian Geographical Society. Vol. 146. No. 3. P. 29-40. [in Russian; *Сапелко Т.В., Кузнецов Д.Д., Корнеенкова Н.Ю., Денисенков В.П., Лудикова А.В.* 2014. Палеолимнология внутренних озер острова Путсаари (Ладожское озеро) // Известия Русского географического общества. Т. 146. № 3. С. 29-40.]

*Seppä H., Poska A.* 2004. Holocene annual mean temperature changes in Estonia and their relationship to solar insolation and atmospheric circulation patterns // Quaternary Research. Vol. 61. P. 22-31.

*Sidorchuk A.Yu., Panin A.V., Borisova O.K.* 2012. Decrease in River Runoff in the Plains of Northern Eurasia during the Holocene Optimum // Water Resources. Vol. 39. No. 1. P. 40. [in Russian; *Сидорчук А.Ю., Панин А.В., Борисова О.К.* 2012. Снижение стока рек равнин Северной Евразии в оптимум голоцена // Водные ресурсы. Т. 39. № 1. С. 40.]

*Sidorchuk A.Yu., Panin A.V., Borisova O.K.* 2018. River Runoff in the East European Plain over the Last 20 Thousand Years and the Problem of Changes in the Southern Seas Water Levels // Questions of Geography. No. 145. P. 144-168. [in Russian; *Сидорчук А.Ю., Панин А.В., Борисова О.К.* 2018. Речной сток на восточно-европейской равнине за последние 20 тысяч лет и проблема изменения уровней южных морей // Вопросы географии. 2018. № 145. С. 144-168.]

*Solomina O.N.* 2010. Climatic Reasons for Fluctuations of the Mountain Glaciers in the Holocene // Ice and Snow. No. 1. P. 103-110. [in Russian; *Соломина О.Н.* 2010. Климатические причины колебаний горных ледников в голоцене // Лед и снег. № 1. С. 103-110.]

*Solomina O., Haeberli W., Kull C., Wiles G.* 2008. Historical and Holocene glacier–climate variations: General concepts and overview // Global and Planetary Change. Vol. 60. P. 1-9.

*Starkel L., Michczyńska D.J., Krąpiec M., Margielewski W., Nalepka D., Pazdur A.* 22013. Progress in the Holocene chrono-climatostratigraphy of Polish territory // Geochronometria. Vol. 40. No. 1. P. 1-21.

*Subetto D.A., Davydova N.N., Sapelko T.V., Wolfart B., Vastegard S., Kuznetsov D.D.* 2003. Climate of North-West Russia at the Turn of the Pleistocene and Holocene // News of RAN. Geographic Series. No. 5. P. 80-91. [in Russian; *Субетто Д.А., Давыдова Н.Н., Сапелко Т.В., Вольфарт Б., Вастегорд С., Кузнецов Д.Д.* 2003. Климат северо-запада России на рубеже плейстоцена и голоцена // Известия РАН. Серия географическая. № 5. С. 80-91.]

*Tarasov P.E., Guiot J., Cheddadi R., Andreev A.A., Bezusko L.G., Blyakharchuk T.A., Dorofeyuk N.I., Filimonova L.V., Volkova V.S., Zernitskaya V.P.* 1999. Climate in northern Eurasia 6000 years ago reconstructed from pollen data // Earth and Planetary Science Letters. Vol. 171. P. 635-645.

*Tarasov P.E., Savelieva L.A., Long T., Leipe C.* 2019. Postglacial vegetation and climate history and traces of early human impact and agriculture in the present-day cool mixed forest zone of European Russia // Quaternary International. Vol. 516. P. 21-41.

*Teller J.T., Leverington D.W., Mann J.D.* 2002. Freshwater outbursts to the oceans from glacial Lake Agassiz and their role in climate change during the last deglaciation // Quaternary Science Reviews. Vol. 21. P. 879-887.

*Thomas E.R., Wolff E.W., Mulvaney R., Steffensen J.P., Johnsen S.J., Arrowsmith C., White J.W.C., Vaughn B.H., Popp T.* 2007. The 8.2 ka event from Greenland ice cores // Quaternary Science Reviews. Vol. 26. P. 70-81.

*Van Geel B.* 1978: A palaeoecological study of Holocene peat bog sections in Germany and the Netherlands, based on the analyses of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals // Review of Palaeobotany and Palynology. Vol. 25. P. 1-120.

*Velichko A.A.* 2012. Evolutionary Geography: Problems and Solutions. Moscow: GEOS. 563 p. [in Russian; *Величко А.А.* 2012. Эволюционная география: проблемы и решения. М.: ГЕОС. 563 с.]

*Velichko A.A., Kremenetsky K.V., Negendank J., Mingram J., Borisova O.K., Gribchenko Yu.N., Zelikson E.M., Klimanov V.A., Novenko E.Yu., Pirumova L.G., Pisareva V.V., Razumovsky L.V., Timireva S.N.* 2001. Late Quaternary Paleogeography of Northeastern Europe (Based on the Data of a Comprehensive Study of Sediments of Lake Galichskoye) // News of RAN. Geographic Series. No. 3. P. 42-54. [in Russian; *Величко А.А., Кременецкий К.В., Негенданк Й., Минграм Й., Борисова О.К., Грибченко Ю.Н., Зеликсон Э.М., Климанов В.А., Новенко Е.Ю., Пирумова Л.Г., Писарева В.В., Разумовский Л.В., Тимирева С.Н.* 2001. Позднечетвертичная палеогеография северо-востока Европы (по данным комплексного изучения осадков Галичского озера) // Известия РАН. Серия географическая. № 3. С. 42-54.]

*Vinther B.M., Clausen H.B., Johnsen S.J., Rasmussen S.O., Andersen K.K., Buchardt S.L., Dahl-Jensen D., Seierstad I.K., Siggaard-Andersen M.-L., Steffensen J. P., Svensson A., Olsen J., Heinemeier J.* 2006. A synchronized dating of three Greenland ice cores throughout the Holocene // Journal of Geophysical Research. Vol. 111. P. X1-X9.

*Walker M., Head M.J., Berkelhammer M., Svante B., Cheng H., Cwynar L.C., Fisher D., Gkinis V., Long A., Newnham R., Rasmussen S.O., Weiss H.* 2019. Subdividing the Holocene Series/Epoch: formalisation of stages/ages and subseries/subepochs, and designation of GSSPs and auxiliary stratotypes // Journal of Quaternary Science. Vol. 34. P. 173-186.

*Wanner H., Beer J., Butikofer J., T. J. Crowley, U. Cubasch, J. Flückiger, H. Goosse, M. Grosjean, F. Joos, J.O. Kaplan, M. Küttel, S.A. Müller, I.C. Prentice, O. Solomina, T.F. Stocker, P. Tarasov, M. Wagner, M. Widmann.* 2008. Mid- to Late Holocene climate change: an overview // Quaternary Science Reviews. Vol. 27. P. 1791-1828.

*Wohlfarth B., Lacourse T., Bennike O., Subetto D., Tarasov P., Demidov I., Filimonova L., Sapelko T.* 2007. Climatic and environmental changes in north-western Russia between 15,000 and 8000 cal yr BP: a review // Quaternary Science Reviews. Vol. 26. P. 1871-1883.

*Wu H., Guiot J., Brewer S., Guo Z.* 2007. Climatic changes in Eurasia and Africa at the last glacial maximum and mid-Holocene: reconstruction from pollen data using inverse vegetation modeling // Climate Dynamics. Vol. 29. P. 211-229.

*Yershova E.G., Krenke N.A.* 2014. Study of Natural and Cultural Landscapes of the Iron Age in the Moskva River Valley Using Palynology and Archeology Methods // Bulletin of Archeology, Anthropology and Ethnography. No. 3. P. 159-172. [in Russian; *Ершова Е.Г., Кренке Н.А.* 2014. Изучение природных и культурных ландшафтов железного века в долине Москвы-реки методами палинологии и археологии // Вестник археологии, антропологии и этнографии. № 3. С. 159-172.]

*Zagwijn W.H.* 1994. Reconstruction of climate change during the Holocene in western and central Europe based on pollen records of indicator species // Vegetation History and Archaeobotany. Vol. 3. P. 65-88.

*Zernitskaya V.P., Matveev A.V., Timereva S.N.* 2010. The History of the Ivanisovka Bog Formation (Belarusian Polesia) // Lithosphere. No. 1 (32). P. 20-30. [in Russian; *Зерницкая В.П., Матвеев А.В., Тимерева С.Н.* 2010. История формирования болота Иванисовка (Белорусское Полесье) // Літасфера. № 1 (32). С. 20-30.]

*Zernitskaya V., Mikhailov N.* 2009. Evidence of early farming in the Holocene pollen spectra of

Belarus // Quaternary International. Vol. 203. P. 91-104.

*Zernitskaya V.P., Novenko E.Yu.* 2016. Reconstruction of Belarusian Climate in the Late Glacial and Holocene // Engineering Journal: Science and Innovations. Vol. 9. No. 163. P. 21-24. [in Russian; *Зерницкая В.П., Новенко Е.Ю.* 2016. Реконструкция климата Беларуси в позднеледниковье и голоцене // Инженерный журнал: наука и инновации. Т. 9. № 163. С. 21-24.]

*Zernitskaya V.P., Novenko E.Yu., Stanchikayte M., Vlasov B.P.* 2019. Environmental Changes in the Late Ice Age and Holocene in the South-East of Belarus // Reports of the National Academy of Sciences of Belarus. Vol. 63. No. 5. P. 584-596. [in Russian; *Зерницкая В.П., Новенко Е.Ю., Станчикайте М., Власов Б.П.* 2019. Изменения окружающей среды в позднеледниковье и голоцене на юго-востоке Беларуси // Доклады НАН Беларуси. Т. 63. № 5. С. 584-596.]