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Abstract

An overview of the archaeological and palaeoenvironmental data from the south-eastern Baltic (Kaliningrad region) is presented on the background of the Holocene climate description. Information on natural palaeoarchives (lakes Kamyshovoe and Chistoe, as well as bogs Kozje, Velikoe, Zelau) combined with archaeological materials from prehistoric sites provides a picture of ancient anthropogenic activity and main stages of evolution of local communities

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starting from the Mesolithic. Modern Analog Technique (MAT) method applied for the Kamyshovoe lake palynological data is used to reconstruct the seasonal temperature and precipitation trends and values during the Holocene in the south-eastern Baltic and to provide a background to ancient human activity. During the Mesolithic, climate conditions changed from those close to the late Glacial through a period of warmer and wetter climate with parameters close to the present day to conditions of climatic optimum, when temperature was several degrees higher that modern ones. Archaeological material testifies that the subsistence strategies of that time were based on fishing, fowling and hunting along with active exploration of forest plant resources, though due to scarcity of data, tracing changes in human activities corresponding to dynamic of climate and palaeoenvironment is difficult. While the first part of the Neolithic fell during the Holocene climatic optimum, from about 5500 cal yr BP the climate changed towards colder temperatures and a shift in seasonal moisture content: summers became wetter and winters less snowy. Farming (cattle breeding and plant cultivation) started to play a role in the subsistence strategy of the local Neolithic population, gaining more importance during the Bronze Age, a period with relative temperature stability but significant precipitation fluctuations. Since the start of the Iron Age (2800 cal yr BP), intensity of anthropogenic activity (farming and metallurgy) in the south-eastern Baltics grew with some interruptions during the Migration period (5-6th centurues AD) and the Teutonic Order's conquest of the area in the 13-14th centuries AD. Since the Iron Age, temperatures remain close to modern ones. Several “wetter” episods are distinguished coinciding with the Roman Time, Migration Period and the Little Ice Age during the Medieval Period.

Keywords: anthropogenic activity, archaeology, prehistory, palaeoclimate, south-eastern Baltic, Modern Analog Technique method

1. Introduction

The Holocene, despite the relatively short duration in geological terms, is a period when radical changes in climate occurred, the main features of modern landscapes were formed, and significant anthropogenic changes in the natural environment first manifested. As an interglacial period, the Holocene appears to be an interval of relatively warm and stable climate. However, numerous fluctuations of precipitation and temperature are visible on a more detailed time scale, showing that climate changed essentially during the last 11 700 years (Borisova, 2014).

Though large number of studies were carried out, the issues related to climatic fluctuations and their reflection at the local and regional level remain poorly understood (Mayewski et al., 2004). During the last decades, at the junction of palaeoclimatology and the humanities, mainly archaeology, a separate line of research formed with a focus on the role of the main climatic fluctuations in the development of human civilisation (Weninger et al., 2006; Chiotis et al., 2018; Novenko et al. 2019; Burke et al., 2021; Degroot et al., 2021). Thus, the influence of sharp climate changes on the heyday and decline of the ancient civilizations of the Middle East and the Mediterranean in the Middle and Late Holocene has been traced (Weninger et al., 2006; Chiotis et al., 2018; Shaikh Baikloo Islam at al., 2020); attempts have been made to identify the connection between individual climatic events with certain aspects of society development, eg. production technologies of flint tools and 8.2 ka BP cooling (Morisaki et al., 2018), drought at 4.2–3.9 ka BP and societal collapse and resilience across the Mediterranean and west Asia (Weiss, 2016), etc. The increasing attention to this topic is triggered by the understanding that the correlation of archaeological data and palaeoenvironmental archives offers a unique opportunity to observe the complex interactions between natural and anthropogenic systems under different climatic regimes and at different spatial and temporal scales (Burke et al., 2021; Degroot et al., 2021). This, in turn, can shed a light at the deep reasons for human society evolution, and serve as a basis for predictive constructions and recommendations for future strategies of interaction with environment.

Over the past decade, the main problems that hinder the development of this scientific direction have become clear: first of all, a critical lack of data at regional and local levels, as well as the lack of detailed data correlation from different branches of science - archaeology, palaeoclimatology, palaeogeography, etc. (Novenko et al., 2019; Degroot et al., 2021). With a significant amount of diverse unconsolidated information available, to date, there are no regional generalising interdisciplinary studies with a sufficient volume and resolution of palaeoecological information that would make it possible to trace or unambiguously demonstrate the influence of palaeoclimatic fluctuations on cultural - economic development of society at all stages of its evolution in the Holocene, especially when it comes to such regions that are insufficiently studied in palaeoecological and archaeological terms, such as the forest zone of Eurasia.

This article is a first step towards understanding of the “climate-ancient society” relation in the south-eastern Baltic. The natural environment of this region was in a stage of active formation during the last deglaciation and in the Holocene and its dynamic is consistently reflected in the palaeoarchives: lacustrine, bog, lagoon sediments (Druzhinina et al., 2015; 2020; 2023). Located at the intersection of several cultural regions, this territory reflects the historical processes that took place in wide areas of Eastern Europe (Suvorov, 1985). At the same time, the presence of unique reserves of amber made the southeastern Baltic, known as far back from the Mesolithic, a regional center of exchange, trade and attraction of various cultural traditions, including those associated with ancient technologies. This together may provide a new insight into the history of nature and society interaction in this part of Europe during the Holocene. This paper presents an overview of the available at the moment published palaeoecological information (Arslanov et al., 2011; Druzhinina et al., 2015, 2020, 2023; Napreenko et al., 2016, 2021) combined with data on economic activities in prehistory obtained from archaeological materials (unpublished reports on archaeological excavations of 1970^{th}; as well as Timofeev, 1996; Levkovskaya and Timofeev, 2004; Zhilin, 2013; Zaltsman, 2019) on the backgrond of detailed climatic reconstruction. The latter is completed using the Modern Analog Technique (MAT) method (Overpeck et al., 1985; Juggins, 2020), applied for the first time on data from the south-eastern Baltic. Previously obtained results of the palynological and geochronological analysis of the Kamyshovoe lake sequence (Druzhinina et al., 2015, 2020) are used for the MAT reconstruction. Function MAT takes a dataset of biological data (species abundances) and a single associated environmental variable, and generates a model of closest analogues, or matches, for the modern data using one of a number of dissimilarity coefficients (Juggins, 2020). Essential novelty of this research is that not only temperature but seasonal precipitation is also described and taken into account when considering the palaeoclimatic base for the prehistoric human activity in the south-eastern Baltic.

2. Study area. Methods and material.

2.1 Study area

The territory of the south-eastern Baltic (Kaliningrad region) is located in the west of the Russian (East European) Plain. The modern relief was formed as a result of the direct activity of glaciers of the last Valdai glaciation, as well as limno- and fluvioglacial processes. The territory is represented by an alternation of vast plains and lowlands with several hilly-ridge uplands. The climate of the region is transitional from the marine climate of Western Europe to the temperate continental climate of Eastern Europe. The cold period of the year ranges from 90 to 105 days with the mean January temperature from -3˚C on the coast to -6.5˚C in the east. The warmest month is July with an average monthly temperature of +16.5˚C to +18˚C. Air humidity is high: from 70% in summer to 80-90% in winter. The annual precipitation is 600-700 mm, its distribution over the territory and seasons is uneven. The area is in a zone of excess moisture. The entire territory of the south-eastern Baltic region belongs to the forest zone, to the mixed coniferous-deciduous forests landscape subzone. The structure of the soil cover is based on the change of soils from brown forest soils with a simple uniform profile to complex soddy-podzolic and soddy-eluvial-gley soils (Geographical..., 2002).

2.1 Palaeoenvironmental and archaeological materials

The palaeoenvironmental data considered in this paper were obtained from the Kamyshovoye and Chistoe lakes (Druzhinina et al., 2015, 2020, 2023) and Velikoe, Zelau and Kozje bogs study (Arslanov et al., 2011; Napreenko-Dorokhova et al., 2016; Napreenko et al., 2021) (Fig. 1). The data from palynological studies at Zedmar archaeological complex are also used (Levkovskaya and Timofeev, 2004). In addition to palynological research data, all of the listed objects have a reliable geochronological basis. The study of the Kamyshovoe sequence also included geochemical and chironomid analysis (Druzhinina et al., 2020, 2022, 2023). Detailed description of the methods is presented in the mentioned papers.

The archaeological materials considered in the article were obtained during excavations of the Vyshtynets Mesolithic sites (Zhilin, 2013); the Zedmar archaeological complex and Utinoe Boloto site, attributed to the late Mesolithic – Neolithic Zedmar Culture (Timofeev, 1973, 1975, 1996); Pribrezhnoe and Ushakovo sites beloning to the Primorskaya Corded Ware Culture Group (Zaltsman, 2019); and Grachevka, Russkoe, and Salskoe Iron Age sites (Gurevitch, 1960; Koval, 2021). Archaeological research at the majority of these sites was complemented by zoo-archaeological and macrobotanical studies (Gurevitch, 1960; Timofeev, 1996; Zaltsman, 2019), while use-wear analysis was perfomed at Vyshtynets and Zedmar tool assamblages (Zhilin, 2013; Timofeev, 1975, 1996).

2.2. Palaeoclimate reconstruction

The palynological data used for the quantitative climate reconstruction have been obtained during the Kamyshovoe lake study (Druzhinina et al., 2015, 2023). The sub-samples of 1–3 cm^3 for pollen analysis were prepared and investigated using a standard chemical procedure (Erdtman, 1936; Grichuk, 1940), including treatment of the sediments with a heavy liquid (CdI_2+KI). Lycopodium spores were added in order to calculate pollen concentrations (Stockmarr, 1971). Pollen identification was based on Moore et al. (1991). In the most of the samples number of counted terrestrial pollen grains exceeded 500 with exception of some samples where the number of pollen grains was extremely low. The Kamyshovoe lake pollen diagram is published in the previous works (Druzhinina et al., 2015, 2023).

In total, 141 samples were used for climate reconstruction, including 120 for the Holocene part of the sequence. Before the reconstruction, fossil pollen records were adjusted to the datasets. All taxon names were harmonized to ensure compatibility between modern and fossil datasets. Almost all the terrestrial pollen types found in the sediments were used for the reconstruction, except some water plants, such as Cyperaceae and *Typha*. The reconstruction was made by the application of the Modern Analog Technique (MAT) using a function integrated with the Rioja package (Juggins, 2020) for R (version 4.2.0) (R Core Team, 2021). The European modern pollen dataset (EMPD) by Davis et al. (2020) was utilized for the reconstruction. The technique is based on a large reference dataset of modern pollen assemblages which is compiled from various geographic locations. Each sample in this dataset is associated with known climate data (e.g., mean annual temperature, seasonal precipitation). Each fossil pollen assemblage is statistically compared to this dataset using similarity measures. Once the closest modern analogs are identified, the climate parameter are averaged to infer the climate conditions for the time period represented by the fossil pollen sample. More details on the method applied can be found in Gedminienė et al. (*In prep*.).

3. Results and Discussion

3.1 Mesolithic (11700 – 6500 cal yr. BP)

People began to explore the south-eastern Baltic territory during the late Palaeolithic – early Mesolithic (Druzhinina, 2010; Druzhinina et al., 2023). The previously obtained chironomid data for the Kamyshovoe lake show that from 11 900 to 11 500 cal yr BP a period of gradual increase in summer temperatures begins (Druzhinina et al., 2020). Based on chironomid data and geochemical indicators, short-term climatic oscillations were recorded ~11 400; 11 200; 10 700; 10 400; 9700; 9300 and 8200 cal yr BP (Druzhinina et al., 2020). During the cooling periods, summer temperatures remained at the values characteristic of the Yonger Dryas, and warming comparable to the Allerød apparently occurred only after 9700 cal yr BP, when the value of the mean July temperature reached +15...+15.2 °C. A relatively stable but gradual temperature increase was reconstructed after 9500 cal yr BP (Druzhinina et al., 2020). MAT reconstruction provides a similar summer temperature trend and points at the more severe winters between 11 300 and 10 300 cal yr BP (Fig. 2). During this interval, along with the reduced snow precipitation mean winter temperature droped to -15 °C, which is about 5 degrees lower than at the beginning of the Holocene. According to MAT reconstruction, seasons became mild and wet after 10 300 and till 9900 cal yr BP, when summer and winter precipitation grew up to 70-90 mm per month, and winter temperature reached -1…-2 °C. Further, summer temperatures increased to about +16 °C and were accompanied by decreased precipitation, while winters became dryer and colder (mean T DJF up to -5 °C). The increase in mean annual temperature, which began about 9000 cal yr BP, marked the onset of the Holocene Climatic Optimum (HCO) with summer and winter temperatures reaching +19 °C and +1 °C accordinally. During the Mesolithic this wamer period was interrupted by several coolings: the "8.2 event", short-term climate fluctuation centered at 7800 – 7600 and a cooling of 7100 – 6600 cal yr BP (Fugure 2).

Undoubtedly, climatic instability was also reflected in the Early Holocene vegetation dynamics. The proportion of birch (*Betula*) and pine (*Pinus*) in the forests composition fluctuated with a gradual increase in the amount of the latter, while the density of vegetation cover changed insignificantly. Elm (*Ulmus*) appeared in the forests of the south-eastern Baltic from about 11 000 cal yr BP, hazel (*Corylus*) became widespread from 10 400 cal yr BP, and later - from 9700 cal yr BP - broadleaved species became increasingly important (Druzhinina et al., 2015; 2020).

Due to the scarse archaeological research, the knowledge on the local south-eastern Baltic Mesolithic communities remains rather general and does not allow tracing changes in subsistence strategies, which probably existed in dynamic palaeoenvironment. Recent studies of early to late Mesolithic sites in the Baltic sea area demonstrate high adaptive flexibility of subsistance strategies and considerable botanical knowledge of Mesolithic communities about local and regional vegetation distributions in different ecozones, using selected taxa for specified tasks (Blaesild et al., 2024; Wačnik et al., 2020; Druzhinina et al., 2023). Archaeological data testify that the subsistence strategies of that time were based on fishing, fowling and hunting along with active exploration of forest plant resources for such daily-life activities as woodworking, textile making, basketry, etc. While the earliest items from organic materials (utensils, traps, etc.) are found in Poland at Szczepanki site (Wačnik et al., 2020), the Mesolithic activities listed above are reflected in the results of the use-wear analysis of flint assamblage from the Mesolithic sites located on the shores of lake Vishtynetskoe (Fig. 1) (Zhilin, 2013). Starting from ~ 10 500 cal yr BP regional pollen and geochemical data testify the first signs of anthropogenic pressure on the landscapes. At that time, the presence of localised deforestation is recorded in the pollen spectra of lakes Kamyshovoe and Chistoe (Druzhinina et al., 2023). Woods may have been burned not only to increase hunting and mobility, but also to spread certain plant species, of which hazel was probably the most important as it constituted part of the Mesolithic diet, was used for various economic purposes (as wood, fibres) and as fuel (Bishop et al. 2015; Gross et al. 2019). Thus, *Corylus* in the pollen spectra in the Kamyshovoe and Chistoe lakes fluctuates between 20 and 40 % throughout the Mesolithic, which is much higher than, for example, the value of it in the Kozje Bog spectrum, not exceeding 2-3 % (Napreenko et al., 2021). The archaeological and palaeobotanical evidence of hazel propagation and simultaneous forest burning was obtained in the neighbouring territories of Suwalki Upland (Wačnik et al. 2020). High values of *Corylus* in the Kamyshovoe pollen record are accompanied by the simultaneous peaks of bracken (*Pteridium aquilinum*, up to 18 %) and the elevated values of geochemical indicators of wood fuel burning (Ba, Sr) (Druzhinina et al., 2023).

3.2 Neolithic (6500 – 4000 cal yr BP)

The Neolithic Period in the south-eastern Baltic coincides with the second half of the HCO and embraces the change of climate, which occured afterwards. According to MAT reconstruction, the Mesolithic – Neolithic transition took place during the relatively long-lasting climatic cooling from 7100 to 6600 cal yr BP. Along with the lower temperature (+16 °C), both summer and winter humidity grew. Wamer and dryer conditions recovered around 6500 cal yr BP and continued until 5500 cal yr BP, except the cooling centered at 6300 – 6200 and the "5.9 event", which is expressed by the short-lasting drop of summer temperature reflected on the MAT reconstruction curves at around 5800 cal yr BP. During the second half of the Neolithic, from ~5500 cal yr BP onwards, the climate started to change substantionally. The mean summer temperature lowered from +19 to +14…16 °C. The lowering of winter temperature was more expressed: from +1 to -5…-7°C. While summer precipitation had increasing trend (from max 80-90 mm per month during the HCO up to 100 mm per month at the end of the Middle Holocene, around 4200 cal yr BP), winters became dryer (from 60 to 40 mm per month respectively). Within the slightly fluctuating climatic trends, several episods deserve attention. Around 5200 cal yr BP, the period with softer and snowy winters took place. Later, conditions close to the HCO with warm, dry summers were observed at ~4700 cal yr BP. The Neolithic – Bronze Age transition is marked by the interval (4100 – 4000 cal yr BP) with the dryest and colder winters on the general background of raising humidity.

During the first half of the Neolithic temperate deciduous forests (Quercetum mixtum) spread over, while values of pine (*Pinus*) and birch (*Betula*) reduced. Oak (*Quercus*), elm (*Ulmus*), lime (*Tilia*) and hazel (*Corylus*) were the main elements (Napreenko et al., 2021). Composition of vegetation started to change at 6000 - 5500 cal yr BP with the end of HCO and was expressed in reduction of deciduous forests and spreading of spruce (*Picea*).

The Neolithic of the region is represented by sites of the two archaeological cultures best studied so far: the Zedmar (Zedmar and Utinoe Boloto sites) and the Primorskaya Corded Ware Culture Group (Pribrezhnoe and Ushakovo sites). In Poland, archaeological studies of the sites also attributed to the Zedmar culture indicate that a new strategy of settling and economy with stationary settlements was spread in this region during the Mesolithic-Neolithic transition (Wačnik et al., 2020). Thus, the significant growth of the local population is indicated by the increased amount and diversity of archaeological finds (animal bones, pottery, flint and stone tools, bone and wooden implements, amber ornaments, dwelling objects, fireplaces, burials) starting from 6500 cal yr BP at Szczepanki site (Wačnik et al., 2020). Emergence of stationary settlements probably inhabited all year round together with a significant growth of the local population resulted in increased anthropogenic pressure on the local landscapes, visible in archaeological and palaeocological data from Kaliningrad region (Druzhinina, 2023). The growing number of plants-indicators of anthropogenic activity (weed, pasture, and meadow plants), microcharcoal and *Pteridium* peaks, presence of Onagraceae (cypress) in the Kamyshovoe and Chistoe pollen records attests to a larger extent of open spaces and wood exploitation starting from ~7000 cal yr BP, while TiO_2 as an indicator of soil erosion shows a gradually increasing trend from ~ 6000 cal yr BP (Druzhinina et al., 2023). Microcharcoal data combined with information on pollen of ruderals, open habitats, and dry pastures, reflect the peaks of human activity at ~ 6300, 5900, 5700, 5200, 4700, 4300, 4000 cal yr. BP.

Fishing, fowling and hunting remained major occupations of the early Neolithic people, as stated from large bone collection at Utinoe Boloto site, represented by wild boar, tur, elk, roe deer, red deer, bear, marten; pike or perch and bird remains (Timofeev, 1975). Bones of cattle, goats/sheep found at Zedmar site provide the first zooarchaeological evidence of domestication and small scale local cattle breeding in this part of the Baltic region at least from ~6000 cal yr BP (Timofeev, 1975, 1996). *Plantago lanceolata* as indicator of agriculture and, in particular, grazing is present in the pollen spectra from 6300 cal yr BP (Druzhinina et al., 2023). During the first half of the Neolithic the earliest attempts to plant cultivation took place. At the Zedmar site, bone and horn tools for soil tilling, identified by use-wear analysis and with the earliest dating of 6950 - 5550 cal yr BP were found. The earliest archaeological layer at Zedmar containing Cerealia and *Fagopyrum* pollen is dated to 5990 - 5710 cal yr BP (Druzhinina, 2023). Along with Cerealia, pollen of segetal and ruderal weeds (Brassicaceae, *Chenopodium, Plantago lanceolata*) were detected in the simultaneous cultural layer. During the second half of the Neolithic period, from 5200 – 5100 cal yr BP, a new stage of the prehistoric farming is observed, when agriculture seems to expand in scale and importance in this part of the Baltic (Druzhinina, 2023). This is evidenced from pollen record at Kozje Bog (since 5100 cal yr BP) and archaeological finds of stone mattocks, grinding stones, pestle grinders and charred grains of wheat embracing intervals of 5250 – 4850 cal yr BP at Pribrezhnoe and 5100 – 3750 cal yr BP at Ushakovo sites. Data from Zedmar site and Chistoe lake indicate the constant presence of Cerealia in the pollen spectrum since 4400 cal yr BP and 4600 cal yr BP respectively. Available archaeological and palaeogenetic data point that aforementioned changes in subsistence strategy related to increasing role of agriculture can be connected to the inflow of new population - agriculturalists from the Cord Ware Culture (Druzhinina, 2023).

3.3 Bronze Age (4000 – 2800 cal yr BP)

The Bronze Age in the south-eastern Baltic can be generally characterised as a period with a relatively stable temperature trend fluctuating near +15 °C during summer and -5°C in winter, but with sharp and essential changes in precipitation (Fig. 2). After short interval (4100 – 4000 cal yr BP) with the dryest and colder winters in the beginning of the period, the remarkable growth of amount of rain and snow occurred in the region. The highest peak of summer precipitation throughout the Holocene is reconstructed for the time ~3700 cal yr BP (120 mm per month). After 3500 cal yr BP it drops to 75 mm per month and further fluctuates not exceeding 90 mm, except for a short-lasting peak of precipitation at ~3100 cal yr BP (107 mm per month). The similar trend is observed for winter as well. The ”2800” cold event, recorded in many natural archives in Europe (Borisova, 2014) marks the end of the Bronze Age in the south-eastern Baltic. According to MAT reconstruction, the cooling was expressed in slightly colder winters and the beginning of a long-lasting trend for reduced precipitation both in summer and winter.

In the Bronze Age, the main feature of vegetation evolution was recovery of pine in the composition of woods, along with continuouse substantial presence of spruse, lime and alder (Napreenko et al., 2021, Druzhinina et al., 2023).

Few details of the Bronze Age settling strategy and economy are known from local archaeological data, so far represented mostly by grave mounds and by the corresponding horizons of Pribrezhnoe and Ushakovo sites (Zaltsman, 2019). According to the latter and to the regional palynological evidence, farming became one of the main occupations of the population (Druzhinina et al., 2023). Cerealia continued to be present in the pollen spectra of Zedmar site and Chistoe lake throughout the Bronze Age. In the Kamyshovoe sediments, Cerealia emerged at ~ 3800 and 2800 cal yr. BP, while in the Kozje Bog a remarkable peak is recorded in the interval 4000 – 3500 cal yr BP. Presence of Cerealia correlates with a simultaneous increase of ruderals and *Pteridium* curves on the pollen diagrams. Taking into account increased agricultural activities, part of the pine forests could also have a secondary origin reflecting human-induced deforestation.

During this historical period, metal became increasingly integral to human life and metallurgy as a new essential activity began to play a role in an anthropogenic impact on landscapes of the south-eastern Baltic (Druzhinina et al., 2022, 2023). Probably, a diverse trade of metal existed in the Baltic and in Scandinavia: finished and prefabricated metal products were transported here from various centres and re-smelted in local workshops according to local traditions and demand (Holmqvist, et al. 2019). While the early Bronze Age (before 3100 cal yr BP) metal producing evidence is rare, several dozen of later sites where bronze casting remains have been found are discovered in the Baltic region from Estonia to Poland (Podėnas and Čivilytė, 2019). A major simultaneous increase in content of the Pb, Ni, Zn and As indicators of metallurgical production since ~3100 cal yr BP in the Kamyshovoe lake sediments may show a growing demand for metal objects in the south-eastern Baltic area, and input of local or regional metal smelting workshop pollution into lakes (Druzhinina et al., 2022).

3.4 Iron Age (2800 – 1400 cal yr BP)

According to the MAT reconstruction, during the Iron Age, the stable temperature trend continued with a mean summer temperature of +16 °C and winter values of -6…-7 °C, except for a period with slightly higher temperature of -4 °C during 2500 – 2000 cal yr BP. The Iron Age embraces the period with stability in precipitation (70-80 mm per month in summer and 40 mm per month in winter). Increased values of this parameter are recorded only for the aforementioned interval with wamer winters, probably marking the beginning of Roman Climatic Optimum. The period under consideration clearly correlates with the visible on the pollen diagrams deforestation (lakes Kamyshovoe, Chistoe; bogs Kozje, Velikoe, Zelau) as the share of NAP increased gradually (Arslanov et al., 2011; Napreenko-Dorokhova et al., 2016; Napreenko et al., 2021; Druzhinina et al., 2023). Secondary pine and birch forests seem to take over the natural vegetation. Spruce remains one of the main species in the woods. Remarkable feature of the Iron Age vegetation is maximum speading of hornbeam (*Carpinus*), reflected in all studied pollen records.

The Iron Age saw a new phase in the intensification of anthropogenic activity. Continuous cultivation of crops and an increasing variety of Cerealia is observed in the region. Pollen of *Secale, Hordeum, Triticum* along with pollen of segetal (*Centaurea cyanus, Chenopodium album, Cannabis*, etc.) and ruderal (species of Asteraceae, Chenopodiumaceae, *Plantago, Polygonum, Urtica*, etc.) weeds recorded in Kamyshovoe, Chistoe, Kozje, Zelau and

Velikoe sequences indicate that the area of arable land was expanding. Archaeological sites attributed to this period provide a substantial macrobotanical evidence for agricultural activities. Besides farming inventory represented in many archaeological assamblages, the Grachevka finds contain charred and non-charred grains of wheat (*Triticum vulgare* and *Triticum aestivum*) and millet (*Panicum miliaceum L.*), while during the excavation of Russkoe site numerous finds of cultivated pea (*Pisum sativum*) were obtained (Gurevitch, 1960; Koval, 2021).

During this period, iron replaced bronze as the most common metal used for making utensils, tools and weapons. One of the advantages of iron over bronze was the availability of raw materials (i.e. lake and bog ores), whereas bronze production needed copper and tin ores, which had to be transported and traded. Iron-smelting required much more heat during the process, thus increasing demand for wood and charcoal and causing further deforestation. Metal slags are found at Salskoe, Russkoe, Grachevka and other sites in Kaliningrad region (Gurevitch, 1960; Koval, 2021). Increase in content of the metallurgical production indicators in the Kamyshovoe sequence continues during the entire interval dated to Iron Age period (Druzhinina et al., 2022, 2023).

3.5 Migration period and Medieval Times (1400 – 400 cal yr BP)

According to MAT reconstruction, the period of relative temperature stabily continued during the time under consideration (Fig. 2). On the contrast to temperature trend, two episods with high peaks of precipitation are observed. The first one at ~1400 cal yr BP shows a sharp increase both in summer (from 70 to 105 mm per month) and winter (from 40 to 60 mm per month) precipitation accompanied by a temperature fluctuation of several degrees, causing colder summer, but wamer winter (Fig. 2). Apparently, this character of climatic change could be related with double-eruption event at 536 AD and 540 AD (van Dijk et al., 2024). The products of volcanic eruptions released into the atmosphere not only change the temperature near the earth's surface, but also contribute to prolonged and/or abundant precipitation (Muravyev, 2007). Double eruptions or cluster eruptions are thought to have a more profound and longer-lasting impact on the surface climate than single ones. According to van Dijk et al. (2024), the double-eruption event in the mid-sixth century was exceptional not only in the CE, but also in the context of the Holocene.

The Migration Period in the European history is characterized by complex social-demographic processes and changes in power and development centres. The study of the anthropogenic activity and settling pattern in the southern Baltic (in particular, western and northen Poland) based on the 52 palynilogical records revealed essential regional differences in terms of chronology and the extent of anthropogenic colonisation reflected in deforestation and crop cultivation (Pędziszewska et al., 2020). During the Roman period (1th-4th century AD), particularly high values of settlement and agricultural indicators were characteristic of Suwalki Upland. The anthropogenic activity did not deminish here drastically also during the Migration period (4th-6th century AD), though the crisis of this time is reflected in the whole study area, as demonstrated by the rising values of forest indicators, reduction of anthropogenic indicators in the vegetation and the disappearance of cereal pollen from many sites (Pędziszewska et al., 2020). In the southern Baltic depopulation and change of settlement pattern began in the 3th–4th century AD and reached it maximum in the 5th-6th century AD. The simultaneous short-term drop of nearly all geochemical indicators of human activity in the interval dated to 4th-6th century AD is observed in the Kamyshovoe sediment record and so do the pollen data on cereals and other plants-anthropogenic indicators in Kamyshovoe and Kozje bog (Napreenko et al., 2021; Druzhinina et al., 2023). Remarkable increase of plants – indicators of soil erosion and grazing (*Artemisia, Plantago lanceolata, Rumex*) starts during this interval. The complex demographic and socio-economic situation of that period is probably reflected in the burials of the 6th-7th centuries AD on the Sambian Peninsula, which are characterised by the scarce funerary inventory (Suvorov, 1985).

The next peak of precipitation took place at ~700 - 600 cal yr BP (Fig. 2). Only summer precipitation values changed at that time: from 77 to 90 mm per month, probably marking the start of the Little Ice Age. Palaeogeographic data for the northern hemisphere and especially data on glaciers and vegetation show that climate changes started at around 700 - 600 cal yr BP were one the most abrupt and profound during the Holocene (Borisova, 2014). The effect of the Little Ice Age cooling, lasting from the 13th to the 19th century according to various estimates, affected medieval society in most parts of Europe (Wanner et al., 2008). Meanwhile, this cooling is hardly expressed on the MAT reconstruction curve. The possible reason may be that during this period the natural vegetation was largely altered by anthropogenic activities, so pollen data composition from this period used in the reconstruction mitigates the real climatic (at least temperature) curves. For example, studies by Pędziszewska et al. (2020) show that in the 9th-10th centuries significant areas in the southern Baltics (Poland) had already largely been deforested and the lands were used for farming purposes. In the south-eastern Baltics, since 7th-8th century AD, the increasing human activity is indicated not only by the considerable amount of settlements in that period (Suvorov, 1985), but also by the remarkable growth of the charcoal and geochemical anthropogenic indicators in the Kamyshovoe sequence (Druzhinina et al., 2023). The regional pollen diagrams (Kamyshovoe, Chistoe, Kozje, Velikoe, Zelau) show the growing amount of Cerealia, and *Secale, Triticum, Hordeum*, *Cannabis* and *Fagopyrum* are present in the spectra. This along with increasing percentage of indicators of pastures, meadows etc. testify that natural vegetation was altered to a high degree, therefore the palaeoclimatic pollen-based reconstruction could be biased.

In this part of the Baltic region, the onset of the Little Ice Age and the resulting changes in natural parameters coincide with the dynamic historical events associated with the Teutonic Order's conquest of the area in the 13-14th centuries (Suvorov, 1985). As previous studies have shown, during this period of struggle between the local population and the Crusader knights, there was a temporary desolation of lands and, on the contrary, an increase in anthropogenic load in certain territories, change of human activities, etc. (Druzhinina et al., 2023). These factors make it extremely difficult to divide causes into climate and anthropogenic when it comes to vegetation dynamics or reasons for certain changes in society.

4. Conclusion

The overview of the archaeological and palaeoenvironmental data from the south-eastern Baltic presented on the background of the detailed climatic description provides a framework for further research of the "climate - human" relation and role of climatic events in the evolution of human society. Within the recent state-of-the-art in archaeologicaland palaeoclimatic research, the following conclutions can be made.

According to the MAT reconstruction, during the Mesolithic, people lived in three different types of climatic conditions. From the beginning of the Holocene until 10 400 cal yr BP, the conditions were cold and close to those of the Younger Dryas; this was the time of birch-pine forest dominance. Then a period of warmer and wetter climate with parameters close to the present day began, causing a change in forest structure and an increase in the number of deciduous species. The third stage of the Mesolithic, since 8500 cal yr BP, took place in conditions of climatic optimum with the dominance of broad-leaved forests. Increase in archaeological data will make it possible to trace the changes in Mesolithic subsistence strategies that probably occurred with changing environmental conditions during that time.

The Mesolithic – Neolithic transition took place during the relatively long climatic cooling (7100 - 6600 cal yr BP) within climatic optimum. A new strategy of settling and economy with stationary settlements marked the beginning of the Neolithic, a period when development of society took place under dynamic climatic conditions as well. While the first part of the Neolithic fell during the climatic optimum of the Holocene and era of broad-leaved forests, from about 5500 cal yr BP the climate changed towards colder temperatures and a shift in seasonal moisture content: summers became wetter and winters less snowy, and the role of conifers increases in broadleaved forests. Since the Neolithic, farming (cattle breeding and plant cultivation) started to play a role in the subsistence strategy of the local population.

The beginning of the Bronze Age corresponds with a start of relative temperature stability in both summer and winter, with values close to modern ones. Along that, significant fluctuations in humidity during this historical period occured: maximum values of summer precipitation for the Holocene in the interval 3900 - 3700 cal yr BP and a sharp decrease in humidity in the second half of the period are recorded. Available archaeological and palynological evidence show that farming became one of the main occupations during the Bronze Age, and according to geochemical study of the lake sediments, since at least ~3100 cal yr BP metallurgy started to gain importance in life of ancient communities.

According to the palaeoclimatic data obtained, the Iron Age was apparently the epoch of the greatest climatic stability with temperatures close to modern ones and lower humidity, except for a wetter interval around 2200 - 2100 cal yr BP. Precipitation increased slightly during the Middle Ages, but remained below modern values. About 1400 cal yr BP (Migration Period) there was a slight temperature fluctuation accompanied by a sharp increase in precipitation, the cause of which should probably be attributed to a double volcanic eruption in AD 536 and 540. The smaller scale peak of precipitation reflected the beginning of the Little Ice Age, though temperature fluctuation is not expressed on the reconstructed curve. Generally, since the start of the Iron Age, intensity of anthropogenic activity in the south-eastern Baltics grew till recent, with some interruptions during the Migration period and local differences in its extent related to the Teutonic Order's conquest of the area in the 13-14th centuries.

The study showed that besides climate, anthropogenic activity had a significant impact on the vegetation cover of the area. The influence of the anthropogenic factor becomes visible from the Neolithic period onwards and has been increasing over the last 3000 years. Given this nuance, it is necessary to be more cautious rearding temperature reconstructions based on pollen data for this period as the himan-induced vegetation changes could mitigate reflection of the actual climate fluctuations.

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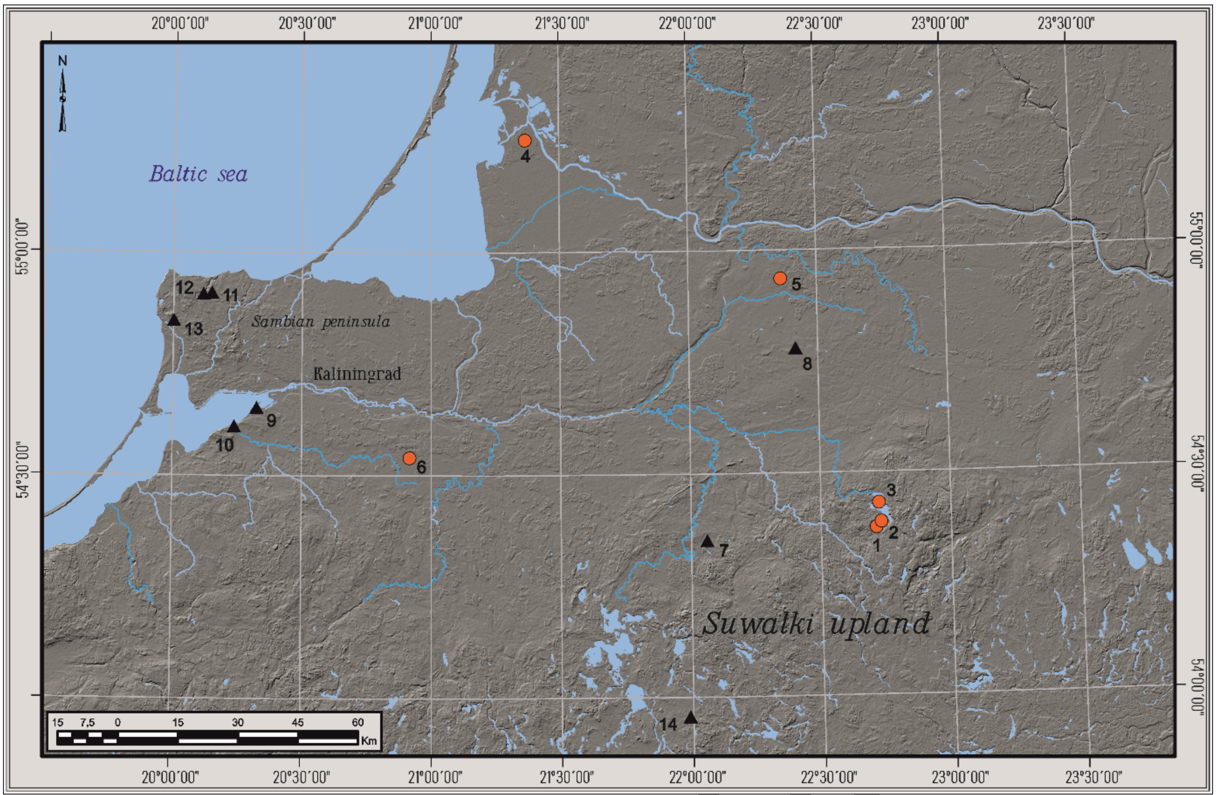

Fig. 1. Study area and locations mentioned in the text (dots – natural archives; triangles – archaeological sites): 1 – Lake Kamyshovoe, 2 – Lake Chistoe, 3 – Lake Vyshtynetskoe, 4 – Kozje Bog, 5 – Velikoe Bog, 6 – Zelau Bog, 7 – Zedmar archaeological complex, 8 – Utinoe Boloto Mesolithic – early Neolithic site, 9 – Pribrezhnoe Neolithic – Bronze Age site, 10 – Ushakovo Neolithic – Bronze Age group of sites, 11 – Salskoe Iron Age site, 12 – Grachevka Iron Age site, 13 – Russkoe Iron Age site, 14 – Szczepanki late Palaeolithic – Neolithic site (Poland) (Map source: GeoGuessr.com).

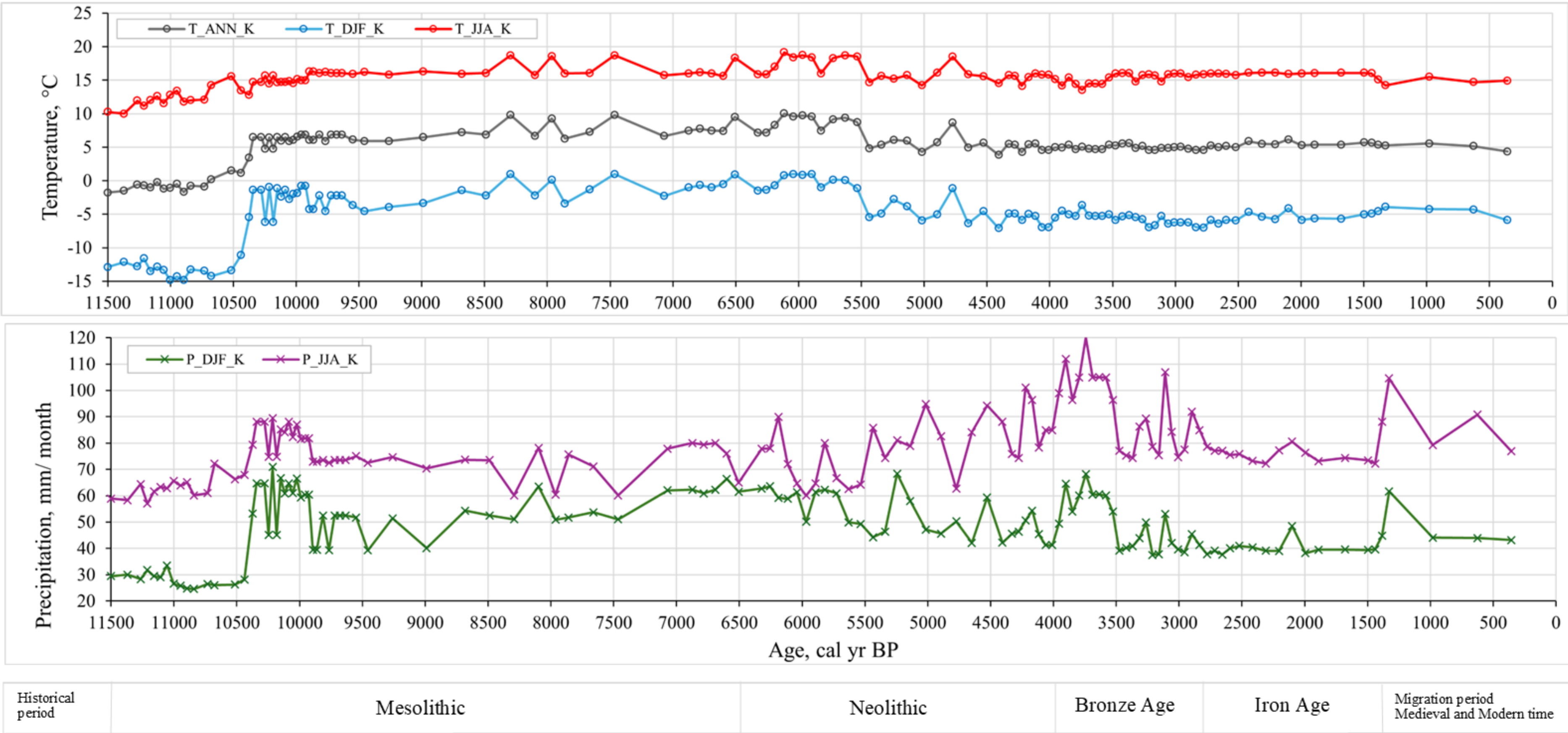
T_ANN_K
T_DJF_K
T_JJA_K
Temperature, °C
P_DJF_K
P_JJA_K
Precipitation, mm/ month
Age, cal yr BP
Historical period
Mesolithic
Neolithic
Bronze Age
Iron Age
Migration period Medieval and Modern time

Fig. 2. Palaeoclimate MAT reconstruction results for the south-eastern Baltic region.

Антропогенная деятельность в эпоху камня и палеометалла по археологическим и палеоэкологическим данным в Юго-Восточной Прибалтике на фоне климата голоцена*.

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Аннотация

Представлен обзор археологических и палеоэкологических данных юго-восточной Балтики (оз. Камышовое, Чистое; бол. Козье, Великое, Целау,

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Калининградская область) на фоне реконструкции климата голоцена. Метод «современных аналогов» (MAT) применительно к палинологическим данным оз. Камышовое использован для реконструкции трендов и сезонных значений температуры и осадков для разных этапов голоцена. Установлено, что в течение мезолита климатические условия менялись от близких к позднеледниковью через период более теплого и влажного климата с параметрами, близкими к современным, к условиям климатического оптимума, когда температура была на несколько градусов выше современной. Согласно археологическим данным, мезолитические стратегии жизнеобеспечения основывались на рыболовстве и охоте, наряду с активным освоением лесных растительных ресурсов, однако из-за скудности имеющегося фактического материала проследить изменения в деятельности человека, соответствующие динамике климата и палеосреды, сложно. В то время как первая часть неолита соответствовала климатическому оптимуму, примерно с 5500 кал. л. н. климат изменился в сторону похолодания и смещения сезонного выпадения осадков: лето стало более влажным, а зима менее снежной. В стратегии жизнеобеспечения неолитического населения разведение скота и земледелие начало играть возрастающую роль, приобретя еще большее значение в бронзовом веке, периоде с относительной температурной стабильностью, но значительными колебаниями количества осадков. С началом железного века (2800 кал. л.н.) интенсивность антропогенной деятельности (земледелия, скотоводства и металлургии) в юго-восточной Прибалтике возрастала, с некоторыми перерывами в периоды Великого переселения народов (5-6 вв. н. э.) и завоевания данной территории Тевтонским орденом в 13-14 вв. н.э. Согласно проведенным реконструкциям, начиная с железного века, температура остается близкой к современным значениям. Выделяются несколько более «влажных» эпизодов, совпадающих с началом Римского времени, периодом Великого переселения народов и малым ледниковым периодом в эпоху Средневековья.

Ключевые слова: антропогенная деятельность, археология, эпоха камня и палеометалла, палеоклимат, юго-восточная Прибалтика, метод современных аналогов