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Palaeoenvironments of the Medieval warm period in the "Kaluzhskiye Zaseki" Nature Reserve (Central European Russia)

E Yu Novenko[1, 2, *], O K Borisova[2], N G Mazei[1], I S Zyuganova[2], M V Kusilman[1] and M V Bobrovsky[3]

[1] Faculty of Geography, Lomonosov Moscow State University, GSP-1, Leninskie Gory, Moscow, 119991, Russia
[2] Institute of Geography Russian Academy of Science, Staromonetny lane, 29, Moscow, 119017, Russia
[3] Institute of Physicochemical and Biological Problems of Soil Science, Russian Academy of Sciences, Institutskaya, 2, Puschino, 142290, Russia

*E-mail: lenanov@mail.ru

Abstract. This paper is focused on environment conditions during the Medieval warm period and human impact on the broadleaved forests in central European Russia. The study area is located in the "Kaluzhskiye Zaseki" Nature Reserve, one of the unique remnants of primary Eastern European broadleaved forests. Here, we present new high-resolution pollen and plant macrofossil records and radiocarbon dating from the sediment sequences in the outcrop of the right bank of Vytebet' River (a tributary of Oka River) in the northern part of the Reserve. The obtained results have shown no clear evidence of vegetation changes in the region in response to the climatic amelioration during the Medieval time. The pronounced changes of forest ecosystems were caused by anthropogenic disturbance since the 13th century AD.

1. Introduction

A great number of palaeoclimatic reconstructions based on various proxy records and modelling approaches have shown that climate in the Medieval time was as warm as, or warmer than, it is today [1 – 6]. Therefore, detailed studies of the Medieval Climate Anomaly (MCA, ca. 900-1350 AD; e.g.,) [2, 3] is important for understanding vegetation response to current climate changes, including increasing air temperature, changing precipitation patterns and increasing frequency of extreme weather events

The present study is focused on the reconstruction of environmental conditions in the "Kaluzhskiye Zaseki" Nature Reserve, located in the north-western part of the Mid-Russian Uplands. These forests, known as Zaseki, are a part of the formerly continuous forest belt along the south-western borders of Muscovy that was created in the 14th–16th centuries AD for the protection of state borders against raids of nomads from steppe [8]. Forest ecosystems in this area are unique remnants of primary broadleaved forests in central European Russia. Modern dynamics of plant cover, soils and human activity in the Reserve were intensively investigated during the last decades [9, 10].

The previous studies of the Holocene vegetation and climate changes in this region demonstrated that mixed broadleaved forests expanded about 8000 cal yr BP, and remained dominant, until nowadays, in the study area [11]; these mixed broadleaved forests were destroyed outside of the "Kaluzhskiye

Zaseki" Nature Reserve for the last few centuries by human impact [12]. However, studies of the Medieval time were very fragmentary due to low sampling resolution for this period in the peat cores and, probably, due to loss of part of the peat profiles after a fire. In this study, we reconstruct environmental changes for the Medieval warm period using high resolution pollen and plant macrofossils analysis from sediment sequences in the outcrop of the right bank of Vytebet' River (a tributary of Oka River) in the northern part of the "Kaluzhskiye Zaseki" Nature Reserve. Analyses of these paleoenvironmental data shed new light on vegetation changes in this region during MCA, and allow us to examine the human influence on forests.

2. Study area

The "Kaluzhskiye Zaseki" State Nature Reserve is located in the Ul'anovo district of the Kaluga region in the north-western part of the Mid-Russian Uplands in the Upper Oka River basin (figure 1). The landscape is a hilly plain of about 150–250 m above sea level dissected by gullies and ravines. Pre-Quaternary deposits are represented by Early Cretaceous clays, sands and sandstones. The Quaternary sediment sequences consist of the Early–Middle Pleistocene till of the Don Glacial complex, Middle Pleistocene fluvio-glacial sediments and Late Pleistocene loess-paleosol sequences [13]. The total thickness of Quaternary deposits varies from 10 to 30 m.

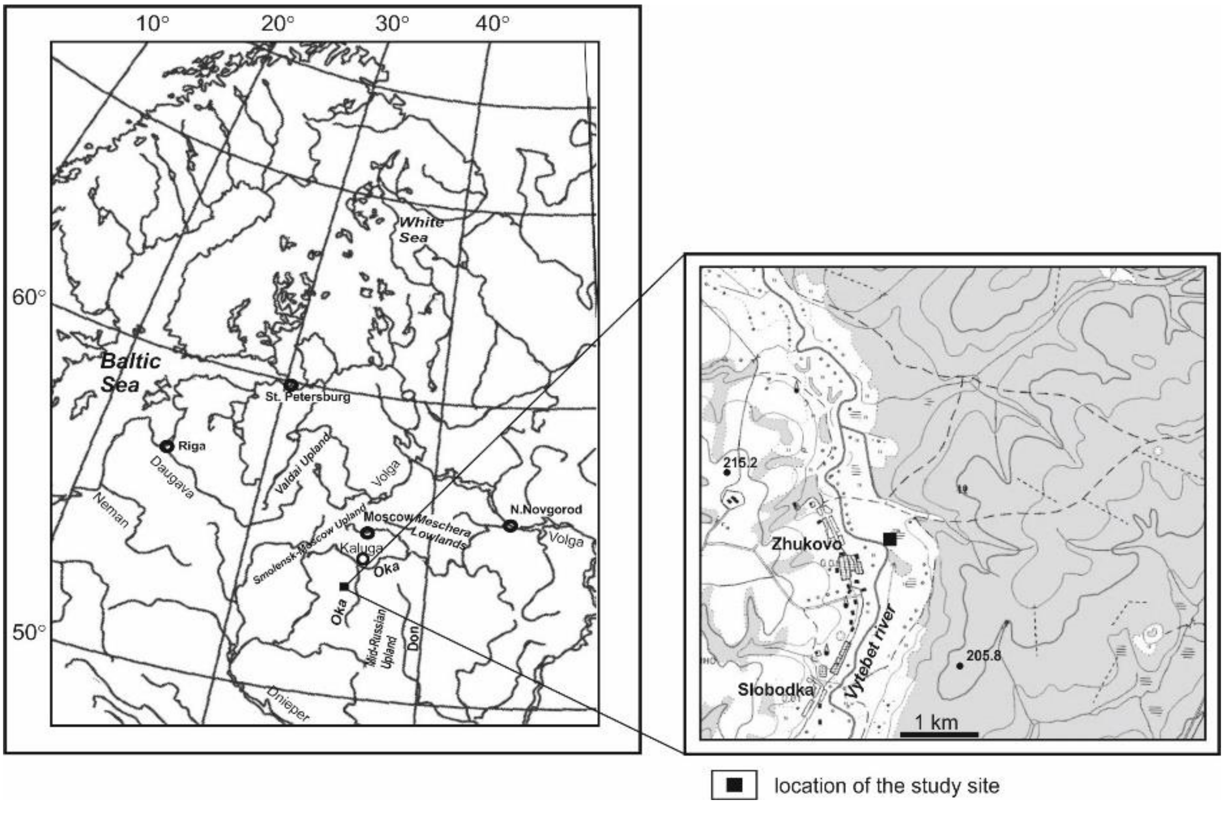

Figure 1. Location of the study area.

The climate of the study area is temperate and moderately continental with relatively cold winters and warm summers. The mean July and January temperatures are +17.5°C and –10.1°C respectively; the mean annual temperature is +4.8°C. Annual precipitation varies from 360 to 1000 mm with a mean value of 630 mm [14].

The area is covered in broadleaved forests formed by *Quercus robur, Fraxinus excelsior, Tilia cordata, Ulmus glabra, Acer platanoides* and *A. campestre,* with an admixture of *Populus tremula* and *Betula verrucosa* [10]. In the shrub layer, *Corylus avellana* is abundant in the forest understorey;

Euonymus europaea, E. verrucosa, Lonicera xylosteum and *Padus avium* are common. "Kaluzhskiye Zaseki" Reserve is located close to the southern border of the *Picea* geographical range [15]. *Picea-Pinus* forests with an admixture of broadleaved tree species and *Corylus avellana* occur in wet habitats with sandy soils.

The study site is located on the floodplain of the right side of the Vytebet' river valley. The following sediment sequences, 200 cm long, were revealed during the exposure of the riverbank (figure 2, 3, 4). The upper part of the outcrop (up to a depth of 116 cm) is represented by a soil layer and alluvial loam, affected by biogenic processes. At a depth of 116-150 cm, an interbedding of peat and powdery loam is revealed; the thickness of the layers varies from several mm to 5 cm. Remains of woody plants (seeds, nutlets, bark, etc.) were abundant in this part of the section. A horizon of high decomposed peat with thin interlayers (up to 1 mm) of powdery loam occur at a depth of 150-170 cm. A low decomposed peat is exposed between depths of 170 and 188 cm. The remains of well-preserved leaves of broadleaved trees were found in this layer. The peat is underlain by alluvial deposits (silt with clay).

Figure 2. Vytebet' River valley and location of the study site: A – oxbow, B – floodplain, C – location of the outcrop.

Figure 3. Location of the outcrop.

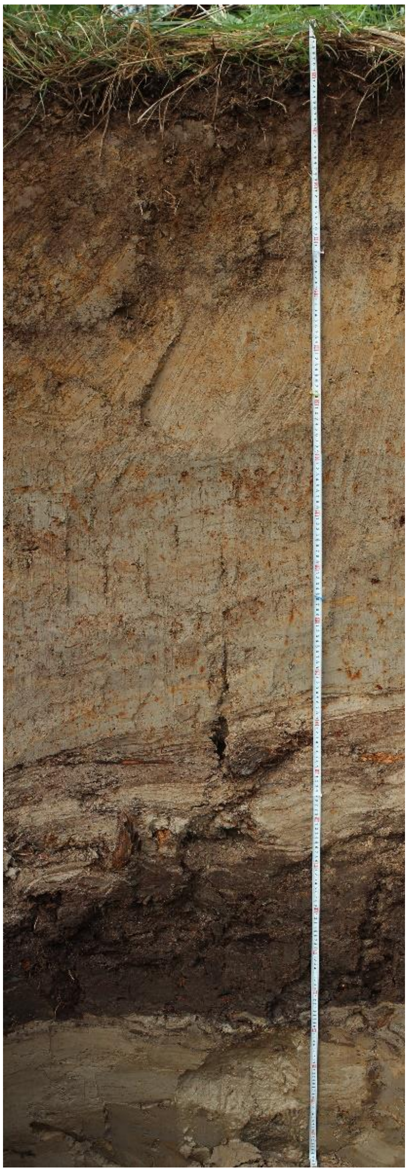

Figure 4. The studied sediment sequences

3. Materials and methods

The sediment sequence in the exposure of the right riverbank of the Vytebet' river was found during field campaign of 2017. The organic reach deposits at depths of 122-188 cm were sampled and studied by pollen and plant macrofossil analyses.

The chronology of the section is based on two AMS radiocarbon dates of plant residuals taking from the depths of 138 cm and 187 cm (table 1). Radiocarbon dating was performed in the CCU "Laboratory of radiocarbon dating and electronic microscopy" of the Institute of Geography of the Russian Academy of Sciences (Moscow, Russia). The 14C dates were calibrated with Calib 7.1 software and the Intcal13 calibration dataset [16]. Age-depth model was constrained by linear interpolation between midpoints of radiocarbon dates.

Table 1. Results of radiocarbon dating of sediments in the outcrop of the right bank of Vytebet' River in the "Kaluzhskiye Zaseki" Nature Reserve.

Laboratory code $IGAN_{AMS}$	Depth (cm)	Material	Radiocarbon date (14C yr BP)	Calibrate age range, BP; 95% confidence interval (probability)
6724	137-138	plant rs.	870±25	709 – 712 (0.003)
				726 - 802 (0.827)
				812 - 828 (0.031)
				862 - 903 (0.139)
				Median Probability: 770±35
6725	186-187	plant rs.	1350±25	1188 - 1202 (0.033)
				1257 - 1309 (0.967)
				Median Probability: 1290±25

14 samples for plant macrofossil analysis with a volume of 300 cm^3 were washed on sieves with 0.25 mm meshes [17]. The obtained organic residue was studied under a stereomicroscope Altami SM-T, and carpological remains (subfossil seeds and fruits) were picked out. Identification of plant remains was carried out in accordance with Katz et al. [18] and the reference collection of the Institute of Geography of the Russian Academy of Sciences. The results of carpological analysis are presented as the number of plant remains in the sample (figure 5).

Additional studies of remains of bryophytes, bark fragments, stems, leaves, and epidermis of vegetative and reproductive organs were performed in samples with volumes of 5–10 cm^3. Probes were rinsed with water onto sieves with mesh (0.25 mm). The plant remains were studied using a Motic BA210 microscope at 200 magnification. The plant remains were identified in accordance with Katz et al. [19] and Dombrovskaya et al. [20]. As this type of plant remains were scarce in studied sediment, we indicated only their presence on the plant macrofossil diagram (figure 5).

The samples for pollen analysis (2 cm^3) were prepared in accordance with Moore et al. [21]. The samples were heated for 7 min in 10% KOH to remove humic materials. The residue was then sieved over a 200 µm mesh, followed by acetolysis in a water bath for 5 min to dissolve the cellulose. Pollen was identified in accordance with Reille [22] and reference collection of the Institute of Geography, RAS. Calculation of pollen percentages was based on the total terrestrial pollen sum – arboreal pollen (AP) plus non-arboreal pollen (NAP) plus spores. A minimum of 500 pollen grains per sample were counted. Pollen and plant macrofossil diagrams were constructed using the Tilia software version 2.6.1.

4. Results

4.1. Plant macrofossil analysis

According to the results of plant macrofossil analysis, three LCAZ (Local Carpological Assemblage Zone) were determined in the studied sediment sequence.

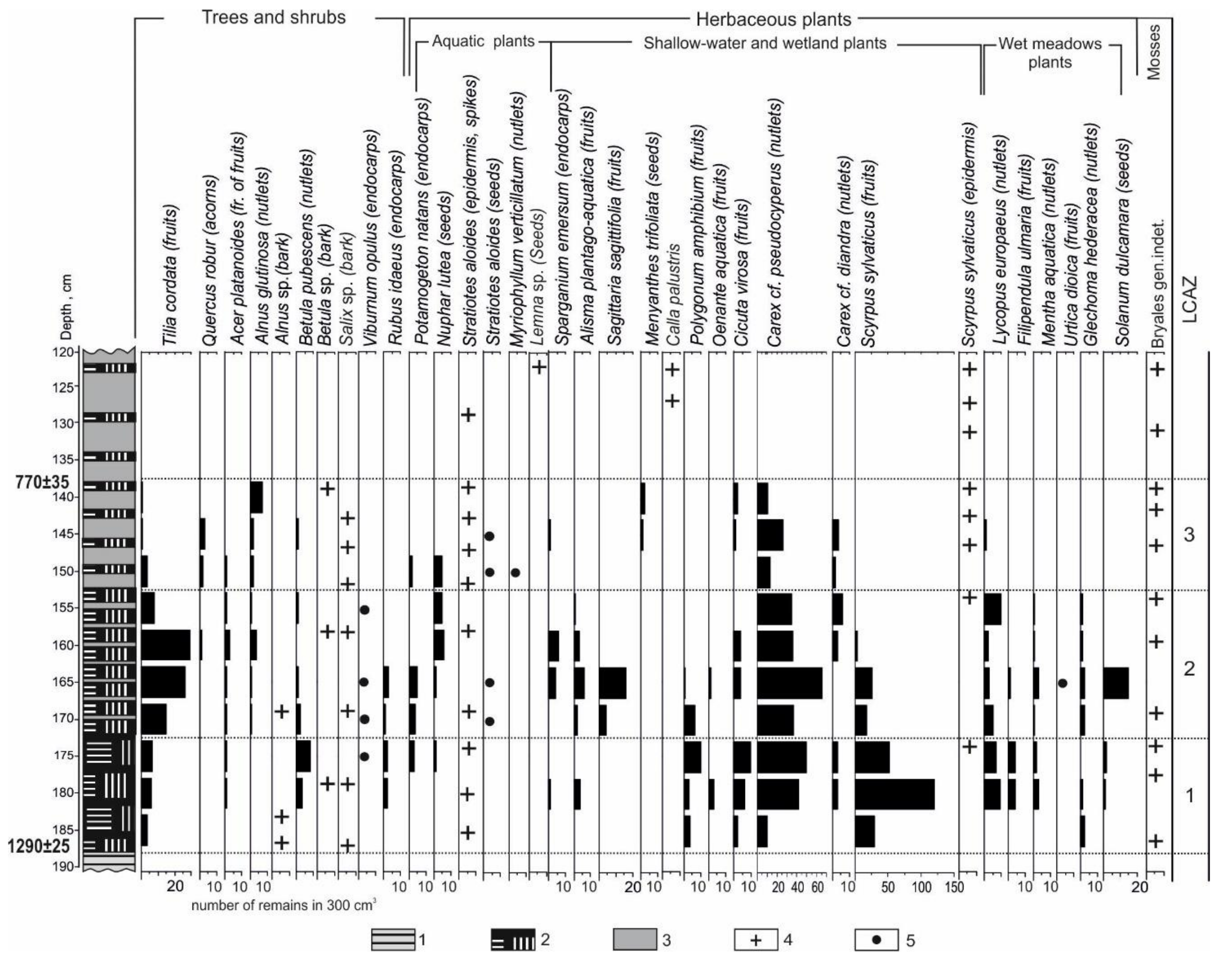

Figure 5. Plant macrofossil diagram: 1. – Clay; 2. – Peat; 3. – Loam; 4. - exact amount of remains wasn't calculated; 5. – presence in amount less than 5 specimens.

LCAZ 1 (depth 188–170 cm) is characterized by a sharp predominance of species from the Cyperaceae family – *Carex cf. pseudocyperus* and *Scyrpus sylvaticus*. Subfossil macroremains of tree species are represented by scanty nutlets of *Tilia cordata* and *Betula pubescens*, as well as fragments of winged fruits of *Acer platanoides*. Endocarps of *Rubus idaeus* and *Viburnum opulus* were identified. Numerous fragments of *Salix* and *Betula* bark were found. Among the aquatic plants, scanty seeds of *Nuphar lutea*, endocarps of *Potamogeton natans* and rare spikes of leaves of *Stratiotes aloides* were identified. Remains of brown mosses were determined.

LCAZ 2 (depth 170–155 cm) is characterized by a relatively high content of *Tilia* nuts. Fruits and fragments of fruits of *Acer platanoides*, remains of *Quercus robur*, *Betula* and *Alnus glutinosa* occurred. In the group of aquatic plants, the occurrence of *Stratiotes aloides* seeds was noted. The diversity of the macroremains of wetland and aquatic species is increasing. This group is represented by the fruits of *Sparganium emersum*, *Alisma plantago-aquatica* and *Sagittaria sagittifolia*, and abundant spines of *Stratiotes aloides*.

In the same interval, bark of *Salix* and *Alnus*, epidermis of *Carex* and spikes of *Nymphaea* sp. were identified.

Composition of the plant macrofossil assemblages of the LCAZ 3 (depth 150 – 140 cm) is similar to that in LCAZ 2; however a number of remains in the LCAZ 3 is lower. The fragments of *Salix* bark, epidermis of *Scirpus sylvaticus*, idioblasts of *Nymphaea* sp., and remains of brown mosses (incl. *Polytrichum commune* Hedw.) were identified.

In the samples from the sediments above 140 cm, no subfossil seeds and fruits were found. Only scanty fragments of xylems of coniferous trees, bark of *Salix* and *Betula*, and rare remains of *Equisetum* sp., *Scirpus sylvaticus*, *Calla palustris*, *Nymphaea* sp., *Lemna* sp., *Hydrocharis* sp. were obtained.

4.2. Pollen analysis

The pollen diagram was divided into 4 local pollen assemblage zones (LPAZ), corresponding to the main phases of vegetation changes (figure 6).

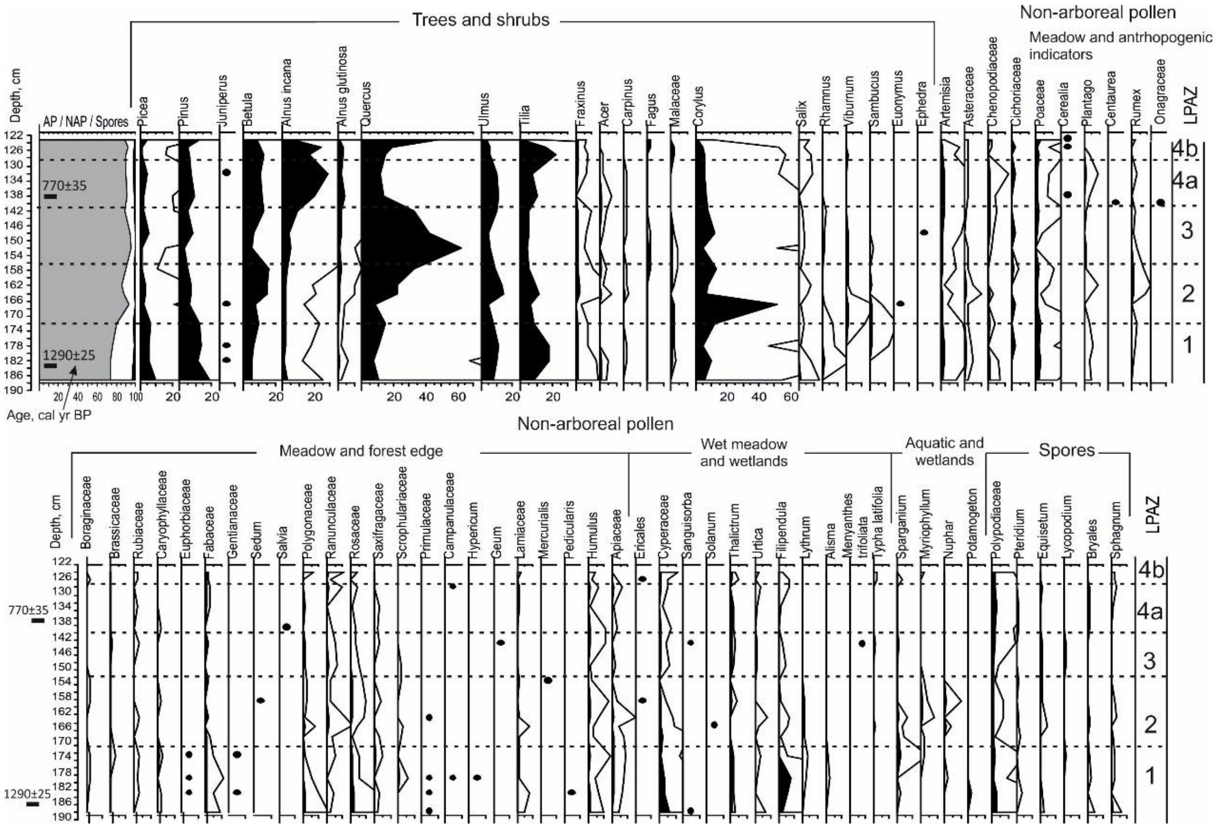

Figure 6. Pollen diagram. Pollen sum: AP+NAP+Spores; additional curves represent x10 exaggeration of base curves. The dots denote the presents of taxa < 1%.

LPAZ 1 (190-172 cm) is dominated by arboreal pollen (up to 80%), with *Tilia*, *Ulmus*, *Quercus*, *Picea* and *Pinus* most abundant (10-20%). Pollens of *Betula*, *Alnus*, *Fraxinus*, *Acer*, *Carpinus*, and *Corylus* were present in lesser quantities; a few pollen grains of *Juniperus*, *Sambucus* and *Salix* were found. Pollens of *Artemisia*, Poaceae and wetland plants, such as Cyperaceae and *Filipendula*, were relatively abundant in the NAP group. Spores of Polypodiaceae were recorded (3-5%).

In LPAZ 2 (172-156 cm), the proportion of AP increased to 85-90%. Corylus formed a sharp peak up to 50% in the lower part of the zone at a depth of 168 cm. Share of *Betula*, *Tilia*, *Ulmus* and *Fraxinus* rose to between 166 and 156 cm. Rare pollen of *Euonymus* was found, so also the pollen of *Fagus*. Among the NAP group, Asteraceae, Poaceae, Ranunculaceae, Rosaceae, Polygonaceae and Apiaceae were common.

In LPAZ 3 (156-140 cm), pollen assemblages were characterized by a noticeable peak of *Quercus* (40-60%), whereas all other taxa except for *Picea* and *Pinus* (7-10%) were reduced. The composition of herbaceous pollen and spores was similar to their composition in the previous zone.

In LPAZ 4 (140 – 122 cm), the proportion of *Quercus* pollen decreased significantly (to 15-17%) in the lower part of the zone (subzone 4a, 128-140 cm), while pollens of *Alnus incana* and *Betula* rose to

25 and 15% respectively. Pollens of *Rumex, Artemisa,* Poaceae, Chenopodiaceae became more abundant; pollens of plant-anthropogenic indicators (*Plantago,* Onagraceae, *Centaurea*) and Cerealia appeared. In the upper part of the zone (subzone 4b, 128-122 cm), the proportion of *Tilia, Quercus* and *Pinus* increased.

Discussions

According to the radiocarbon dating (tabl.1), organic reach deposits formed in a small oxbow lake on the floodplain of the Vytebet' River between ca. 1300 and 700 cal yr BP. Therefore, the period of their accumulation must have spanned the Medieval Climatic Anomaly. Plant macrofossil analysis have shown environment conditions of a shallow lake with relatively diverse aquatic and shore vegetation. The presence of peatland species *(Carex cf. pseudocyperus, Alisma plantago-aquatica, Sagittaria sagittifolia, Sparganium emersum* and *Scyrpus sylvaticus*) and aquatic ones (*Nuphar lutea, Stratiotes aloides,* and *Potamogeton natans*) suggests the unstable hydrological regime that was characteristic of the oxbow depression on the floodplain. Obviously, typical aquatic plants grew in the oxbow lake, while peatland species thrived at its shore and on the floodplain. A little further from the lake shore also grew *Salix* and *Alnus* thickets and broadleaved forest. The lake gradually became shallow, filling with peat, as well as silt, during floods.

The obtained pollen data make it possible to suppose an existence of broadleaved forests formed by *Quercus, Tilia, Acer, Fraxinus* and *Ulmus*. In sediments formed between 1300 and 1000 cal yr BP, pollen values of *Quercus*, *Tilia,* and *Ulmus* were about 20-30% while those of *Acer* and *Fraxinus* reached 5%, which indicates a significant abundance of broadleaved tree species in forest stands. Numerous nutlets of *Tilia cordata*, occurrence of plant macrofossils of *Quercus robur* and *Acer platanoides,* and finding of well-preserved leaves of *Quercus* and *Tilia* in the peat layer (depth 188-170 cm) indicate that the study site was located at the margin of broadleaved forest.

Obviously, this forest was characterized by well-developed undergrowth. Pollens and endocarps of *Rubus idaeus* and *Viburnum opulus* and pollens of *Corylus, Rhamnus,* and *Euonymus* are frequent components of the pollen and plant macrofossil assemblages. The diversity of pollens of herbaceous plants (mainly species of meadows and forest edges) and the presence of Polypodiaceae spores indicate a rich herbaceous layer.

The share of *Picea* pollen reached 5-10% in assemblages from studied sediment sequence, which points to the local presence of spruce in the forest [23]. In pollen records from the peatland Mochulya located within the "Kaluzhskiye Zaseki" Nature Reserve, similar proportions of *Picea* pollen were traced since about 4000 cal yr BP [11]. Probably, *Picea* could grow as an admixture in broadleaved forests or occupy wet habitats. Spruce prefers fertile moderately moist soil, but not waterlogged places with stagnant moisture conditions.

Pollens of *Carpinus* and *Fagus* registered in pollen records from the study site were obviously wind-transported from other regions. However, it could be supposed that the geographical range of *Carpinus* was situated close to the area of "Kaluzhskiye Zaseki" Nature Reserve. Composition of pollen assemblages from 250 surface samples from the East European Plain show that *Carpinus* pollen can be transferred by wind to a distance of 200 km from places of its native occurrence and plantations in parks, botanical gardens, etc. [24]. Remote places of finding *Fagus* pollen in surface probes are situated 1000 km from its place of growth.

Pollens of *Alnus incana* is abundant in the sediment, especially in its upper part. At the same time, gray alder is now found sporadically in the research area and its area of continuous distribution is located 100-150 km to the northeast.

A comparison of other pollen records from the study region, such as the peatland Mochulya in "Kaluzhskiye Zaseki" Reserve [11] and peatland Klukva [12] located 70 km south-east from the Reserve, and several pollen records from Tula region [25 – 27] indicates that the broadleaved forests occupied the north-western part of Mid-Russian Uplands at about 8000 cal yr BP, and persisted throughout the Middle and Late Holocene, being widespread in the Medieval time. Climatic reconstructions based on various proxy and model simulations indicate that the MCA in Europe was characterized by warmer and relatively drier climate than modern climate (e.g.) [28]. Obviously, such conditions were favorable for the existence of broadleaved forests in the region. The relative abundance of pollens of wood species that require enough soil moisture, such as *Tilia* and *Picea*, in the study site does not suggest long and severe summer droughts.

Composition of pollen assemblages from the study site indicates dramatic changes in plant cover between 1000 and 800 cal yr BP. *Quercus* pollen forms a high peak (up to 60%), while there is a reduction in the occurrence of other broadleaved species. Most likely, this phase of vegetation changes with duration of 180-200 years was caused not by climatic fluctuations but was a result of vegetation successions possibly after fire. The macro-charcoal data from the peatland Mochulya indicate that fire activity increased considerably in the same time [11]. *Quercus* as a light-loving species benefitted at the collapse of the forest canopy. After regeneration of other broadleaved species, abundance of oak in forest stands and, consequently, the share of its pollen declined.

The pollen records from the study site reveal the beginning of human impact on forest ecosystems. After about 770-750 cal yr BP (in 13th century AD), pollens of anthropogenic indicators (*Plantago*, Onagraceae, *Centaurea*) and cultivated cereals appeared. The proportions of *Alnus incana* and *Betula*, which grow often as secondary forest stands after clear cutting, increased notably. In studied sediment sequences, these changes in pollen assemblages coincided with transition from high decomposed peat to an interbedding of peat and powdery loam. An increase of clastic materials in the peat could be an indirect evidence of active erosion processes in the Vytebet' river valley after vegetation disturbance. However, high ratio of AP to NAP as an indicator of forest coverage [29, 30] and high relative abundance of *Tilia*, *Quercus* and *Ulmus* in pollen assemblages suggest low anthropogenic influence in the vicinity of the study site. In the areas within radii of 40-50 km from the studied section, there are several settlements of the 14th-17th century. Archeological findings of this time are quite common in this part of the Kaluga region [31]. According to pollen data from the peatland Mochulya [11], deforestation and notable anthropogenic transformations of plant cover occurred later, about 500 cal yr. BP. Evidences of human impact on vegetation detected at the study site seem to be one of the waves of this process.

Conclusions

The data obtained allow us to conclude that during the Medieval Warm period, the area of "Kaluzhskiye Zaseki" Nature Reserve was occupied by broadleaved forests formed by *Quercus, Tilia, Acer, Fraxinus* and *Ulmus*, with an admixture of *Picea*. As shown by pollen data from this region, broadleaved forests were widespread in the northwestern part of the Mid Russian Uplands during the Middle and Late Holocene, and despite climatic fluctuations, broadleaved forests persisted in the area. The present high-resolution study of the period including the MCA also reveals no clear evidence of vegetation changes in the region in response to the climatic amelioration. The beginning of human impact on forest ecosystems in the Medieval time corresponded to the 13th century, although significant vegetation changes caused by anthropogenic disturbance occurred later.

Acknowledgements

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References

[1] Bradley R S, Hughes, M K and Diaz H F 2003 *Science* **302** 404–405
[2] Moberg A, Sonechkin D M, Holmgren K, Datsenko N M and Karlén W 2005 *Nature* **433** 613–617
[3] Mann M E, Zhang Z, Rutherford S, Bradley R S, Hughes M K, Shindell D, Ammann C, Faluvegi G and Ni F 2009 *Science* **326** 1256–1260
[4] Graham N E, Ammann C M, Fleitmann D, Cobb K M and Luterbacher J 2011 *Climate Dynamics*

37 (5–6) 1217–1245

[5] Diaz HF, Trigo R, Hughes M K, Mann M E, Xoplaki E and Barriopedro D 2011 *Bulletin of the American Meteorological Society* **92** 1487–1500

[6] PAGES 2k Consortium 2013 Continental-scale temperature variability during the last two millennia *Nature Geoscience* **6** 339–346.

[7] IPCC 2013 *IPCC Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC* (Cambridge: Cambridge University Press) p 1535

[8] Bobrovsky M V 2002 *Kozelsky Zaseki (Ecological-historical outline)* (Kaluga, N. Bochkarevoy) 92 p (in Russian)

[9] Bobrovsky M V and Khanina L G 2000 Reserve Kaluga Zaseki *Assessment and conservation of forest cover biodiversity in reserves in the European part of Russia* (Moscow: Nauchnyy Mir) pp 104–124 (in Russian)

[10] Smirnova O V, Bobrovsky M V, Khanina L G, Braslavskaya T Yu, Starodubtseva E A, Evstigneev O I, Korotkov V N, Smirnov V E and Ivanova N V 2017. Nemoral forests *European Russian Forests. Their Current State and Features of Their History* (Netherlands: Springer) pp 337–480

[11] Novenko E Y, Tsyganov A N, Mazei N G, Kupriyanov D A, Rudenko O V, Bobrovsky M V, Erman N M and Nizovtsev V A 2019 *Quaternary International* **516** 58–69

[12] Novenko E Y, Tsyganov A N, Volkova E M, Babeshko K V, Lavrentiev N V, Payne R J and Mazei Y A 2015 *Quaternary Research* **83** 459–468

[13] Petrov V G, 2003 *Geological structure and minerals of the Kaluga region* (Kaluga: Eydos) 440 p (in Russian)

[14] Kaluga weather station: http://meteo.ru/data

[15] Gribova S A, Isachenko T I and Lavrenko E M 1980 *Vegetation of the European Part of the USSR* (Leningrad: Nauka) 429 p (in Russian)

[16] Reimer P J, Bard E, Bayliss A, Beck J W, Blackwell P G, Bronk Ramsey C, Buck C E, Cheng H, Edwards R L, Friedrich M, Grootes P M, Guilderson T P, Haflidason H, Hajdas I, Hatté C, Heaton T J, Hoffmann D L, Hogg A G, Hughen K A, Kaiser K F, Kromer B, Manning S W, Niu M, Reimer W, Richards D A, Scott E M, Southon J R, Staff R A, Turney C S M and van der Plicht J 2013 *Radiocarbon* **55** 1869–1887

[17] Nikitin V P 1969 Paleokarpologicheskij metod (Paleocarpological method) (Tomsk: Izd-vo Tomskogo un-ta Publ.) 82 p (in Russian)

[18] Katz N Ya, Katz S V and Kipiani M.G 1965 *Atlas and key to fruits and seeds found in the Quaternary deposits of the USSR* (Moscow: Nauka publ.) 364 p (in Russian)

[19] Katz N Y, Katz S V and Skobeva E I 1977 *Atlas of plant residues in peat* (Moscow: Nedrapress) 373 p (in Russian)

[20] Dombrovskaya A V, Koreneva M M and Turemnov S N 1959 *Atlas of plant residues in peat* (Moscow: Nauka-press) 228 p (in Russian)

[21] Moore P D, Webb J A and Collinson M E 1991 *Pollen Analysis* (Oxford: Blackwell) 1991 p

[22] Reille M 1992 *Pollen et spores d'Europe et d'Afrique du Nord* (Marseille: Laboratoire de Botanique Historique et Palynologie)

[23] Giesecke T and Bennett K D 2004 *Journal of Biogeography* **31** 1523–1548

[24] Mazei N G, Kusilman M V and Novenko E Yu 2018 *Russian Journal of Ecology* **49** (6) 484–491

[25] Serebryannaya TA 1976 The relationships between forest and steppe on the Mid-Russian Upland in the Holocene *The history of biogeocenoses of USSR in the Holocene* (Moskow: Nauka) pp 59–66 (in Russian)

[26] Klimanov V A and Serebryannaya T A 1986 *Izvestiya of the Academy of Sciences of the USSR Geografiya* **2** 93–101 (in Russian)

[27] Novenko E, Tsyganov A, Payne R, Mazei N, Volkova E, Chernyshov V, Kupriyanov D and Mazei Yu 2018 *Holocene* **28** (2) 308–322

[28] Goosse H, Renssen H, Timmermann A and Bradley R S 2005. *Quat. Sci. Rev.* **24** 1345–1360
[29] Behre K E 1981 *Pollen et Spores* **23** 225–245
[30] Vuorela I 1986 Palynological and historical evidence of slash-and-burn cultivation in South Finland *Antropogenic indicators in pollen diagrams* (Rotterdam: Balkema) pp 53–64
[31] Archaeological map of Russia. Kaluga region 1992 (Moskow: Avto) 158 p (in Russian)