A 10 000-year pollen and plant macrofossil record from the Losiny Ostrov National Park (Moscow, Russia)

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Abstract. The paper presents the first results of pollen and macrofossil analysis of a peat bog located near the Moscow city within the territory of the Losiny Ostrov National Park. Macrofossil data demonstrate that the bog development started from the stage of a spring calcotrophic fen at the very beginning of the Holocene. After 9.9 ka BP it became a meso-oligotrophic herbaceous-sphagnum bog. Pollen data manifest early spread of spruce in the Moscow region (before 10.2 ka BP). Predominance of broad-leaved temperate deciduous forests is characteristic of the Holocene thermal optimum (8.5-4.8 ka BP). The new spread of spruce forests began after 4.8 ka BP. The first signs of deforestation for agriculture date back to 1.8-1.7 ka BP (Early Iron Age). The next massive deforestation for agriculture was recorded 0.7-0.4 ka BP (Middle Age). After the 17th century, anthropogenic activity decreased, as a result of the establishment of the reserve status.

1. Introduction
Despite the long history of using pollen analysis for studying of paleovegetation and paleoclimate of the European part of Russia [1-9], many regions, including central ones, remain understudied. The Moscow region, especially Moscow city and its suburbs, is the most densely populated, urbanized and well-studied region of the Russian Federation. Surprisingly, data on vegetation reconstruction and climate in the Holocene for this critical region is still sporadic and fragmented. Only one complete and thoroughly dated pollen sequence has been published, reflecting regional changes in vegetation over 15 thousand years: a diagram of the sediment core from Lake Dolgoe, which is located 50 km north-west of Moscow [8]. Additionally, pollen data for several small upland and floodplain peat bogs has been published, however these studies correspond to only part of the Holocene [10, 11]. It is also important to note several studies of buried soils in the floodplain of the Moskva River [10, 12, 13] and paleosols found during archaeological research [14, 15]. All this data allow for some local reconstructions. Nevertheless, researchers who are trying to get a general picture of changes in vegetation and climate in Moscow and its environment over the past 10-12 thousand years [8, 16] are still forced to rely on climate reconstructions made in adjacent regions. Here, we present a research object that could become a basis for comprehensive regional paleoecological studies.

2. Settings
We present the results of a study of a watershed peat bog located in the territory of the Losiny Ostrov ("Elk Island") National Park (figure 1). The National Park is located on the north-eastern outskirts of Moscow, on the border of the Meshchera Lowland and the Klinsko-Dmitrov Ridge, and lies in the...
watershed of three rivers: Pekhorka, Yauza and Klyazma; its area is 116,215 km². The relief is composed mainly of moraine-glacial sediments; numerous swampy depressions alternate with small weakly hilly plains; the absolute height is 146-175 m above sea level. Soils in the area are represented by various Podzolic soils and gleyed Histosols. The outskirts of Moscow are located in the southern taiga zone, where mixed coniferous forests (the association Pino-Quercetum) are zonal; dominant species are spruce (Picea abies), pine (Pinus sylvestris), birch (Betula pendula) and lime (Tilia cordata). Currently, most of the forests in the region have been cleared, and Losiny Ostrov is the only large forest that has survived in Moscow and its suburbs. From the 15th to the 17th century, Losiny Ostrov was a hunting ground for the royal family, and for over 500 years its forests were not felled to make arable land. Although historical and archaeological data indicates that in the Middle Ages its territory was quite densely populated, even in the 14-15th centuries (i.e. during the period of maximum ploughing activity), there were still some areas of forest and swamps that were mostly unaffected by economic activity [17]. Such an area was the object of our study.

Figure 1. The location of the studied bog on the map of Eastern Europe, on the map of the Moscow region and on the map of the Losiny Ostrov (Elk Island) National Park.

The researched bog is located in the southern part of the National Park, in the 35th quarter of the Losino-Pogony forest park, within the specially protected natural area (figure 1). It is situated on a small closed watershed slope, from which streams flow into the rivers Pekhorka and Yauza. The bog is 162.8 m above sea level, it is fed from the atmosphere and ground waters. At the moment, the bog has an area of approximately 2.5 hectares. According to historical documents, before the reclamation works performed in the mid-20th century, it was treeless, and its area was more than 10 ha [17]. Modern vegetation is a sphagnum poor fen with pine (Sphagno–Pinetum sylvestris). Dominant species are oligomesotrophic (Andromeda polifolia, Chamaedaphne calyculata, Ledum palustre, Oxyccoccus palustris, Vaccinium myrtillus, V. vitis idaea, V. uliginosum, Drosera rotundifolia, Eriophorum vaginatum, Sphagnum angustifolium, S. divinum, S. fallax, S. balticum, Polytrichum strictum) and meso-eutrophic (Salix cinerea, S. aurita, Calamagrostis canescens, Carex canescens, C. lasiocarpa, C. rostrata, Comarum palustre, Juncus filiformis, Naumburgia thysiflora) [18]. Projective cover of the herb and dwarf shrub layer is about 50%, Sphagnum centrale, S. girgensohnii dominate in the moss cover. Earlier studies of the deposits showed that the maximum depth of peat is 7.2 m, and its age is more than 10 thousand years; the stratigraphic structure is not disrupted [18, 19]. Thus, the studied peat bog is a unique object for paleoecological and paleoclimatic reconstructions for both Moscow and the entire region.

3. Methods

Peat samples were taken in 2004 and 2019 from the centre of the bog (N 55.84973, E 37.84597), using a Russian core, with 1 cm thick slices every 2.5-5 cm. Macrofossil analysis was performed by G.G. Kulikova using standard methods [20]. Samples for pollen analysis were processed using the standard method for peat [21] with the addition of Lycopodium spores for the concentration calculations [22]. A minimum of 500 pollen grains per sample were identified. Identification was carried out using pollen atlases [23, 24] and reference collections (http://botany-collection.bio.msu.ru). Statistical processing and construction of diagrams was carried out using TILIA, TILIA GRAPH [25]. Six peat samples were submitted to A.E. Lalonde Laboratory (University of Ottawa) for AMS-radiocarbon dating (table 1);
calibration of the results was performed using the method described by Bronk Ramsey (OxCal v. 4.1.7) [26]; the age-depth model was constructed using TILIA [25].

| Sample description | Dated material | Lab code | $^{14}$C yr BP | cal BP (1σ, 68.2%) | cal BP (2σ, 95.4%) | Mean(μ)±σ(σ) cal BP | (m) cal BP |
|--------------------|----------------|----------|----------------|---------------------|---------------------|----------------------|----------|
| 60-65              | peat           | UOC-4724 | 660±23         | 665 - 566           | 670 - 560           | 615±39               | 604      |
| 152-155            | peat           | UOC-9317 | 1792±25        | 1805 - 1630         | 1815 - 1625         | 1717±53              | 1717     |
| 220-225            | peat           | UOC-4472 | 2863±22        | 3032 - 2945         | 3063 - 2890         | 2981±41              | 2979     |
| 300-305            | peat           | UOC-4471 | 3452±25        | 3819 - 3644         | 3819 - 3644         | 3724±56              | 3712     |
| 425-430            | peat           | UOC-4470 | 4706±23        | 5568 - 5329         | 5577 - 5324         | 5423±80              | 5390     |
| 670-675            | peat           | UOC-4725 | 8826±27        | 10113-9773          | 10134-9706          | 9896±114             | 9872     |

4. Results

4.1. Macrofossil analysis

According to the results of the macrofossil analysis presented in the diagram (figure 2), we can describe the structure of the peat deposit as follows (dates are calibrated).

715-720 cm. Dark dense gleyed loam with sand.

700-715 cm (more than 10.2 ka BP). Eutrophic grassy peat with sand (peaty sapropel). Peat contains remnants of the vascular plants (*Epilobium palustre*, *Eriophorum angustifolium*, *Menyanthes trifoliata*, *Nuphar lutea*, *Polygonum amphibium*, *Scheuchzeria palustris*) and mosses (*Straminegron stramineum*, *Sphagnum translucidum*, *Sphagnum squarrosum transitional*, *Habrozypallium transitional*, *Habrozypallium capillaceum*).
Warnstorfia fluitans, Sphagnum balticum, S.plerapus, S. centrale, S. cuspidatum, S. obtusum). Some fragments of Picea abies remains is noteworthy at this depth.

680-700 cm (about 10 ka BP). Herbaceous-hypnum peat (peaty sapropel) with a degree of decomposition of 35%. The peat composition includes the remains of vascular plants typical for shallow water bodies (Eriophorum angustifolium, Menyanthes trifoliata, Nuphar lutea, Phragmites australis, Polygonum amphibium, Scheuchzeria palustris, Schoenoplectus lacustris, Triglochin palustris, Typha latifolia) and brown mosses (Calliergonella cuspidata, Drepanocaldus sendtneri, Hamatocaulis vernicosus).

600-680 cm (8.5-9.9 ka BP). Herbaceous-sphagnum transitional peat (Calla palustris, Comarum palustre, Epilobium palustre, Equisetum sp., Eriophorum angustifolium, E. vaginatum, Menyanthes trifoliata, Phragmites australis, Polygonum amphibium, Scheuchzeria palustris, Schoenoplectus palustris, S. balticum, S. centrale, S. cuspidatum, S. divinum, S. fallax, S. obtusum, S. teres) with a degree of decomposition of 29%.

575-600 cm (8.1-8.3 ka BP). Sphagnum (Sphagnum angustifolium, S. balticum, S. centrale, S. cuspidatum, S. divinum, S. fuscum, S. obtusum) transitional peat with a degree of decomposition of 45%.

550-575 cm (7.7-8.0 ka BP). Herbaceous-sphagnum (Calla palustris, Equisetum sp., Eriophorum vaginatum, Menyanthes trifoliata, Polygonum amphibium, Scheuchzeria palustris, Typha latifolia, Sphagnum balticum, S. centrale, S. divinum, S. fuscum, S. majus, S. majus) peat with a degree of decomposition of 23%.

525-550 cm (7.3-7.6 ka BP). Scheuchzeria-sphagnum (Scheuchzeria palustris, Sphagnum angustifolium, S. balticum, S. centrale, S. cuspidatum, S. divinum, S. fuscum, S. majus, S. obtusum) transitional peat with a degree of decomposition of 48%.

500-525 cm (6.8-7.3 ka BP). Scheuchzeria peat with a degree of decomposition of 25.5%.

475-500 cm (6.3-6.7 ka BP). (Calla palustris, Eriophorum vaginatum, Menyanthes trifoliata, Polygonum amphibium, Scheuchzeria palustris, Typha latifolia, Sphagnum balticum, S. centrale, S. divinum, S. fuscum, S. majus, S. majus) transitional peat with a degree of decomposition of 28%.

450-475 cm (6.0-6.3 ka BP). Scheuchzeria-sphagnum (Scheuchzeria palustris, Sphagnum angustifolium, S. balticum, S. centrale, S. divinum, S. fuscum, S. majus, S. teres) transitional peat with a degree of decomposition of 17 %.

400-450 cm (5.0-6.0 ka BP). Herbaceous-sphagnum (Calamagrostis canescens, Eriophorum angustifolium, E. vaginatum, Menyanthes trifoliata, Scheuchzeria palustris, Typha latifolia, Sphagnum angustifolium, S. balticum, S. centrale, S. cuspidatum, S. divinum, S. fallax, S. fuscum, S. majus, S. obtusum) transitional peat with a degree of decomposition of 30%.

350-400 cm (4.2-5.0 ka BP). Scheuchzeria-sphagnum (Scheuchzeria palustris, Sphagnum angustifolium, S. balticum, S. centrale, S. cuspidatum, S. divinum, S. fallax, S. fuscum, S. girgensohnii, S. majus, S. obtusum, S. squarrosum) transitional peat with a degree of decomposition of 24%.

0-400 cm (0-4.2 ka BP). Sphagnum transitional peat (Sphagnum angustifolium, S. balticum, S. centrale, S. cuspidatum, S. divinum, S. fallax, S. fuscum, S. girgensohnii, S. majus, S. obtusum, S. squarrosum, S. teres), with a degree of decomposition of about 20%.

The bog developed at the very beginning of the Holocene as minerotrophic (calcicretic) spring fen. After 10.2-9.8 ka BP there was a change in the type of nutrition, and from a depth of 675 cm to the modern surface the dominant group of peat-forming plants were herbs, dwarf shrubs and sphagnum mosses of the oligotrophic group, with a constant small participation of meso- and eutrophic species. Starting from a depth of 350 cm (4.2 ka BP), sphagnum mosses became dominant. Wood remains (Pinus and Alnus bark) were rare (less than 4%), spruce bark was found only in the bottom sample. Based on the results of the botanical analysis, the studied deposit can be classified as transitional meso-oligotrophic herbaceous-sphagnum peat.

Significant variations in the degree of decomposition indicate periodic changes in the hydrological regime of the bog, which are associated with climate change. A sharp increase in the degree of decomposition in the uppermost layers is associated with land reclamation works of the mid-20th century, as a result of which peat growth slowed down.
4.2. Pollen analysis

The results of the analysis are presented on a pollen diagram indicating modelled dates (figure 3). The percentage of pollen taxa was calculated as percentage from total pollen, and the percentage of spores as percentage from the total number of pollen and spores. Local pollen zones (LPZ) are selected based on the CONISS cluster analysis.

LPZ 1. 695-705 cm, more than 10.1 ka BP, beginning of the Holocene, beginning of peat formation. Pollen of trees dominate the spectra, namely *Picea* and *Pinus* (up to 20%), temperate deciduous species, such as *Tilia, Ulmus, Corylus*, total up to 25%. The remains of *Picea* wood were also identified in this peat layer, thus giving evidence for the presence of spruce among the vegetation surrounding the water reservoir.

LPZ 2. 675-695 cm, 10.1-9.8 ka BP. Herbaceous-hyphnum transitional peat (peaty sapropel). The zone sharply differs from the previous one in the composition of the pollen spectra. Pollen of *Picea, Pinus, Tilia, Ulmus* and other broad-leaved trees disappear, while the share of *Betula* pollen sharply increases up to 90%. Some pollen grains of dwarf shrub birch (*Betula nana*) are present. There is also a large number of *Sphagnum* spores (up to 40%).

LPZ 3. 600-675 cm, 9.8-8.5 ka BP. Herbaceous-sphagnum transition peat. Dominant species in the pollen spectra are *Betula* (60%) and *Pinus* (up to 30%); *Corylus* is present (5%), and the participation of *Betula nana* is reduced.

LPZ 4. 560-600 cm, 8.0-8.5 ka BP. Sphagnum and herbaceous-sphagnum transitional peat. *Tilia* and *Ulmus* pollen appear on the lower boundary of the zone (5-10% each), at a level of 570-580 cm their presence is decreased. We additionally see a sharp drop in *Pinus* (10%) and *Betula* peak (up to 80%).

LPZ 5. 450-560 cm, 8.0-6.0 ka BP. Herbaceous-sphagnum transitional peat. The percentages of *Betula* and *Pinus* pollen are reduced (to 40% and 10%, respectively), while the participation of broad-leaved trees (*Quercus, Ulmus, Tilia, Acer, Fraxinus, Alnus*) reaches a maximum (up to 40% in total). The proportion of *Sphagnum* spores increases up to 40%.

LPZ 6. 380-450 cm, 6.0-4.8 ka BP. Sphagnum and herbaceous-sphagnum transitional peat. *Betula* participation in the spectra gradually decreases (about 20%). *Picea* is present, but its share does not exceed 5-10%. The share of broad-leaved trees pollen in total remains approximately the same as in the previous zone (about 40%).

LPZ 7. 210-380 cm, 4.8-2.8 ka BP. Sphagnum transitional peat. In the pollen spectra, the participation of *Picea* gradually increases – up to 25% in the upper part of the zone (“the first upper maximum of spruce” according to Khotinsky [1]). The proportion of broad-leaved species remains high (up to 40% in total), and *Corylus* reaches a maximum (18%). *Carpinus* pollen, which is currently absent in the region, is singly recorded.

LPZ 8. 70-210 cm, 0.7-2.8 ka BP. Sphagnum transitional peat. The participation of broadleaf and *Corylus* declines. *Picea* participation reaches its maximum in this zone (up to 40%). However, the period of *Picea* decline (to 10-15%) due to the growth of *Pinus, Betula* and *Salix* at the interval of 150 cm (dated 1717±53 ka BP) can be clearly distinguished. At the same interval, the well-defined pollen of *Triticum* appears for the first time with some other indicators of agricultural activity (*Rumex, Carduus, Brassicaceae, Chenopodiaceae*). At the level of 70-100 cm (1.5-0.8 ka BP), the dominance of *Picea* is restored, cultivated cereals disappear.

LPZ 9. 0-70 cm, present-0.7 ka BP. Starting from the level of 70 cm (0.7-0.8 ka BP), the composition of pollen spectra changes dramatically: the share of all broad-leaved trees and *Picea* decreases sharply at the expense of *Pinus* and *Betula*. Also, the share of the pollen indicative for anthropogenic activity, such as *Cerealia, Centaurea cyanus, Cirsium, Plantago, Rumex, Urtica, Chenopodiaceae, Asteraceae, Artemisia*, and meadow herbs) increases significantly.
5. Discussion

The results of the pollen and macrofossil analyses allowed us to reconstruct the history of the bog and its surrounding vegetation and evaluate the feedback of the vegetation of the environs of Moscow to the climatic events of the Holocene, known from data obtained in other regions. In general, our results are very well comparable with the data for Lake Dolgoye [8]. This confirms our assumption that the peat column we selected reflects the regional pollen signal.

As illustrated by the structure of the peat deposit, the bog developed at the very beginning of the Holocene in place of a shallow water reservoir or a permanent watercourse on the peripheral part of a former glacier. At first it was minerotrophic (calcetrophic), as evidenced by the presence of eutrophic species of vascular plants (Parnassia palustris) and hypnum mosses (Humatocaulis vernicosus, Drepanocaldus sendtneri) in the peat. The presence of spruce in the peat and in the pollen spectra indicate the early spread of spruce in the Moscow region, which is in line with the data from other regions of the European part of Russia. After that, during the period of early Holocene warming, the “lowest maximum of spruce” after Khotinsky [1] can be seen based on diagrams from European part of Russia [1-4, 6, 8]. Its upper boundary dates approximately 10.3 -10.2 ka BP.

During the period of climatic cooling (10.2-10.3 ka BP, «Erdalen cold event») [27], the eutrophic peat/sapropel was replaced by transitional mesotrophic peat due to the change of nutrition conditions. At the same time an abrupt decline in Picea and broad-leaved trees occurred, as the only found woody species were Betula with a small admixture of Pinus and Corylus.

Spread of Tilia and Ulmus began around 8.5 ka BP, but slowed down briefly between 8.2 and 8.0 ka BP. A thin layer of sphagnum peat could be distinguished at the corresponding depth, and a sharp pronounced peak of birch was observed on the pollen diagram, which presumably reflects the response of vegetation to the 8.2 ka cold event. This event is usually poorly expressed in pollen sequences in the central regions of European Russia [27, 28]. At the same time, our results show that a high degree of temporal resolution makes it possible to confidently identify a sharp, but short-term change in dominants of vegetation cover, similar to that observed in Western and Northern Europe. Similar signals can be seen in some detailed and well-dated pollen diagrams from neighboring regions [6, 29].

The time span 8.0k-4.8 ka BP corresponds to The Holocene Thermal Maximum, when temperate deciduous forests with the partipance of Quercus, Tilia, Ulmus, Acer, Fraxinus and Corylus dominated in the Moscow region. Later, we can observe the beginning of growth of the share Picea pollen, probably due to the cooling of 6.0-6.2 ka BP. After 4.8 ka BP, spruce-deciduous forests with Corylus began to spread in the Moscow region, first along river valleys and then on watersheds [12, 13]. In Losiny Ostrov, the first upper peak of Picea was dated 3.4-3.5 ka BP. After 2.5 ka BP, Picea became dominant in the forest stands, although broad-leaved trees could still survive until the mass deforestation of the 15-16th centuries AD.

The first well-defined signs of deforestation for arable land in the vicinity of Losiny Ostrov date back to 1.8-1.7 ka BP. We assume that this anthropogenic signal is attributed to the Early Iron Age people.
(Dyakovskaya culture), which inhabited the Moskva River basin at the beginning of the 1st millennium AD [16], although monuments of this time have not yet been found within the territory of the National Park. The «second highest maximum of spruce» [1] was observed between 0.9 and 1.5 ka BP, which could be both a reflection of the climatic cooling and the desolation that happened in the Moscow region during the Time of Troubles, as noted by archaeologists [17]. The next massive deforestation for plowing was recorded starting from 0.7 ka BP, its maximum was in the 14-15 centuries, which is confirmed by findings of Slavic burial mounds and settlements of the 14-15 centuries in the National Park [17]. After the 17th century, the level of anthropogenic disturbances decreased, as the territory of present-day Losiny Ostrov became the hunting grounds of the royal family.

In the 20th century, the continuation of secondary successions followed as a result of the establishment of the reserve status of the National park. Currently, birch forests prevail in Losiny Ostrov (up to 40% of the total forest area of the park), in which the second tier is comprised of Tilia and Picea, or both of these species in various ratios. Spruce forests occupy 12-14% of the National park area and are gradually replaced by linden, maple (Acer platanoides) and oak, which corresponds to the restoration of their natural range. If the current climatic conditions will stay consistent, these forests will develop in the direction of the formation of broad-leaved communities [30].

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