The Early Holocene vegetation changes in the vicinity of the Gorbunovo peat bog in the Middle Urals (Russia)

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Abstract. The paper presents the results of a comprehensive palaeobotanical research of lacustrine and peat deposits of archaeological Mesolithic sites discovered at the Gorbunovo peat bog (Middle Urals). Pollen and plant macrofossil data, as well as a biome model were used to describe the vegetation changes in the study area in the Early Holocene. It was found out that in the second half of the Pre-Boreal and the first half of the Boreal periods of the Early Holocene (approximately to 9,800–9,600 cal BP), the vicinity of the Gorbunovo peat bog was dominated by cold deciduous forests. Larch, spruce-larch and birch forests and meadow communities with periglacial elements were widespread. Various aquatic plants could be found in the pond, though it started to turn into swamp. In the second half of the Boreal period (approximately at 9,600–9,500 cal BP), the taiga biome, including pine and birch-pine forests with occurrence of spruce started to prevail. Periglacial communities became degraded. Aggressive water logging led to the formation of a peat bog.

1. Introduction
Detailed palaeoenvironmental reconstruction based on palaeobotanical methods requires all available palaeofloristic, palaeophytocoenotic and palaeoclimatic data sets obtained for the study area. Degree of confidence in respect of the results depends on the representativeness of the obtained palynological materials together with the results of plant macrofossil and botanical analyses.

The Gorbunovo peat bog attracts our attention and makes it interesting for studying vegetation changes in the Early Holocene in the Middle Urals as there are pits that have already been well studied both from the deep waters of the pond and from its shallow waters where multilayer Stone Age sites have been excavated. The trenches from the archaeological sites yield the set of radiocarbon dates for peats and sapropels, as well as for the objects made from organic materials obtained from the cultural layers from these deposits.

Pollen data obtained so far for the Middle Urals is quite vast. Pollen studies of the peat deposits within this area commenced in the first half of the 20th century. The first pollen diagram for the Gorbunovo peat bog deposits yield the patterns of birch and spruce-larch forests typical of the Early Holocene [1]. Later, pollen analysis of a 5-meter trench of the peat deposits from the Gorbunovo peat bog made it possible to distinguish six patterns of vegetation change in the Holocene, typical of the Middle Urals [2]. Then, the evolutionary patterns obtained for the Middle Urals vegetation in the Holocene underwent correlation with the patterns distinguished for the East European Plain and...
Western Siberia [3]. New pollen data from the Gorbunovo peat bog were acquired during the studies of the trench from the multilayer site Beregovaya II whose lower layers are dated to the Mesolithic [4]. Radiocarbon dating gave a detailed analysis of the vegetation dynamics in the Early Holocene. These data are well correlated with the palynological materials obtained earlier from the trenches of the Gorbunovo peat bog [3] and other Middle Urals peat bogs and lakes [5; 6; etc.].

In contrast to pollen studies, the study of plant macrofossils in the peat and lacustrine deposits of the Middle Urals began only in recent decades. Lacustrine-boggy deposits from the trenches of the Shigirsky and Gorbunovo peat bogs have undergone botanical analysis in addition to pollen studies of the peat bogs carried out by T Antipina [4; 7]. Archaeological Eneolithic sites from the Shigirsky peat bog were subjected to the plant macrofossil analysis [8]. Fruits and seeds in the Gorbunovo peat bog deposits have not been studied before.

New pollen and plant macrofossil data together with the results obtained through the radiocarbon method and archaeological studies made it possible to reconstruct in a very detailed way landscape climatic conditions of the living environment of the ancient people in the vicinity of the Gorbunovo peat bog during the Mesolithic period. The obtained data enabled us to significantly clarify palaeoenvironmental specifics of the Early Holocene in the Middle Urals.

2. The study area
The Gorbunovo peat bog is located on the eastern slope of the Middle Urals in the Prigorodny district of Sverlovskaya province, 5 km to the South from Nizhny Tagil, 2.7 km to the South, South-East from Gorbunovo community (Figure 1) [9].

![Figure 1. Location of the Gorbunovo peat bog in the Middle Urals.](image_url)

The study area is located in the moderate continental climatic zone. Mean annual temperature is 1.7°C. Average monthly temperature in January reaches −14.5°C, while that of July is 17.8°C. Mean annual precipitation is of 500–600 mm [10]. Modern primary forests in the study area are represented by middle taiga larch-pine forests and southern taiga pine forests with occurrence of larch and linden in the understory [11].

The Beregovaya I site is located on the rocky headland of the aboriginal northeastern shore of the Gorbunovo peat bog. At the root of the headland, M Zhilin and S Savchenko (Sverdlovsk Regional Museum, Yekaterinburg) excavated 44 m² of the peat in 2013. Early and Middle Mesolithic cultural layers are deposited in sapropels, Late Mesolithic in the bottom of peat, while Early Neolithic layer in its middle part and Eneolithic in the upper part of peat [9].

The Seryi Kamen site is located on the rocky headland of the eastern shore of the Gorbunovo peat bog. At the root of the headland, M Zhilin and S Savchenko in 2013 excavated six test pits, which demonstrated that Early and Middle Mesolithic cultural layers were formed in sapropels, while Late
Mesolithic layers in peat. At the root of the rocks, peat yields the Eneolithic cultural layer which has not been found in other test pits [9].

3. Materials and methods

To reconstruct the changes of the natural habitats of ancient people and local conditions of the peat bog formation at the sites of the Gorbunovo peat bog, archaeologists M Zhilin and S Savchenko took samples for pollen, plant macrofossil and radiocarbon analyses. The samples have been taken as a continuous column without any intervals: monolith peat samples were taken at 10 cm intervals, while sapropel samples at 5 cm. The changes in the nature of the deposits have been recorded during the sampling. Every site yielded 25 samples from the 210-cm depth trenches of the deposits.

Peat and sapropel samples for pollen and plant macrofossil analyses were subjected to standard methods [12; 13]. Pollen and spores have been identified in temporary glicerine solutions under Olympus BX51 microscopes at x200 and x400 magnification. Pollen and spores in each specimen were counted to 500 arboreal pollen grains. Dry peat and sapropel were sifted through the sieves with a mesh diameter of 10 to 0.2 mm. Plant macrofossils were selected from each fraction under a Carl Zeiss Stemi 2000-C microscope. Micro- and macrofossils have been identified using a reference collection of pollen, fruits and seeds from the Museum of the IPAE UB RAS (Yekaterinburg, Russia), and the Atlases [14; 15; 16]. Data processing and plotting were performed in TILIA software 2.0.41 [17].

To reconstruct palaeovegetation on the basis of the obtained palaeobotanical data, a biome model has been applied [18; 19; 20]. Biome affinity scores for the samples from the Gorbunovo peat bog were calculated with the PPPBase software [21].

The radiocarbon age of the samples was determined in the Laboratory of Isotope Geochemistry and Geochronology (Geological Institute, Russian Academy of Sciences, Moscow) (GIN RAS) (GIN index in sample designation) and in the Laboratory of Isotope Studies of the Resource Sharing Centre Geocologia, Department of Geology and Geocology, Department of Geography in Gertsen Russian State Pedagogical University (SPb index in sample designation) and falls into the Early Holocene. Radiocarbon dates were calibrated using OxCal v.4.2.4 software and the IntCal13 calibration curve [22]. The age-depth models were constructed with Bchron v. 4.3.0 [23]. For the chronological division of the Early Holocene, recommendations of the Working Group of INTIMATE [24] were followed.

4. Results and discussion

4.1. Age-depth modelling

The set of $^{14}$C radiocarbon dates (Table 1) has been obtained from the sapropel and peat samples from the trenches of the Beregovaya I and Seryi Kamen sites. They correspond well to the radiocarbon dates obtained from the archaeological objects from the Mesolithic layers from the Beregovaya I, Beregovaya II and Seryi Kamen sites [4; 9].

Two age-depth models for the deposit formation have been plotted on the basis of available radiocarbon dates (Figure 2). This is a general representation of the rate of deposit accumulation in the Early Holocene. These models demonstrate a linear ratio of depth to age. The second half of the Pre-Boreal (~11,000–10,500 cal BP) and first half of the Boreal periods (~10,500–9,600 cal BP) are characterized by low rate of sapropel accumulation, being equal to 0.3–0.4 mm/year. In the second half of the Boreal period (9,600–9,100 cal BP), the accumulation rate for sapropels and lower part of peat deposits significantly increased and was equal to approximately 2 mm/year. Generally, the obtained rate of organic deposit accumulation for the Gorbunovo peat bog falls within the range of average sapropel accumulation rates.

4.2. Pollen and plant macrofossil data of the Beregovaya I site

Seven local zones can be distinguished on the diagrams of changes in pollen and plant macrofossils content (Figure 3).
Table 1. Radiocarbon dating of Gorbunovo peat bog deposits.

| Section     | Depth, cm | Material dated | Laboratory reference | $^{14}C$ yr BP | Calibrated age (cal BP) 95% probability |
|-------------|-----------|----------------|----------------------|----------------|-----------------------------------------|
| Beregovaya I| 170–175   | Peat           | GIN-15104            | 8660±40        | 9539–9697                               |
|             | 175–180   | Peaty sapropel | SPb-1793             | 8587±60        | 9479–9687                               |
|             | 180–185   | Sapropel       | SPb-1792             | 8850±70        | 9690–10183                              |
|             | 200–208   | Sapropel       | SPb-1791             | 8995±80        | 9790–10366                              |
|             | 208–210   | Sapropel       | SPb-1790             | 9340±70        | 10297–10726                             |
| Seryi Kamen | 100–110   | Peat           | SPb-1789             | 8115±70        | 8777–9282                               |
|             | 175–180   | Peat           | GIN-15103            | 8430±30        | 9422–9523                               |
|             | 180–185   | Sapropel       | SPb-1788             | 8543±60        | 9440–9529                               |
|             | 190–195   | Sapropel       | GIN-15102            | 8590±30        | 9502–9604                               |
|             | 195–200   | Sapropel       | SPb-1787             | 8615±60        | 9489–9733                               |
|             | 205–210   | Sapropel       | GIN-15101            | 8620±40        | 10779–11172                             |

Figure 2. The age-depth curves for the Beregovaya I (a) and Seryi Kamen (b) deposit sections.
Figure 3. Pollen (a) and plant macrofossil (b) diagrams of the Beregovaya I section:

1 – peat, 2 – sapropel, # – rare macrofossils, ## – numerous macrofossils.

Zone B-1 (the depth of 210–208 cm). In the pollen spectrum from the sample of grey sapropel containing forest litter, twigs, cones and larch trunks, sand, small stones and pieces of coal, arboreal pollen concentration reaches about 55%. Pollen of *Betula* sect. Albae (more than 30%) prevail with occurrence of those of *Larix sibirica* and *Picea* (about 5%). *Betula nana* dominate the pollen of shrubs (about 10%) with sporadic occurrence of *Salix*. Pollen concentration of herbaceous plants reaches 35% with abundance of *Poaceae*, *Artemisia*, and *Rosaceae*. Pollen of macrophytes (*Typha, Sparganium/Potamogeton-type*) and spores of higher spore-bearing plants are scarce.
Arboreal plants are represented by numerous coniferous macrofossils, mainly *Larix sibirica* with significantly fewer quantities of *Picea obovata*. Besides, numerous winged fruits and scales of *Betula* sect. Albae have been found. Aquatic plants (*Caulinia flexilis, Najas marina, Potamogeton* sp.sp.) dominate herbaceous plants with lesser quantities of marsh and semi-aquatic plants (*Carex* sp.sp., *Typha angustifolia, Eleocharis palustris, Scirpus lacustris*, etc.). Macrofossils of meadow forbs (*Urtica dioica, Potentilla* sp.sp., etc.) and of forest forbs (*Fragaria vesca, Rubus saxatilis*) can be found in lesser quantities.

According to the obtained radiocarbon date (see Table 1), the zone is dated to the second half of the Pre-Boreal period [25]. It also shows evidence of the Early Mesolithic cultural layer.

Zone B-2 (208–200 cm). In the pollen spectrum from the lower grey sapropel sample, the total content of arboreal and herbaceous pollen slightly reduces, while that of dwarf birches increases to 20% and of willows exceeds 5%. Pollen concentration of *Pinus sylvestris* increases to 25%, while that of *Betula* sect. Albae and *Picea* reduces. Sporadic occurrence of *Larix sibirica* pollen is observed. No significant changes in the group of herbaceous plants have been identified, except for a decrease in the content of Poaceae pollen and an increase in Cyperaceae.

Macrofossils of the same arboreal plants typical of the previous zone (larch, spruce, birch) have been identified here with sporadic occurrence of winged fruits of *Alnus incana*. Herbaceous plants are represented by macrofossils of aquatic, marsh and semi-aquatic plants, as well as forest and meadow plants. This zone differs from the previous one by smaller quantities of macrofossils of all groups of plants.

According to the obtained radiocarbon date (see Table 1), this zone is dated to the initial phase of the Boreal period [25].

Zone B-3 (200–175 cm). The upper fine-detrital grey sapropel and olive sapropel samples demonstrate an increase in arboreal pollen concentration with predominance of *Betula* sect. Albae (30–40%) and *Pinus sylvestris* (about 20%) pollen. *Picea* pollen concentration increases to 10%. *Larix sibirica* is sporadic. Pollen concentration of dwarf birches reduces to 10–15%. The group of herbaceous plants is mainly formed by pollen of *Artemisia* (about 10%) with sporadic occurrence of forbs, including *Ephedra*, *Chenopodiaceae*, and *Rosaceae*.

Species composition of arboreal macrofossils is similar to the previous zone (larch, spruce, birch, alder), though macrofossil quantities are significantly fewer. Larch macrofossils occur sporadically. *Juniperus* sp. seeds that have not been found in previous zones have been identified here. There continues to be a gradual reduction in the quantities of aquatic, semi-aquatic, forest and meadow plants. Sporadic *Sphagnum* sp. twigs can be found.

According to the obtained set of the radiocarbon dates (see Table 1), this zone is dated to the second half of the Boreal period, the so-called Middle Boreal warming [25]. The olive sapropel layer shows evidence of the Middle Mesolithic cultural layer.

Zone B-4 (175–160 cm). Pollen spectra of two samples from the bottom of highly decomposed dark brown peat demonstrate an increase in the pollen concentration of herbaceous plants to 45%. The content of Cyperaceae pollen increases to 10–20%, while that of *Poaceae* to 10%. The pollen content of dwarf birches is less than 10%. Insignificant increase in the content of *Pinus sylvestris* pollen to 30% can be noted, while *Betula* sect. Albae demonstrates its reduction. Concentration of spores of ferns has gone up.

Arboreal macrofossils are dominated by birch winged fruits. Macrofossils of *Pinus sylvestris* and *Salix* sp. start to appear. The quantities of fruits and seeds of semi-aquatic and marsh plants are higher in comparison with the previous zone, whereas aquatic plants have practically disappeared. Macrofossils of forest and meadow forbs are still sporadic. *Sphagnum* spore cases have been found.

According to the obtained radiocarbon date (see Table 1), this zone is also dated to the second phase of the Boreal period [25]. The lower sample yields artefacts of the Late Mesolithic cultural layer.

Zone B-5 (160–150 cm). Pollen spectrum of highly decomposed dark brown peat sample demonstrates a sharp increase in pollen concentration of *Pinus sylvestris* to almost 70% with a
decrease in pollen of *Betula* sect. Albae and sporadic occurrence of *Betula nana*. Birch macrofossils have been found. Small quantities of marsh and semi-aquatic macro-remains occur. Sporadic meadow and forest forbs can be found. No aquatic macrofossils have been identified. This zone is likely to correspond to the end of the Boreal period.

Zone B-6 (150‒100 cm). Pollen spectra of the upper part of dark brown peat and lower part of brown peat demonstrate predominance of *Pinus sylvestris* pollen (80‒90%) with sporadic occurrence of *Betula* sect. Albae. Albae. Spores of sphagnum mosses start to appear from the depth of 120 cm, whereas *Picea* pollen concentration increases to 10% starting from the depth of 110 cm.

Increased quantities of spruce and pine macrofossils are observed with a decrease in the quantities of birch winged fruits and scales. Larch is rare. Small quantities of *Salix* and stones of *Rubus idaeus* have been found. Herb macrofossils are scarce, including fruits and seeds of marsh and semi-aquatic plants, meadow and forest plants. This zone is likely to correspond to the end of the Boreal period.

Zone B-7 (100–0 cm). Pollen spectra of the upper peat layers are predominated by *Pinus sylvestris* pollen. Spruce pollen concentration gradually increases to 25%. Rare pollen of *Abies sibirica*, *Tilia cordata*, *Ulmus*, and *Quercus robur* occur. Spores of sphagnum mosses are abundant at a 90‒30 cm depth.

Macrofossils of sphagnum mosses prevail. The lower part is predominated by numerous spruce macroremains, whereas pine, larch and birch are significantly fewer in numbers, however, this depth does not yield fruits and seeds of arboreal plants. Small quantities of raspberry stones with rare fruits and seeds of marsh, semi-aquatic, forest and meadow plants occur.

Peat formation is likely to take place in the Atlantic and Subboreal periods of the Holocene [25]. The lower part of dark brown peat yields artefacts of the Eneolithic Ayat Culture.

4.3. Pollen and plant macrofossil data of the Seryi Kamen site

Four local zones can be distinguished on the diagrams of changes in pollen and plant macrofossils content (Figure 4).

Zone SK-1 (210‒200 cm). Pollen spectra of grey-brown sapropel samples are predominated by arboreal pollen (about 75%) with pollen of *Pinus sylvestris* and *Betula* sect. Albae in equal proportions (about 30%). Sporadic pollen of *Picea*, *Pinus sibirica* and *Larix sibirica* occur. Pollen concentration of *Betula nana* reaches about 10%; *Salix* pollen is rare. Pollen of herbaceous plants is diverse and represented mainly by *Artemisia*, Poaceae, and Cyperaceae, and forbs, including *Filipendula*, *Ranunculaceae*, and *Apiaceae*. Pollen of semi-aquatic plants occur, mainly that of *Typha*. Polypodiophyta spores are present with scarce occurrence of *Bryales* and *Sphagnum*.

Coniferous macrofossils, namely larch, spruce and pine, demonstrate equal proportions. Birch winged fruits and scales are abundant. Macrofossils of marsh and semi-aquatic plants dominate herbaceous plants, while the quantities of aquatic plants are significantly less frequent, whereas seeds of forest and meadow plants occur sporadically. Macrofossils of sphagnum mosses are also scarce.

According to the obtained radiocarbon date (see Table 1), this zone is dated to the second phase of the Boreal period, the so-called Middle Boreal warming [25]. Early Mesolithic artefacts covered with a layer of grey-brown sapropel have been found on the bedrock (continent).

Zone SK-2 (200‒170 cm). Pollen spectra of the upper grey-brown sapropel sample, olive sapropel sample and lower dark-brown peat samples are predominated by arboreal pollen with abundance of *Pinus sylvestris* pollen (70‒90%) and occurrence of *P. sibirica* with insignificant content of *Betula* sect. Albae (less than 10%) and *Betula nana*. Sporadic occurrence of herbaceous pollen is rather typical. Content of spores of higher spore-bearing plants has not significantly changed.
Pine macrofossils dominate coniferous plants in comparison with the previous zone. Spruce is rare. No larch has been found. Birch is considerably higher in numbers. Scarce *Padus avium* macrofossils have been found. Fruits and seeds of marsh and semi-aquatic plants dominate herbs. Only few forest forb macrofossils can be found, however, the quantities of *Urtica dioica* seeds have increased.

Sphagnum twigs occur sporadically. The depth of 180–170 cm demonstrates qualitative and quantitative changes in composition of herbaceous plants. Species diversity has increased in the group of meadow and forest forbs (macrofossils of *Filipendula ulmaria*, *Thalictrum* cf. *simplex*, etc. occur). The quantity and diversity of marsh and semi-aquatic plants have significantly increased due to an
increase in the macrofossils quantities of some species and appearance of new species, namely Naumburgia thyrsiflora and Bidens cernua. Dramatic increase in the quantities of Comarum palustre nutlets is indicative of advancing weediness of waters. At the same time, the quantities of fruits and seeds of aquatic plants have dropped. According to the obtained set of radiocarbon dates (see Table 1), this zone is also dated to the second phase of the Boreal period [25]. Olive sapropel yields Middle Mesolithic artefacts, whereas lower part of dark-brown peat – Late Mesolithic artefacts.

Zone SK-3 (170–80 cm). Pollen spectra of the main mass of dark-brown and lower part of brown peat with large quantities of wood are characterised by predominance of Pinus sylvestris pollen with occurrence of P. sibirica and rare appearance of Betula sect. Albae. Pollen concentration of Picea has insignificantly increased, whereas scarce Betula nana pollen has been found only at a depth of 170–160 cm. Abies sibirica pollen has been identified in some spectra. Polypodiophyta spore concentration has increased to 20% in the lower spectra, whereas Sphagnum spore concentration has dramatically increased in the upper spectra.

Coniferous macrofossils belong to spruce and Scots pine. One of the samples yields carbonized Siberian stone pine needles. The quantities of Betula sect. Albae macrofossils decrease when moving upward with no birch macrofossils in the upper part of the mass to be found. Besides, the lower samples yield insignificant quantities of alder, willow and bird cherry. Rare raspberry stones have been found. When moving downward, the quantities of marsh and semi-aquatic plants decrease. Fruits and seeds of aquatic and forest plants occur sporadically. The upper sample yields small quantities of sphagnum mosses. According to the available radiocarbon date (see Table 1), this zone corresponds to the end of the Boreal period [25]. Rare artefacts and bird bones have also been found in this layer.

Zone SK-4 (80–0 cm). Pollen spectra of the upper part of the peat deposits are characterized by the predominance of Sphagnum spores (about 50%) with high content of Pinus sylvestris pollen. Picea pollen concentration does not exceed 10%. Pollen of Larix, Abies sibirica occur. Sporadic occurrence of Tilia cordata and Ulmus pollen has been recorded in this zone for the first time.

Macrofossils are dominated by sphagnum mosses. The lower sample is characterized by large quantities of pine and spruce macrofossils with poor content of birch macrofossils. Then, the quantity of arboreal macrofossils dramatically decreases with an increase in the content of sphagnum mosses. Raspberry stones, as well as Ledum palustre leaves, Empetrum nigrum seeds, forest forbs and sedges occur sporadically. This zone is likely to characterize the Atlantic period.

4.4. Biome method

For biome reconstruction, we applied a biome-taxon matrix consisting of 34 pollen and 30 plant macrofossil taxa. This matrix served as a basis for calculation of the affinity scores for 10 biomes assigned for the North Eurasia [19]. The biome-taxon matrix of the dominant biomes and biomization results are given in Table 2 and Figure 5. Biomization revealed that cold deciduous forest biome dominated till 9,800–9,600 cal BP. At the same time, taiga biome affinity scores are close to those of cold deciduous forest biome. Steppe and tundra biomes do not have significant biome affinity scores. Joint findings of the plant micro- and macrofossils typical of the steppe and tundra biomes, are characteristic of the periglacial palaeocommunities. Starting from 9,600 (9,500) cal BP, taiga biome prevails.

4.5. Characteristics of the Early Holocene ecosystem dynamics in the vicinity of the Gorbunovo peat bog

The obtained results together with those published earlier [2; 4; etc.] enable us to carry out a detailed analysis of the Early Holocene natural conditions in the vicinity of the Gorbunovo peat bog in the Middle Urals.
The data from the Beregovaya II [4] and Beregovaya I sites indicate that within the period from ~11,000–10,800 cal BP to ~10,300 cal BP, the Gorbunovo peat bog was dominated by cold deciduous forests (Figure 5), namely larch-birch light forests with spruce and meadow communities. Similar plant formations are typical nowadays of the mountains in the North, Nether-Polar and Polar Urals [11].

Forest formations consisted of spruce, birch and larch. Spruce concentration in the forest formation was lower than that of larch, which is indicated by significantly lower content of spruce seeds in the samples (with equal seed production). Numerous subfossil larch trunks, cones and twigs dated to 9,800±40 14C yr BP (11,176–11,262 cal BP) (GIN-14088), 9,230±60 14C yr BP (10,298–10,692 cal BP) (GIN-14136), etc. in the deposits of the Beregovaya II site [4] and 9,320±60 14C yr BP (10,247–10,555 cal BP) (GIN-14774) of the Beregovaya I site [9] also indicate larch predominance in the forest formations. Birch was one of the leading species in the forest stand, which is indicated by the abundance of its pollen and macrofossils in the samples. The forest stand was likely formed mainly by Betula tortuosa Ledeb. with occurrence of B. pendula Roth. and B. pubescens Ehrh. The former together with larch form nowadays northern

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**Table 2. Dominant biomes and their characteristic plant functional types with pollen and plant macrofossil taxa reconstructed from the Gorbunovo peat bog.**

| Biomes           | Plant functional types                                                                 | Pollen taxa                                                                                   | Plant macrofossil taxa                        |
|------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------|
| Tundra           | Arctic-alpine dwarf shrubs and forbs                                                    | Betula nana, Alnus sp., Betula sect. Albae, B. nana, Picea sp., Larix sibirica, Pinus sylvestris, Salix sp. | Betula nana, Bistorta vivipara, Empetrum nigrum, Ledum palustre, Salix sp., Vaccinium viti-idaea |
| Grass            | Heath                                                                                   |                                                                                                |                                               |
| Cool deciduous forest | Arctic-alpine dwarf shrubs and forbs                                                    | Betula sect. Albae, B. nana, Ericales, Larix sibirica, Pinus sylvestris, Salix sp.             |                                               |
| Boreal summegreen trees and shrubs | Eurythermic conifer trees and shrubs                                                      |                                                                                                |                                               |
| Heath            | Boreal evergreen and summegreen forbs                                                   | **Abies sibirica, Alnus sp., Betula sect. Albae, Ericales, Larix sibirica, Picea sp., Pinus sylvestris, Salix sp.** | **Abies sibirica, Alnus sp., A. incana, Betula sect. Albae, Juniperus sp., Larix sibirica, Ledum palustre, Moehringia sp., Pados avium, Picea obovata, Pinus sibirica, P. sylvestris, Rubis idaeus, Rubus saxatilis L., Salix sp., Vaccinium viti-idaea Cirsium cf. arvense, Fallopia convolvulus, Fragaria vesca, Lamiaceae, Polygonum sp., P. aviculare, Potentilla spp., P. supina, Primulaceae, Thalictrum cf. simplex, Th. minus, Viola spp.** |
| Taiga            | Boreal evergreen and eurythermic conifer trees and shrubs                               | **Abies sibirica, Alnus sp., Betula sect. Albae, Ericales, Larix sibirica, Picea sp., Pinus sylvestris, Salix sp.** |                                               |
| Boreal summegreen trees and shrubs | Heath                                                                                   |                                                                                                |                                               |
| Steppe           | Meadow-steppe forbs                                                                      | Apiaceae, Artemisia sp., Asteraceae, Boraginaceae, Caryophyllaceae, Chenopodiaceae, Ephedra sp., Fabaceae, Plantago sp., Poaceae, Polemonium sp., Ranunculaceae, Rosaceae, Rubiaceae, Sanguisorba sp., Thalictrum sp. |                                               |
| Grass            |                                                                                         |                                                                                                |                                               |
forest border in the mountains of the North, Nether-Polar and Polar Urals [11]. Scots pine was likely to occur there sporadically. This is proven by low content of its pollen in the spectra, lack of vegetative and generative macrofossils, and presence of isolated pine artefacts. For example, a burnt notched log from the lower cultural layer of the Beregovaya II site dated to 9,850±40 $^{14}$C yr BP (10,199–11,326 cal BP) (GIN-14135) is made of pine [4].

Open areas were covered by sagebrush and goosefoot, with occurrence of ephedra and forb-grass meadow communities. Willow and dwarf birch formed the shrub layer. It must be noted that neither pollen, nor Ericales macrofossils, typical of modern tundra and forest-tundra, have been found. Generally, coexistence of forest, steppe and tundra elements in the palaeocommunities formed periglacial features of vegetation.

There existed a shallow lake at the initial stage of swamping. Aquatic communities were dominated by hydrophytes forming plant communities at all the depths reachable by aquatic macrophytes, mostly at shallow waters within 0.5–3 m: *Potamogeton perfoliatus* and *P. pectinatus*, growing in modern ponds at the depths of up to 5–6 m, *Caulinia flexilis*, *Myriophyllum spicatum* and *M. verticillatum*. Semi-aquatic plants (helophytes), such as *Scirpus*, *Typha angustifolia* and water-line plants (hydrohelophytes) *Carex*, *Eleoharis palustris* could be found at the littoral shelf. Generally, the flora of the pond was mainly formed by freshwater euryhaline species, i.e. species capable of growing within a wide range of water salinity, though there were also some plants-halophytes capable of growing in saltish water, namely *Zannichellia palustre* and *Potamogeton vaginatus*.
Spruce-larch-birch light forests were also widespread among open meadow areas at about ~10,300 cal BP. However, forest formation proportion reduced, which is indicated by the reduction of total pollen concentration and quantities of arboreal macrofossils. The role of dwarf birch in the plant communities increased.

Aquatic communities were still dominated by hydrophytes. Semi-aquatic and water-line plants could be found at the littoral shelf. Generally, aquatic macroflora of the pond was mainly formed by freshwater euryhaline species with occurrence of plants-halophytes.

Then, within the interval of ~10,300–9,800 cal BP, the quantities of larch and spruce decreased in the forest stand, and pioneer birch forests started to form. Similar birch forests can be found at the upper forest border of the mountains in the North and Polar Urals [11]. Periglacial elements in meadow communities were replaced by marginal forest and marginal meadow species. The areas covered by dwarf birch standing bushes shrank, which is indicated by the reduction of its pollen and lack of macrofossils. Water logging of the lake shore significantly increased; bushes of reed mace and sedges started to grow, which is proven by an increase in the quantities of macrofossils of these plants. Species diversity and the quantities of macrofossils of aquatic macrophytes reduced, which is also indicative of aggressing water logging.

Starting from ~9,800–9,600 cal BP, the biome of cold deciduous forests was replaced by taiga: Scots pine actively penetrated forest formations, while concentration of larch and birch reduced. An increased role of pine is proven by significant concentration of its pollen and presence of macrofossils. Water logging advanced: the group of aquatic-marsh plants prevailed if compared to the group of aquatic macrophytes with regard to species diversity and macrofossil quantities.

Starting from ~9,600–9,500 cal BP, taiga pine forests with birch, spruce and rare larch began to dominate. This is indicated by the abundance of Scots pine pollen and presence of Pinus sylvestris needles and seeds with the abundance of plant macrofossils and presence of pollen of Betula sect. Albae. Bird cherry formed standing bushes. Insignificant quantities of dwarf birch could be found at the swamped areas. Grass-bush layer was represented by marginal forest and marginal meadow forbs. Species diversity (about 30% of total floristic composition) and abundance of aquatic plant macrofossils prevail over the group of marsh and semi-aquatic marsh plants. This means that the area of the open water in the pond was quite large and favourable for the development of aquatic macrophytes. At the same time, the presence of peat-forming plant macroremains indicates active process of water logging.

At the boundary between the Early and Middle Holocene, pine forests with occurrence of spruce, birch and Siberian stone pine prevailed. Padus avium and Salix sp. formed standing bushes. Insignificant quantities of dwarf birch could be found at the swamped areas. Grass-bush layer was dominated by marsh and semi-aquatic marsh plants (47.8% of total floristic composition). It was mainly formed by Carex rostrata, C. riparia, C. acuta and C. cf. acutiformis, Comarum palustre, Lycopus europaeus, Cicuta virosa, Naumburgia thyrsiflora, Typha angustifolia and Menyanthes trifoliata. Open water areas considerably shrank, thus aquatic macrophytes practically disappeared.

Later, in the Middle Holocene, taiga elements started to play an important role in the vegetation cover of the Middle Urals. At the Holocene climatic optimum, in the second half of the Atlantic period, broad-leaved elements, namely linden, elm-tree, oak and hazel, penetrated taiga forests. Sporadic pollen of nemoral species occurred in the upper peat layers from the studied trenches of the Gorbunovo peat bog. Detailed reconstruction of the vegetation changes and natural conditions in the Middle and Late Holocene is described in a number of papers [6; 7; 26].

5. Conclusion
Joint analysis of pollen, plant macrofossil and radiocarbon data, obtained during the studies of the deposit trenches from the multilayer sites of the Gorbunovo peat bog revealed main evolutionary patterns of the forest vegetation in the Early Holocene.

During the second half of the Pre-Boreal period (to 10,300 cal BP), cold deciduous forests dominated the study area, namely birch-larch light forests with spruce and sporadic occurrence of
Scots pine. There existed a shallow lake at the initial stage of water logging. Various aquatic macrophytes inhabited the lake.

Spruce-birch-larch light forests were also widespread among open meadow areas during the period of early Boreal cooling (at about ~10,300 cal BP). However, the share of forest formations reduced, though larch was still present in the area. Periglacial meadow communities still kept their positions. Various aquatic macrophytes actively developed in the lake.

At the onset of the Middle Boreal warming, larch quantities sharply reduced; forest communities were dominated by birch (~10,300–9,600 cal BP). Periglacial communities became degraded. Overgrowing of the water in the lake with aquatic marsh plants started. Then, in the second half of the Middle Boreal warming, cold deciduous forests were replaced with taiga: pine started to penetrate forest formations, larch and birch concentration decreased. The lake shores overgrew with aquatic and marsh plants. In the end of the Middle Boreal warming (starting from ~9,600–9,500 cal BP), taiga pine forests with birch, spruce and rare larch began to dominate. The area of the open water in the pond was quite large and favourable for the development of aquatic macrophytes. At the same time, active water logging started. Valley peat deposits started to form.

At the boundary between the Early and Middle Holocene, at the end of the Boreal period, the area was dominated by pine forests with occurrence of spruce and Siberian stone pine. Open water areas shrank considerably, thus aquatic macrophytes practically disappeared. Due to active peat formation, the lake gradually turned into a peat bog. Later, in the Middle Holocene, taiga elements started to play an important role in the vegetation cover of the Middle Urals.

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