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The Holocene Dynamics of Vegetation and Ecological Conditions in the Polar Urals

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Abstract—Palynological, paleocarpological, and paleoentomological analyses of frozen peat deposits near Lake Pereval'noe, the Polar Urals, were performed to reveal the main stages of change in the pattern of vegetation over the period from the beginning of warming after the last Pleistocene glaciation to the late Holocene. Nine to four thousand years ago, the study region (at the present-day upper boundary of open larch forests) was covered with taiga forests, as the climate there was significantly warmer. These were larch–birch forests with an admixture of spruce and, later, spruce forests with larch and birch.

Key words: peat, palynological spectrum, plant macrofossils, entomofauna, vegetation, climate.

Factual data on the history of vegetation in the postglacial period are necessary for revealing the past and present trends in its development both in individual regions and on the global scale. Climate changes in the Holocene had the maximum amplitude in the Subarctic, and this was reflected in the contemporary dynamics of vegetation. Studies in the Arctic and Subarctic are crucial for understanding the mechanisms of global environmental changes, and natural scientists are giving increasing attention to these regions.

The results of paleogeographic and paleobotanical investigations performed in the North as early as in the 1920s–1940s (Sukachev, 1922; Kats and Kats, 1946, 1948) provided evidence for a considerable change in climatic conditions and the expansion of forest vegetation to the present-day tundra zone in the postglacial period. They were confirmed and elaborated in subsequent studies, and radiocarbon dating made it possible to ascertain the chronology of these events (P'yavchenko, 1955; Levkovskaya, 1977; Vasil'chuk *et al.*, 1983; Panova, 1990; Hantemirov and Shiyatov, 1999).

In the Polar Urals, studies on the Holocene dynamics of vegetation and climate by palynological, cryological, and radiocarbon methods have been performed in the mountain-valley tundra zone in the northern and southern parts of the mountain range with elevations of 210–220 and 240–250 m a.s.l., respectively (Boyarskaya and Zaikina, 1967; Surova, 1967; Surova *et al.*, 1971, 1975). The object of our study is in the central part of the Polar Urals, in the area where dendroclimatic research at the timberline has been performed over many years (Shiyatov, 1964, 1986; Vaganov *et al.*, 1996, 1998).

STUDY REGION, OBJECTS, AND METHODS

Studies were performed on the eastern macroslope of the Ural Ridge, in the Sob' River basin. The present-day type of vegetation in the study region is the birch–spruce–larch forest–tundra with the prevalence of *Larix sibirica*, *Picea obovata*, and *Betula tortuosa*. The subgoltzy belt consists of virtually pure larch forests. The timberline lies at an elevation of 200–250 m, but isolated clusters of larch trees are found as high as 300 m a.s.l. Open spruce–larch and spruce–birch forests grow in the foothills and, in places, ascend along mountain valleys to an elevation of 150–160 m a.s.l. (Shiyatov, 1964). The forest–tundra zone of the Polar Urals has a severe subarctic climate with long, cold winters and short, cool summers. The monthly average temperatures range from –19 to –24°C in January and from 12 to 14°C in July, and the annual average precipitation in the mountains is 500–700 mm (Shvareva, 1962).

We studied frozen peat deposits exposed in a natural way on the shores of large and small frost-thaw lakes (Panova and Jankovska, 2000). These deposits were no more than 2 m deep. The results described in this paper were obtained by analyzing the profile of a peat deposit near the lake located on the mountain pass at the eastern slope of the Rai-Iz massif (66°51′ N, 65°41′ E) at an elevation of 260 m a.s.l. (conventionally named Lake Pereval'noe). The lower peat layers in this flat hummocky deposit lay approximately 1 m above the water level. The profile was 250 cm deep, including a 190-cm peat layer and a 60-cm layer of marl (a silty organomineral deposit gradating into clay).

The vegetation on the peat deposit and in its vicinity was of the tundra type and consisted of herbaceous plants and shrubs, with rare larch trees occurring on the slopes. Small clumps of spruce and birch trees adjoined the deposit on the east. The shrub layer was dominated by dwarf birch (*Betula nana*) and included several willow species (*Salix lanata, S. lapponum, S. phylicifolia, S. reticulata, S. glauca,* and others), alder (*Alnus fruticosa*), and, rarely, juniper (*Juniperus sibirica*). The herb–dwarf shrub layer on peat hummocks and nearby slopes consisted mainly of dwarf shrubs of the heath family (*Ledum palustre, Empetrum hermaphroditum, Arctous alpina, Arctostaphylos uva-ursi, Andromeda polifolia, Vaccinium uliginosum,* and *V. vitis-idaea*); in moist depressions, there were cloudberry (*Rubus chamaemorus*), cotton grass (*Eriophorum vaginatum*), sedges (*Carex globularis, C. hyperborea,* etc.), buckbean (*Menyanthes trifoliata*), grass of Parnassus (*Parnassia palustris*), mixed mesophilic herbage (*Rubus arcticus, Sanguisorba polygama, Polygonum bistorta, P. viviparum, Lagotis minor, Veratrum lobelianum, Valeriana capitata, Pedicularis lapponica, P. oederi, Saxifraga hirculus, Solidago virgaurea, Saussurea alpina, Cardamine pratensis, Conioselinum vaginatum,* etc.), and horsetails (*Equisetum sylvaticum* and others); *Dryas octopetala, Dianthus repens, D. superbus, Silene acaulis, Minuartia arctica,* and *Saxifraga caespitosa* occurred on relatively dry slopes. The ground vegetation layer consisted mainly of green mosses (*Aulacomnium turgidum, Chrysohypnum stellatum, Hylocomium splendens, Ptilidium ciliare, Rhacomitrium lanuginosum,* etc.), with spots of lichens (*Alectoria ochroleuca, Cladonia alpestris, C. silvatica, C. rangiferina, Cetraria islandica, C. nivalis, C. mitis, C. cucullata, C. tilesii, Dactylina arctica, Thamnolia vermicularis,* and *Stereocaulon paschale*).

From the profile of the deposit, we took 50 samples of peat and marl (at 5-cm intervals) for palynological analysis and 11 samples of peat (at 15- to 20-cm intervals) for paleocarpological and paleoentomological analyses. Their laboratory processing and identification were performed using conventional methods (Grichuk and Zaklinskaya, 1948; Kats *et al.*, 1965; Nikitin, 1969; Kiselev, 1987). The percent ratio of the identified palynological taxa was calculated relative to the sum of the pollen of tree and shrub species.

Interpretation of the results was based on the actuality principle. In other words, we took into account the present-day geographic distribution and ecological features of the genera and species of plants and arthropods whose fossils were detected in the course of analysis, as well as the reflection of the present-day vegetation pattern in the spectrum of spores and pollen found in the surface layer.

RESULTS OF PALYNOLOGICAL ANALYSIS

We distinguished six palynological zones (palynozones) in the spore–pollen diagram (Fig. 1).

Palynozone 1a was located at a depth of 190–250 cm. The pollen of birch (*Betula*), mainly of fruticose species (sections *Nanae* and *Fruticosae*), prevailed in mineral deposits. Relatively large amounts of pollen were contributed by willows (*Salix*) and herbaceous plants of the families Poaceae, Cyperaceae, Asteraceae, Caryophyllaceae, Polygonaceae, Rosaceae, Ranunculaceae, and others, including wormwood (*Artemisia*) and goosefoots (Chenopodiaceae). The last two groups are characteristic of the late glacial deposits and include many ruderal and xerophytic plants. There were the spores of sphagnum mosses, green mosses (Bryales), club mosses (mainly of the hypoarctic species *Lycopodium pungens, L. alpinum,* and *L. appressum*), and ferns (Polypodiaceae). Very small amounts of pollen belonged to alder (*A. fruticosa*) and coniferous trees: larch (*Larix*), spruce (*Picea*), and, in single cases, pine (*Pinus sibirica* and *P. sylvestris*). Even single findings of larch pollen in the deposit could be regarded as evidence for the growth of larch in this area, whereas pine and spruce pollen was probably transferred from some other region.

The structure of this spore–pollen complex reflected the prevalence of herb–shrub tundra vegetation combined with open larch–birch forests. The climate in the corresponding period was similar to the present-day climate, except for lower humidity.

Palynozone 1b was distinguished at a depth of 180–190 cm by a sharp increase in the amount of willow and sedge pollen, which apparently reflected an increase in moisture supply and the onset of swamping.

Palynozone 2 (155–180 cm) was characterized by the prevalence of birch species of the section *Albae*. The amounts of spruce and larch pollen were greater, and the pollen of juniper (*Juniperus*) appeared. The palynological spectra were characteristic of open larch–birch forests with an admixture of spruce in the tree stand and alder, willows, and fruticose birch species in the undergrowth; i.e., it was indicative of climate warming. A large amount of sedge pollen in this zone could be a consequence of local swamp formation.

Palynozone 3a (105–155 cm) was distinguished by the highest content of spruce pollen (up to 84%, averaging 60%) and the lowest content of birch pollen, including that of fruticose species. The amounts of larch and juniper pollen, as well as horsetail, fern, green moss, and sphagnum moss spores, markedly increased in this zone.

The palynological spectra were apparently formed by the vegetation of taiga spruce forests with an admixture of larch and with juniper and alder in the undergrowth, reflecting an increase in moisture supply and a decrease in climate continentality.

Palynozone 3b (35–105 cm) contained increased amounts of birch and pine pollen and slightly decreased amounts of larch and spruce pollen. However, spruce pollen still prevailed in the spectrum: its content reached 52%, averaging approximately 40%. Fir pollen (*Abies*) occurred in single cases. The amounts of horse-

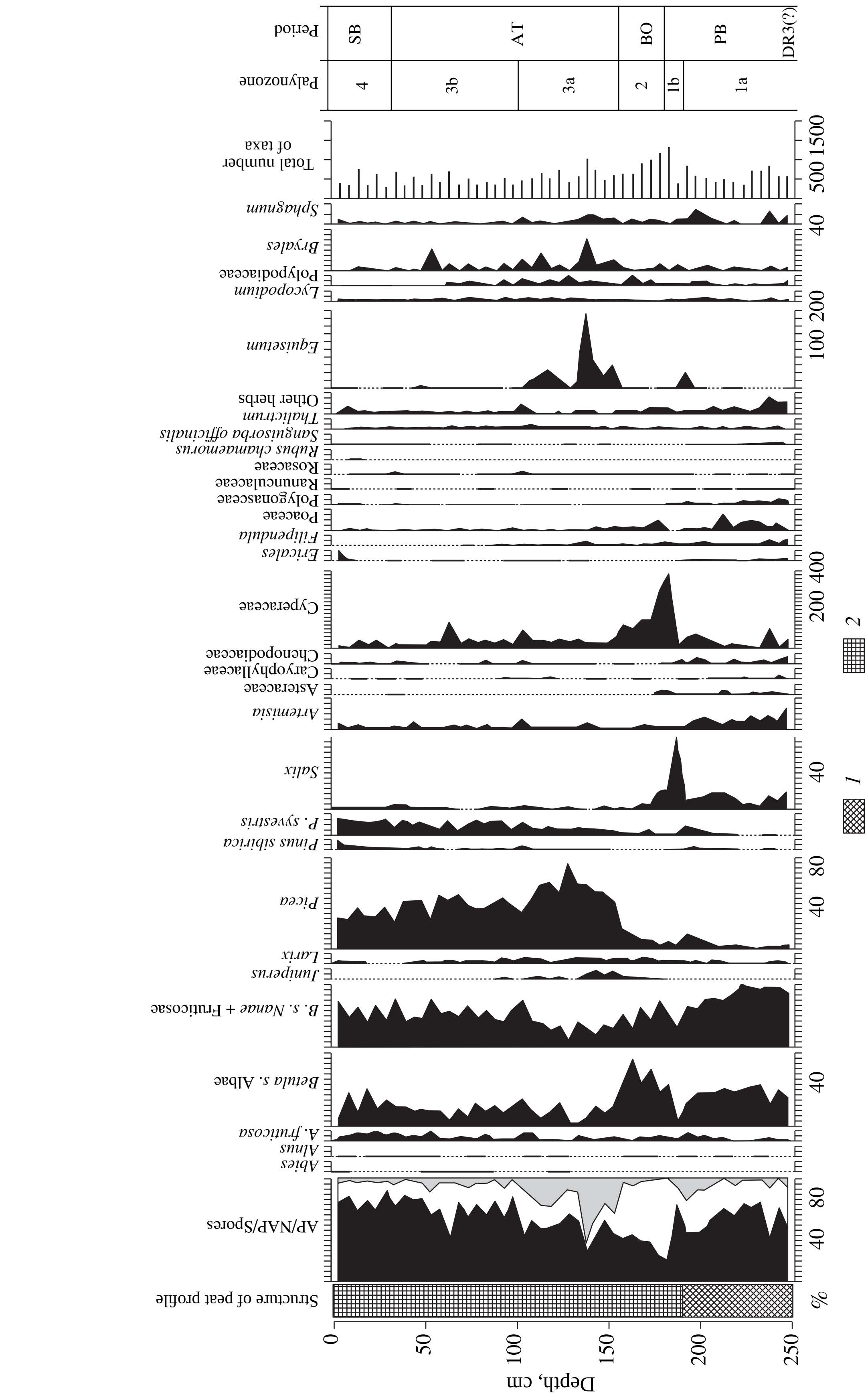

Fig. 1. Spore–pollen diagram of the peat deposit near Lake Pereval'noe (analyst N.K. Panova): (*1*) peat, (*2*) marl; (AP) arboreal pollen (trees + shrubs), (NAP) nonarboreal pollen (herbs + dwarf shrubs), (Spores) sum of spores.

tail and moss spores decreased. The spores of forest species of club mosses (*Lycopodium annotinum* and *L. complanatum*) occurred more frequently. The palynological spectra of this zone were characteristic of the vegetation of birch–spruce forests with larch that grew under moderately warm and moist climatic conditions.

Palynozone 4 (the upper 35-cm peat layer) was characterized by a decreased content of spruce pollen (20–35%), whereas the contribution of birch species (especially fruticose), alder, and pine increased. The palynological spectra were indicative of cooling. The vegetation in the corresponding period was apparently typical of open larch–birch–spruce forests. In the spectrum of the surface layer, which reflected the pattern of recent forest–tundra vegetation, the pollen of fruticose birch species prevailed, and the amount of pollen contributed by heaths (Ericales) was markedly greater.

RESULTS OF PALEOCARPOLOGICAL ANALYSIS

Macrofossils found in the peat deposit belonged to 45 plant taxa. Species identification was successful in 24 cases; other specimens were identified to the levels of genus (13), family (7), or order (1) (Table 1). With rare exceptions, the seeds were well preserved, and there were no signs of their redeposition.

The arboreal vegetation was represented mainly by the seeds and seed scales of arborescent birch, probably *Betula pubescens* (we found the seed scales of this species, but most other scales, poorly preserved, were identified as *Betula* sp.). Most fossils of coniferous woody plants belonged to spruce (*Picea obovata* and larch (*Larix sibirica*). Three samples contained the remains of juniper (*Juniperus communis*). Of deciduous shrubs, the fossils of dwarf birch (*Betula nana*) prevailed, and the sample from the bottom peat layer contained numerous fossils of willows (*Salix*).

Dwarf shrubs in the spectrum of fossils were represented by species of the heath family (*Andromeda polifolia, Empetrum nigrum, Ledum* sp., *Arctostaphylos uva-ursi*, and *Vaccinium vitis-idaea*). These plants grow in the taiga and forest–tundra zones and in bogs. There were also numerous fossils of *Comarum palustre*, especially in the lower part of the profile. This dwarf shrub is usually found on the silty shores of swamped lakes, on floating mats, and over the margins of sedge–sphagnum and grass–hypnum bogs in the forest and forest–tundra zones.

Most herbaceous plant fossils belonged to the species growing in bogs. The fruits and nutlets of different sedge species prevailed; *Eriophorum* sp., *Eleocharis palustris, Hippuris vulgaris, Cicuta virosa*, and *Rubus arcticus* were represented by single findings. The fossils of violets *Viola* sp.) were abundant. Among sedges, we identified the species occurring in both forest and forest–tundra zones (*Carex chordorrhiza, C. magellanica*) and the species characteristic mainly of the forest zone and absent from the present-day flora of the Polar Urals (*C. cinerea, C. diandra*, and *C. vesicaria*). Among grasses, there was a group of plants typical of disturbed areas (e.g., Chenopodiaceae gen. indet. and *Stellaria graminea*). Their seeds concentrated at a depth of 100–120 cm, which probably reflected activation of erosional processes in the corresponding period.

The spectrum of macrofossils isolated from the bulk of peat deposits was characteristic of the vegetation of swamped birch forests with spruce and larch, indicating that the climate at that time was warmer and milder than today.

The fossils found in the 15- to 30-cm horizon provided evidence for the disappearance of spruce and thermophilic sedges, decreased abundance of arborescent birch species, and reduced diversity of dwarf shrubs and herbs, which was probably explained by drastic cooling that occurred in the corresponding period.

RESULTS OF PALEOENTOMOLOGICAL ANALYSIS

In the peat samples, we found approximately 2000 fragments of insects attributed to 601 individuals and 20 remains of Oribatei mites (Table 2). Most insects were of the orders Coleoptera, Diptera, and Hymenoptera (Fig. 2a).

Among beetles, specimens of the family Staphylinidae prevailed (Fig. 2b). Most of them were of the subfamily Omaliinae and, in particular, of the genus *Olophrum* (*O. rotundicolle, O.* spp.) inhabiting various types of bogs. Beetles of the family Helodidae were relatively abundant, especially in the lower peat horizons (these insects prefer the areas with herbaceous vegetation). Ground beetles (Carabidae) ranked third in abundance; the genus *Agonum* was represented by the greatest number of species, including *A. fuliginosum, A. gracile*, and *A. exaratum* characteristic of bog habitats. Our observations showed that *Pterostichus diligens* ground beetles, regarded as inhabitants of small-leaved forests, were also abundant in peat bogs. Water beetles (mainly of the genus *Hydroporus*, including *H. arcticus*) were not abundant but occurred in many peat samples. Peat samples from depths of 45–60 and 120–140 cm contained the remains of the weevil *Phytobius* sp. (probably, of *Ph. comari* trophically connected with *Comarum palustre*). The remains of dipterans included numerous head capsules of crane flies (Tipulidae), the inhabitants of overmoistened soils.

The insects inhabiting different zones, such as the road beetle *Olophorum* cf. *rotundicolle* and the weevil *Notaris aethiops*, prevailed in all peat samples. Boreal forest species occurred singly in the majority of samples. In addition to the aforementioned forest–bog species *P. diligens*, they included the ground beetle *Calathus micropterus* inhabiting forest litters and some xylophilous forms: the beetles *Xyletinus* sp. feeding on dead wood, *Phtorophloeus spinulosus* living on spruce, and *Polygraphus* sp. living on spruce and larch; true bugs of the family Acanthosomatidae; and carpenter ants of the genus *Camponotus.* Beetles of the genus *Anisotoma* (Liodidae) represented the group connected with myxomycetes.

The number of arctoboreal insects was relatively small. This group included the species occurring on both northern taiga forests and southern tundras, such as *Pterostichus brevicornis, Agonum exaratum,* and *Curtonotus hyperboreus.* The peat sample from a depth of 15–30 cm contained the remains of the beetle *Aphodius melanostrictus*, the species ecologically connected with dung of large herbivorous mammals (e.g., deer). It is noteworthy that we did not find some arctic and arctalpine species currently occurring in the Polar Urals, such as ground beetles *Pterostichus middendorffi* Esch., *P. negligens* Sturm, and others (Ol'shvang, 1977).

We revealed no apparent succession of insect communities within the peat profile, except for the absence of dendrobiontic species from the three upper samples. This is evidence that the bulk of the peat deposit has been formed under relatively constant conditions. On the whole, the observed structure of paleoentomological complexes is characteristic of upland bogs located in the taiga zone of the Western Siberian Plain. Together with the fact that many arctalpine species presently inhabiting the Polar Urals were absent from the peat profile, this is evidence that the climate in the period of peat formation was warmer than today.

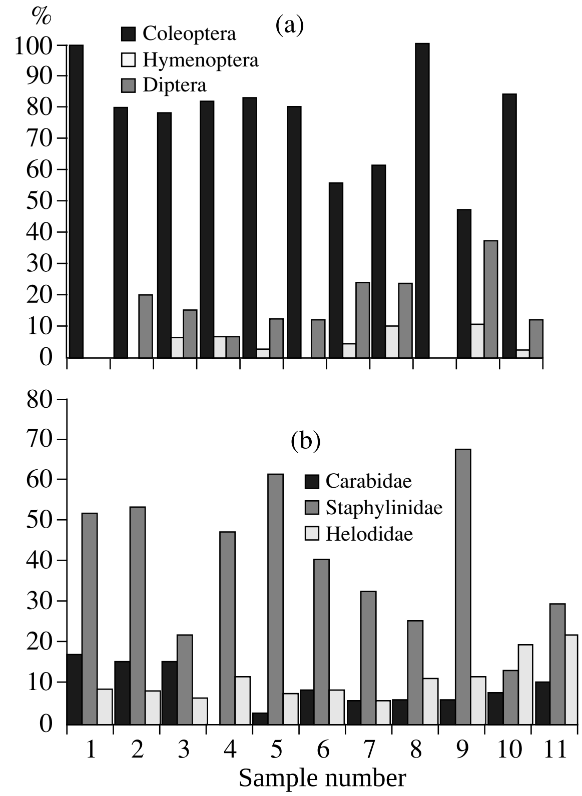

Fig. 2. Quantitative ratios of (a) the orders of insects and (b) the families of the order Coleoptera most adequately represented in the peat deposit near Lake Pereval'noe.

DISCUSSION

Comparison of the results obtained by different methods shows that they are compatible and complementary. The spectra of arboreal pollen in bogs basically reflect the regional pattern of vegetation at the level of subzones and formations, whereas the data of paleocarpological and paleoentomological analyses characterize mainly the local vegetation and conditions of its growth.

In the quantitative aspect, the frequency distribution of arboreal plant macrofossils is comparable to the palynological spectrum. Thus, the fossils of birch and larch were most numerous at a depth of 160–190 cm (palynozone 2); of willows, at a depth of 180–190 cm (palynozone 1b); and of spruce, at depths ranging from 30 to 160 cm (palynozones 3a and 3b). An increase in the numbers of arborescent birch macrofossils at a depth of 30–60 cm and a significant decrease in the numbers of spruce and birch macrofossils in the upper 30-cm peat layer correspond to changes in the palynological spectra at the same depths (palynozones 3b and 4).

The species composition and distribution pattern of herbaceous and fruticose plant macrofossils in the peat profile confirm the conclusions concerning the dynamics of vegetation and climate based on the data on pollen spectra and arboreal plant macrofossils. Thus, the fossils of sedges characteristic mainly of the forest zone prevail in the middle layers of the deposit but are absent from the two upper samples. The fossils of sedges growing in both forest and forest–tundra zones occur in the middle and upper parts of the profile. On the other hand, quantitative changes in the frequency of sedge fossils largely depend on the local hydrologic conditions corresponding to certain stages of bog formation. Numerous findings of sedges *C. rostrata* and *C. vesicaria* in the lower peat layers can be explained by the fact that they are typical mainly of lowland bogs. The sedge *C. magellanica* and dwarf shrubs of the heath family grow mainly in the transitional and upland bogs, and this probably accounts for the fact that their fossils are absent from the lower peat layers and appear at a depth of 120–140 cm. The accumulation of *Comarum palustre* fossils in the lower peat layers is also explained by local conditions at the initial stage of bog formation.

The complexes of insects found in the peat deposit are characteristic of bogs and swamped habitats. The species connected with the herbaceous vegetation are more numerous in the layers corresponding to the lowland, grass–sedge stage of bog formation, and the species connected with both herbs and shrubs, in the middle and upper peat layers. Dendrobiontic insects

Table 1. Composition and number of plant macrofossils found in the peat deposit near Lake Pereval’noe

Taxon	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
	Depth, cm										
	0–15	15–30	30–45	45–60	60–80	80–100	100–120	120–140	140–160	160–180	180–190
Sphagnum spp.		+	+		++			+	+		
Paludella squarrosa Brid.					+						
Brydae fam. indet.								+	++		
Picea obovata Ledeb.	9V		1; 20V	3; 10V	2; 4V	sam; 3V	3; 5V	2; 3V	1; 1V	1V	–
Larix sibirica Ledeb.				1				1 sam		3; 2 frg	3
Pinaceae gen. indet.			2				1				1V
Juniperus communis L.			10	6			1				
Poaceae gen. indet.						1	1				
Eleocharis palustris (L.) Roem.											1
Eriophorum sp.											1
Carex chordorriza Ehrh.	7	4	69	77	5				80		
C.cinerea Poll.			18	14	65	35	21	72		3	
C.diandra Schrank.			4			6	4	3		1	
C.magellanica Lam.	10	5	11	56	67	24	182	158			
C. rostrata Stokes. + *C.vesicaria* L. etc.			56	428	81	145	444	660	95	+++	+++
Carex $sp._1$		53	704	334		74	114	76	33	50	3
Carex $sp._2$											18
Carex $sp._3$											14
Carex spp.	30	46	5		131		2	83	14		85
Cyperaceae gen. indet.											6
Salix sp.			V							1	11
Betula betula (cf. *pubescens*), sam/sc	59/0	22/1	882/319	477/242	115/13	65/5	118/25	76/17	106/14	692/89	460/39
Betula nana L., sam/sc	4/0	2/0	4/1			1/4		1/0	1/0	4/0	5/3
Betula sp., sam/sc	0/50	1/8	0/121			0/6	2/0	1/0	1/1	0/26	0/50

Table 1. (Contd.)

Taxon	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
	Depth, cm										
	0–15	15–30	30–45	45–60	60–80	80–100	100–120	120–140	140–160	160–180	180–190
Alnus sp.											1 sam
Chenopodiaceae gen. indet.			1	1	5	12	150				
Stellaria graminea L.						1	23				
Ranunculus repens L.											1
*R.*spp.		2	1	2	7						
Rubus arcticus L.				1				2		2	1
Comarum palustre L.	3	12	8	13	27	16	263	193	123	133	144
Potentilla sp.											1
Rosaceae gen. indet.							1				
Empetrum nigrum L.		1, V	11, 3V	V							2, V
Viola sp.			41; 3 fr	45; 5 fr	13	74; 10 fr	136; 28 fr	122; 34 fr	54; 19 fr	35; 8 fr	5
Hippuris vulgaris L.				1						1	1
Andromeda polifolia L.	3	27	199	218; V	319; fr	63; V	89; fr				
Ledum sp.	V										
Arctostaphylos uva-ursi Spreng.	V						1				
Vaccinium vitis- idaea L.							2				
Menyanthes trifoliata L.	12	5	180	106			1				
Caryophyllaceae gen.							2				
Cicuta virosa L.							1 hc				
Asteraceae gen. indet.							2				
Others	3	10	2	5	9	1	3				3

Note: (+) single fossils (less than 15), (++) 15–1000 fossils, (+++) more than 1000 fossils; (frg) fragments, (sam) samaras, (sc) scales, (fr) fruits, (hc) hemicarps, (V) vegetative parts.

Table 2. Species composition of arthropods found in the peat deposit near Lake Pereval’noe

Taxon	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
	Depth, cm										
	0–15	15–30	30–45	45–60	60–80	80–100	100–120	120–140	140–160	160–180	180–190
Class Insecta											
Order Coleoptera											
Family Carabidae											
Bembidion sp.			1			1					
Lorocera pilicornis (F.)								1			
Patrobus assimilis Chd.	2		1								
Patrobus septentrionis Dej.										1	1
Pterostichus nigrita F.			1								
Pterostichus brevicornis (Kby)							1				
Pterostichus diligens (Sturm)	3	3	1				1	1			1
Agonum fuliginosum (Pz.)							2		1	1	
Agonum gracile (Sturm)					1	1	1	2		1	1
Agonum exaratum (Mnnh.)		1								2	1
Agonum sp.		1	1							1	
Calathus micropterus (Duft.)										1	
Curtonotus hyperboreus (Dej.)										1	
Carabidae indet.	1	1									1
Family Dytiscidae											
Agabus sp.	1	1	1	2			1			1	
Hydroporus sp.		1	2	2	1	2		1			2
Dytiscidae indet.		1						1			1
Family Hydrophilidae											
Hydrobius fuscipes L.							1				
Cercyon sp.									1		1
Family Catopidae											
Catops sp.				2				1			
Family Liodidae											
Anisotoma sp.	3	1	3	1			3	1			
Family Staphylinidae											
Micropelpus sp.				2			3				
Acidota cruentata (Mnnh.)											1
Olophrum rotundicolle C. Sahlb.	7	3		6	5	2	4	3	2	2	1
Olophrum sp.		6	2		5	3	6	4	2	4	2
Omaliinae indet.	6	5	2	15	8		6	2	2	1	5
Lathrobium sp.	1	3		5	3	2	5	2	4		1
Paederinae indet.				2	2					1	
Tachinus sp.				1							
Tachyporinae indet.							1	1	1	1	
?*Ocypus* sp.			1					1			1

Table 2. (Contd.)

Taxon	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
	Depth, cm										
	0–15	15–30	30–45	45–60	60–80	80–100	100–120	120–140	140–160	160–180	180–190
Quedinus sp.	2	1					2	2		1	1
Aleocharinae indet.	1			1		1				1	
Stenus sp.		1		3	1			2		1	1
Oxythelinae indet.											1
Staphylinidae indet.	1	2	2	1	1	2	3	1	1	2	1
Family Pselaphidae											
Pselaphidae gen. sp.					1						
Family Scarabaeidae											
Aphodius cf. *melanostictus* Mnnh.		1									
Scarabaeidae indet		1								1	
Family Anobiidae											
Xyletinus sp.						1		2			
Family Helodidae											
?*Helodes* sp.								2			1
Cyphon sp.	3	3	2	9	3	2	5	6	2	21	10
Family Lathridiidae											
Corticaria sp.							1				
Family Byrrhidae											
Cytilus sericeus L.				2		1		2		1	4
Byrrhus sp.							1				
Family Cantharidae											
Cantharis sp.						1					
Family Coccinellidae											
Anisosticta novemdecimpunctata L.									1		
Family Elateridae											
Hypnoidus sp.										1	
Family Chrysomelidae											
Donacia sp.								1	1		
Alticinae indet.	2			3	2	1	2	3			
Chaetocnema sp.				1			1				
Family Curculionidae											
Notaris aethiops F.		3	3								
?*Magdalis* sp.											2
Limnobaris sp.										1	
Phytobius sp.				1				1			
Family Brenthidae											
Betulapion simile (Kby.)				2							1
Curculionidae indet.			1						1		
Family Scolytdae											
Phtorophloeus spinulosus Rey				1							

Table 2. (Contd.)

Taxon	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
	Depth, cm										
	0–15	15–30	30–45	45–60	60–80	80–100	100–120	120–140	140–160	160–180	180–190
Polygraphus sp.					1						
Coleoptera indet.	1	1	1	1				1			
Order Homoptera											
Homoptera indet.										1	1
Order Hemiptera											
Family Saldidae											
Chiloxanthus sp.							2	2			
Family Pentatomidae											
Pentatomidae indet.								1			
Family Acanthosomatidae											
Acanthosomatidae indet.							1				
Order Hymenoptera											
Family Formicidae											
Camponotus sp.								1			
Formica sp.			1				1			2	1
Hymenoptera indet.			1	5	1		3	6		9	
Order Diptera											
Family Tipulidae											
Tipulidae indet.		1		5	4	3	22	13		33	
Diptera indet.		9	5		1			4		7	6
Order Trichoptera											
Trichoptera indet				2	1		1	1		5	
Insecta indet.	1			1							
Class Arachnida											
Arachnida indet.				1		2	11				
Total number of individuals	35	50	32	77	41	25	92	72	18	108	51

occur only in the lower and middle layers, which agrees with the data of palynological and paleocarpological analyses concerning the prevalence of forest vegetation in the corresponding period.

The results of analysis of peat samples from the depth of 30–35 cm by all three methods are indicative of drastic cooling: the content of spruce pollen markedly decreases, whereas the contribution of fruticose birch species increases, and the samples contain no macrofossils of spruce, thermophilic sedges, and insects ecologically connected with forest vegetation.

The age of the observed changes in the vegetation and climatic conditions can be determined due to a good correlation between the spore–pollen diagram of the peat deposit near Lake Pereval'noe and the dated diagrams of other Holocene profiles in the Polar Urals, such as the diagram of the Chernaya Gorka peat deposit located in the Bol'shaya Paipudyna River valley, approximately 40 km northwest of Lake Pereval'noe (67°05' N, 65°21′ E; 170 m a.s.l.) (Panova and Yankovska, 2000). In both profiles, the content of willow pollen reaches a peak at the boundary of mineral and peat deposits. According to radiocarbon dating, the age of mineral deposits is 9230 ± 280 years (Gd-9935); i.e., they date from the preboreal period (PB), and their lower layers probably date from the late postglacial period (Dr_3). Boreal deposits (BO) in the Chernaya Gorka profile are limited by two dates: 8620 ± 270 years

(Gd-9947) and 8720 ± 180 years (Gd-10776). In the diagram of peat profile near lake Pereval'noe, deposits of the same age are in palynozone 2. The spectra with the prevalence of spruce pollen (palynozones 3a and 3b) are characteristic of the Atlantic period of the Holocene (AT). The age of these deposits is confirmed by radiocarbon dating of the upper layer with the maximum content of spruce pollen: 6020 ± 200 years (Gd9938). The beginning of the Atlantic period (8000 years ago) coincides with a sharp rise of the spruce pollen curve. This level has been well dated by the radiocarbon method in the spore–pollen diagrams of other Holocene profiles of the Polar Urals (Surova *et al.*, 1975).

Deposits corresponding to palynozone 4 were apparently formed in the post-Atlantic period. The corresponding layers are absent from the Chernaya Gorka profile, as the upper part of this peat mound has been destroyed by wind and frost erosion.

The cooling diagnosed by analyzing deposits at a depth of 30–35 cm apparently marked the beginning of the subboreal period. According to the results of radiocarbon dating, this occurred approximately 4500 years ago (Surova *et al.*, 1975). This early subboreal cooling was short-term: in overlying deposits, spruce macrofossils appeared again, and the content of spruce pollen became slightly.

Our data suggest that the Holocene dynamics of the vegetation and climate in the study region were as follows.

The preboreal period that followed the last Pleistocene glaciation—in northern Eurasia, between 10300 to 9200 years ago (Khotinskii, 1977)—was characterized by the prevalence of herb–shrub vegetation (dwarf birch, willows, alder, grasses, sedges, wormwood, goosefoots, and mixed herbs) combined with open larch–birch forests, which retained some features of the late glacial flora. Climatic conditions were similar to those observed today.

The boreal period (9200–8000 years ago) was marked by the beginning of peat formation and the spread of shrubs and, later, tree species (larch, birch, and, finally, spruce). This is the period of formation of open larch–birch forests with an admixture of spruce and with fruticose birch, alder, and juniper in the undergrowth. The climate was warmer than today but apparently drier and more continental.

The Atlantic period (8000–5000 years ago), according to our data, was the most humid and warm period of the Holocene. The study region was covered with taiga forests with the prevalence of spruce and considerable proportions of birch and larch trees. The appearance of fir pollen in the deposits corresponding to the second half of this period indicated that the range of this species expanded northward and, hence, that the climate became even milder. Peat deposits formed in this period have the greatest depth.

The early subboreal period was marked by cooling, which resulted in degradation of the forest vegetation. In general, however, the climate of this period was warmer than the present-day climate, providing adequate conditions for the growth of open larch–birch–spruce forests. Severe cooling with the ensuing freezing of bogs and cessation of peat formation occurred approximately 3700 years ago. The taiga vegetation in the study region was replaced by the forest–tundra. This cooling was also traced in the course of dendrochronological analysis and radiocarbon dating of buried wood from the Yamal Peninsula (Hantemirov and Shiyatov, 1999).

Concluding, we should note that the results of this study agree with the data obtained by Surova *et al.* (1975) with respect to both correlation of the spore–pollen spectra and interpretation of changes in the vegetation and climate in the Holocene. On the other hand, they do not confirm the conclusions drawn by Koshkarova *et al.* (1999) on the basis of paleocarpological and radiocarbon analyses of a 1.5-m peat deposit located 1 km south of Lake Pereval'noe (near Chernyi Ruchei) at an elevation of approximately 270 m a.s.l. According to these authors, the boreal period (8500 years ago) was the warmest in the Holocene, and that is when spruce forests with larch and pine grew in the study region, and the undergrowth and herbaceous layer included the species characteristic of the present-day vegetation of the middle and even southern taiga subzones (raspberry, strawberry, and brambles). The Atlantic period, conversely, was characterized as relatively cold and humid.

This interpretation agrees with data by Hantemirov and Shiyatov (1999), who regard the boreal period (7200–6000 BC) as most favorable for the growth and northernmost expansion of woody vegetation in the Yamal Peninsula. Note, however, that this expansion was accounted for by larch. The first findings of spruce wood in this region date from the early Atlantic period (approximately 6000 BC). Moreover, we have not found the macrofossils of pine or the aforementioned middle- and southern-taiga species in the peat profile near Lake Pereval'noe. As to the presence of pine pollen, we explain it by transfer from some other region. This follows from the fact that the contents of pine pollen were very low in the "forest" palynological spectra of the boreal and Atlantic periods but increased in the spectra of upper, "forest–tundra" horizons. Surova *et al.* (1971, 1975) arrived at the same conclusion on the basis of studies on the surface palynological spectra and the botanical composition of peat in the Polar Urals: all macrofossils of tree species found in peat belonged to spruce, larch, or birch. Still, the data discussed above are inconsistent, which implies the necessity of further studies.

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