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Holocene Dynamics of Vegetation and Ecological Conditions in the Southern Yamal Peninsula According to the Results of Comprehensive Analysis of a Relict Peat Bog Deposit

N. K. Panova[a], S. S. Trofimova[b], T. G. Antipina[a], E. V. Zinoviev[b], A. V. Gilev[a], and N. G. Erokhin[b]

[a] *Botanical Garden, Ural Division, Russian Academy of Sciences, ul. Bilimbaevskaya 32a, Yekaterinburg, 620134 Russia; e-mail: natapanova@mail.ru*

[b] *Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia; e-mail: common@ipae.uran.ru*

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Abstract—A comprehensive analysis of samples from a frozen peat deposit in the upper reaches of the Khadytayakha River by palynological, carpological, entomological, and radiocarbon methods has been performed to reconstruct changes in the regional and local vegetation and climatic conditions during the Holocene. The results show that this peat deposit was formed from 8000 to 5000 years BP. During that period, the climate in the southern Yamal Peninsula was considerably warmer, and the present-day subarctic shrub tundra zone was occupied by plant communities of spruce, birch, and larch forests.

Key words: peat, palynological spectrum, palynozone, plant macrofossils, insect fauna, vegetation, climate, Holocene.

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The Holocene trends of nature development in northern Eurasia largely differed from those at middle latitudes. It is especially true of maritime areas, including the Yamal Peninsula (Vasil'chuk et al., 1983; Vasil'chuk, 1992; Tarasov et al., 1995). The results of palynological and botanical studies on southern Yamal peat bogs carried out in the 1940s and 1950s (Kats and Kats, 1946, 1948; P'yavchenko, 1955) showed that the present-day shrub tundra zone was occupied by forest vegetation in the postglacial period. The factual paleobotanical and paleoentomological data presented here contribute to the paleoecological database and can help to understand the processes that took place in this area during the Holocene and to make more detailed historical reconstructions.

STUDY AREA, MATERIAL, AND METHODS

The study area lies in the zone of southern subarctic shrub tundras of the Yamal Peninsula (*Priroda Yamala*, 1995). The climate of this area is severe, with long, cold winters and short, cool summers and precipitation exceeding evaporation (Shiyatov and Mazepa, 1995). The study object was a frozen peat deposit bog outcropped on the western shore of Nyulsaveito Lake in the upper reaches of the Khatydayakha River (67°32' N, 70°10' E, 57 m a.s.l.). The peat bog occupies a relatively deep (over 3 m) and narrow depression amid upland (plakor) areas with shrub–moss tundra communities dominated by dwarf birch (*Betula nana*), willows (*Salix*), cloudberry (*Rubus chamaemorus*), and green mosses. Samples for analyses were collected by N.G. Erokhin from a cleaned part of the exposure.

Changes in vegetation and paleoecological conditions were reconstructed mainly on the basis of palynological and carpological analyses carried out according to the standard procedures (Grichyuk and Zaklinskaya, 1948; Nikitin, 1969). In addition, the paleoentomological method was used. The age of deposits was determined by radiocarbon analysis performed by N.G. Erokhin in the laboratory of the Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences (Table 1). The dates were calibrated using the OxCal 3.10 program.

According to the study on the plant composition of peat (carried out by T.G. Antipina) and Erokhin's description, the structure of the deposit is as follows:

0–6 cm: sod (cotton grass–hypnum moss);

6–23 cm: dark brown hypnum moss–sphagnum–cotton grass peaty soil;

Table 1. Radiocarbon dates from peat bog section near Nyulsaveito Lake

Sampling depth, cm	Dated material	Laboratory number	^{14}C date, years BP	Calibrated date, years BP	2σ calibrated range
23–42	Peat humic acids	IPAE-67k	5620 ± 188	6395 ± 405	6800–5991
42–92	Peat cellulose	IPAE-69s	6081 ± 207	6934 ± 491	7425–6443
120–124	Peat cellulose	IPAE-69sm	7041 ± 281	7913 ± 490	8403–7423
230–240	Peat cellulose	IPAE-71s	7291 ± 219	8108 ± 431	8540–7677
240–280	Wood cellulose	IPAE-72	8179 ± 231	9033 ± 517	9551–8516

23–42 cm: reddish, weakly decomposed sedge–sphagnum peat;

42–60 cm: light brown cotton grass–hypnum moss–sphagnum peat;

60–92 cm: light, weakly decomposed sedge–sphagnum peat;

92–111 cm: pale yellow sedge–sphagnum peat;

111–124 cm: dark humus-containing hypnum moss–cotton grass–sphagnum peat;

124–160 cm: brown sedge–sphagnum peat;

160–205 cm: light orange sphagnum (*S. angustifolium*) peat;

205–225 cm: dark orange cotton grass–sphagnum peat;

225–240 cm: dark brown sedge–cotton-grass peat with fragments of roots and wood of birch and larch;

240–280 cm: gray clay sand with remains of larch and birch roots and trunks;

280–350 cm: light gray sands.

Most of the identified remains of sphagnum mosses from peat were of two species, *Sphagnum angustifolium* (in sedge-containing peat) and *S. subsecundum* (in sedge–sphagnum peat); *S. cuspidatum* was found in the recent soil and sod. The botanical composition of peat is indicative of considerable waterlogging in the period when the bulk of peat deposit was formed. The alteration of sedge–sphagnum and cotton grass–sphagnum peat reflects heterogeneity of the bog's microrelief.

RESULTS OF PALYNOLOGICAL ANALYSIS

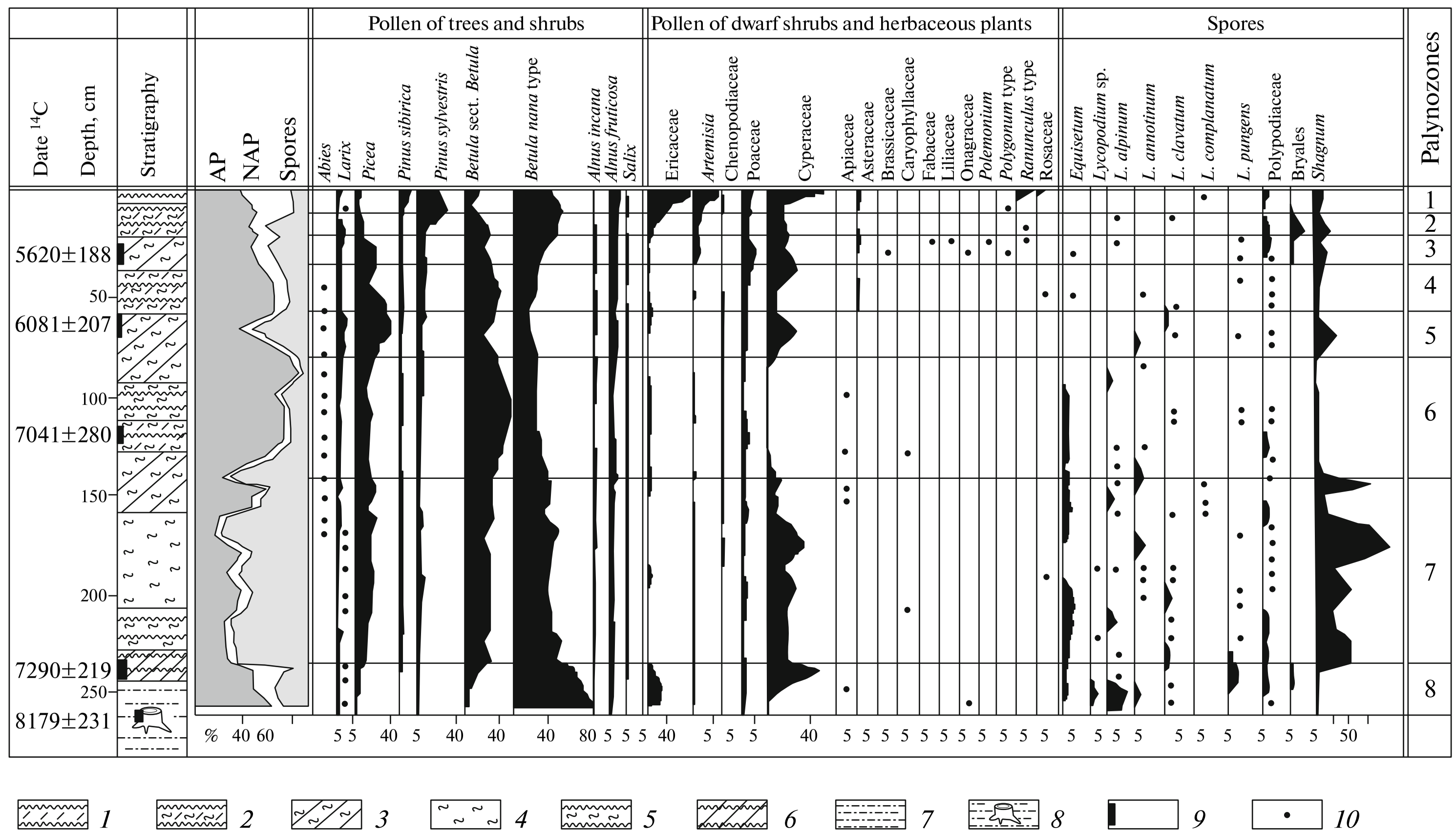
Eight basic palynozones could be distinguished in the spore–pollen diagram of the deposit (figure). The contributions of different taxa were estimated from the percent ratios of their pollen to the total amount of tree and shrub pollen.

Palynozone 8 (depth 250–225 cm). Its characteristic feature is the highest content of dwarf birch (*Betula nana* type) pollen, with "peaks" of heath (Ericaceae) and sedge (Cyperaceae) pollen and spores of arctic club mosses (*Lycopodium alpinum, L. pungens*) and horsetails (*Equisetum*). Pollen of alder (*Alnus fruticosa*), willows (*Salix*), common birch (*Betula* sect. *Betula*), spruce (*Picea*), and larch (*Larix*) is also present. The palynological spectra are characteristic of larch–spruce–birch forest–tundra with shrub–dwarf-birch cover at the initial stage of waterlogging. Changes in the contents of tree, shrub, and herbaceous plant pollen in the bottom-to-top direction (an increase in the proportion of spruce, common birch, and sedge pollen and decrease in the proportion of dwarf birch pollen) are indicative of increasing heat and moisture supply. According to radiocarbon data (8179 ± 2231 to 7290 ± 219 years BP), the deposits of this zone date from the late Boreal to early Atlantic periods.

Palynozone 7 (depth 225–140 cm). Prevalence of spores of *sphagnum* mosses and sedges, which are characteristic of local bog vegetation, reflects the process of peat formation. The composition of subregional vegetation is reflected by tree and shrub pollen spectra: the main component (40–50%) is the pollen of dwarf birch; then follows the pollen of common birch and spruce (about 30 and 20%, respectively); permanent minor components include the pollen of larch, alder, and willows, along with sparse grains of pine (*Pinus sylvestris*) pollen. Fir (*Abies*) pollen appears closer to the upper surface of the zone. Pollen spectra are indicative of sparse larch–birch–spruce forest vegetation and considerable climate warming and humidification. The deposits date from the first half of the Atlantic period.

Palynozone 6 (depth 140–80 cm). The pollen of common birches prevails, with the content of spruce pollen being slightly lower. Fir and larch pollen is a permanent component, as also is the pollen of willows and alder. The contents of dwarf birch and sedge pollen and the spores of sphagnum mosses markedly decrease. The palynological spectra are indicative of warmer and less humid climate, compared to the previous phase. The deposits are dated 7041 ± 280 years BP. Birch forests with spruce and larch dominated in vegetation of that time.

Palynozone 5 (depth 80–60 cm). It has the highest content of spruce pollen and the lowest content of dwarf birch pollen. The amount of sedge pollen and sphagnum spores increases again. The spectra are indicative of taiga forest vegetation with dominance of spruce and admixtures of larch and birch; they correspond to the Holocene climatic optimum. The deposits of this phase date from 6081 ± 207 years BP.



Spore–pollen diagram of peat bog near Nyulsaveito Lake, southern Yamal (analyzed by N.K. Panova): (*1*) sod (cotton grass–hypnum moss); (*2–6*) peat: (*2*) cotton grass–hypnum moss–sphagnum, (*3*) sedge–sphagnum, (*4*) sphagnum, (*5*) cotton grass–sphagnum, (*6*) sedge–cotton grass; (*7*) sandy loam; (*8*) buried larch stumps; (*9*) site of sampling for ^{14}C analysis; (*10*) proportion of pollen less than 1%; AP, total pollen of trees and shrubs; NAP, total pollen of dwarf shrubs and herbaceous plants; Spores, total amount of spores.

Table 2. Species composition and numbers of plant macrofossils from peat bog section near Nyulsaveito Lake (analyzed by S.S. Trofimova)

Species	Sampling depth, cm						
	23–42	42–92	92–124	134–145	225–230	230–240	350
Shagnum sp. sp.	v	v	v	v	v	v	v
Picea obovata Ledeb.	10v, 2	10v, 2		17v	40v, 10	1v	
Larix sp.		1					
Calla palustris L.				1			
Carex sp. sp.	32	5	14	38	24		5
Eleocharis palustris (L.) R. Br.					1		
Betula nana L.	Leaf	4		Leaf			
Betula sect. *Betula*	8	8	10	46v, 45	2v, 40	2	
Ranunculus cf. *acer* L.							1
Ranunculus sceleratus L.						2	
Rubus arcticus L.					7		
Rubus chamaemorus L.					5		
Empetrum nigrum L.					15		
Andromeda polifolia L.	vv, 40	vv, 12	vv, 1080	1	4	15	
Ledum palustre L.	Leaf						
Vaccinium vitis-idaea L.			9		2	Leaf	
Menyanthes trifoliata L.							3

Note: (v) vegetative plant parts (needles, twigs, fruit scales, etc.); (vv) numerous vegetative parts (over 100).

Palynozone 4 (depth 60–40 cm). The pollen of common birches is prevalent; spruce pollen content decreases. The spectra indicate the replacement of taiga spruce forests by larch–spruce–birch forests, with the climate becoming less humid. This is also indirectly confirmed by the decreased contents of sedge pollen and sphagnum spores.

Palynozone 3 (depth 40–23 cm). The pollen of dwarf birches becomes prevalent. The amounts of spruce and common birch pollen are approximately equal (25% each). Fir pollen disappears. Sparse pollen grains of Siberian stone pine (*Pinus sibirica*) can be found. The spectra are indicative of sparse larch–birch–spruce forests and climate cooling and humidification. The deposits are dated 5620 ± 188 years BP.

Palynozones 1 and 2 (the upper 23 cm of peat soil). The pollen of dwarf birches prevails. Zone 2 still contains relatively large proportions of the pollen of common birches (up to 30%) and spruce (up to 10%), while their contents in zone 1 are minimal, with the second most abundant component being pine pollen (apparently, extraneous). The amount of alder pollen is considerable; all samples also contain the pollen of willows and larch. In addition, palynozone 1 contains increased proportions of pollen from Ericaceae dwarf shrubs and herbaceous plants, such as sedges, grasses (*Poaceae*), wormwood (*Artemisia*), mixed herbs (Varia), and cloudberry (*Rubus chamaemorus*). The spectra are indicative of the replacement of larch–spruce–birch forest–tundra vegetation (zone 2) by shrub and herb–dwarf shrub–dwarf birch tundra communities (zone 1), as well as of increasing climate cooling.

No absolute dating was obtained for the upper part of the deposits. Apparently, it was formed later, during the Subboreal and Subatlantic periods. The strong Subboreal cooling resulted in freezing of the peat bog and considerable deceleration of peat formation.

RESULTS OF CARPOLOGICAL ANALYSIS

Seven samples were collected for carpological analysis (Table 2). The assemblage of plant macrofossils from deposits at the depth of 350 cm provided little information: it contained sparse seeds of buckbean (*Menyanthes trifoliata*), sedge, and meadow buttercup (*Ranunculus acer*).

In the sample from the depth of 230–240 cm, sparse remains of spruce (*Picea obovata*), common birch (*Betula* sect. *Betula*), cowberry (*Vaccinium vitis-idaea*), and bog rosemary (*Andromeda polifolia*) were found. Of interest is the presence of the fruits of celery-leaved buttercup (*Ranunculus sceleratus*) in this sample, since the present-day northern boundary of its range in Western Siberia lies at 62°30' N (*Flora Zapadnoi Sibiri*, 1958; *Rastitel'nyi pokrov,* 1982). The assemblage was formed during the Early Atlantic warming (7290 ± 219 years BP).

The macrofossil assemblage from the depth of 225–230 cm contains the highest proportion of spruce seeds and needles and numerous remains of birch. It is characteristic of birch–spruce forest with a well-developed herb–dwarf shrub layer formed by hypoarctic dwarf shrubs, black crowberry (*Empetrum nigrum*) and cowberry, together with sedges (*Carex*), cloudberry (*Rubus chamaemorus*), arctic raspberry (*Rubus arcticus*), and bog rosemary.

The sample from the depth of 134–145 cm is rich in birch remains (the main component) and contains spruce needles. A fragment of dwarf birch (*B. nana* leaf was also found. Such an assemblage is indicative of spruce–birch forest with dwarf birch in the undergrowth.

In deposits at the depth of 92–124 cm, the species composition of macrofossils is sharply depleted: the remains of spruce are absent, the seeds of birch and sedges are few, and the bulk of the assemblage (up to 95% of the total number of remains) consists of the leaves, fruits, and seeds of bog rosemary (*A. polifolia*). Apparently, extremely rapid accumulation of peat (the deposits are dated 7041 ± 280 years BP) and soil waterlogging because of permafrost thawing during the Early Atlantic warming resulted in degradation of spruce–birch forests into paludified open birch forests.

The assemblage from the depth of 42–92 cm contains remains of spruce and dwarf birch; the content of bog rosemary remains is sharply reduced. A well-preserved fragment of a larch seed was found in this sample. The appearance of larch in the environs of the bog may be evidence for the improvement of drainage during the Late Atlantic thermal maximum, 6081 ± 207 years BP. In general, the assemblage is characteristic of open birch–spruce forest with larch and dwarf birch.

Two assemblages from the depth of 23–42 cm date from the Late Atlantic maximum (5620 ± 188 years BP). They contain the remains of spruce, dwarf birch (*Betula nana*), Labrador tea (*Ledum palustre*), sedge, and bog rosemary and are indicative of open birch–spruce forest with dwarf birch.

The results of carpological analysis showed that trees (spruce and birch) were constantly present in the environs of the peat bog during the period of peat formation. The expansion of tree stands reached a peak at the beginning of the Atlantic period. The relatively small amount of *B. nana* remains is probably explained by the growth of this species mainly in the upland (plakor) areas rather than in the bog itself, as is the case in the recent zone of southern subarctic tundras (Andreyaskina and Peshkova, 1995).

RESULTS OF ENTOMOLOGICAL ANALYSIS

The remains of insects were fairly scarce in all samples studied, except for no. 3 (Table 3). There were a total of 212 fragments attributed to 153 individuals. The scarcity of the material makes it impossible to provide detailed descriptions of insect complexes. However, it is known from experience that small samples usually contain the most abundant insect taxa. Thus, even a small set of fragments is sufficient for describing, in general terms, the landscape and climatic conditions under which the layers of the deposit were formed.

Insect assemblages from peat (samples 1–5) are similar to each other and generally typical for bogs. They are dominated by multizonal species and contain no arctic components, except for a single finding of the acrtoboreal click beetle *Hypnoidus arcticus,* which dwells in nemoral habitats. Specific features of these assemblages include the presence of rove beetles of the subfamily Omaliinae (*Acidota quadrata*, *Olophrum* cf. *rotundicolle, Olophrum* sp.), a small number of ground beetles represented by a single polyzonal species, *Dyschiriodes* cf. *globosus,* and the occurrence of marsh beetles (Helodidae). A considerable number of fragments of small diving beetles (from the genus *Hydroporus*), which dwell both in water and in wet, mossy sod, may indicate the presence of waterlogged biotopes. Such sod is also a typical habitat of the click beetle *Sericus brunneus*, which occurs mainly in taiga forests.

Remains of ants were found in samples 1, 3, 4, and 5. They were represented exclusively by head capsules of three species from the families Formicidae and Myrmicidae. Most specimens were classified with the subgenus *Serviformica* of the genus *Formica*. Judging from the size and proportions of the head, they most probably belonged to the polar ant *Formica gagathoides*, which is now widespread in the study area. Two head capsules belonged to ants of the genus *Leptothorax*, probably *L. acervorum*, which inhabit the taiga and forest–tundra zones and are common in the southern Yamal Peninsula (Olschwang, 1992). One head capsule (sample 1) belonged to an ant of the genus *Lasius*, most probably from the *Lasius niger* group, which is now widespread throughout Eurasia but is not common in the north.

The species *Leptothorax acervorum, Formica gagathoides,* and *Camponotus herculeanus* constitute the hypoarctic assemblage of ants and occur farther north than other ant species (Berman and Zhigul'skaya, 1995; Dlusskii, 1967). At the same time, they inhabit the forest–tundra and dwarf shrub tundra subzones but do not occur in the true tundra. *Camponotus herculeanus*, which is closely associated with trees, is absent from the deposits, which can be explained by local conditions of the bog biocenosis.

Thus, the ants species found in peat deposits could have inhabited forest–tundra and shrub (southern) tundra, as well as taiga. In general, the insect assemblage found in peat deposits is dominated by polyzonal species with preference for the taiga zone, which is evidence that the climate of that period was warmer than today.

The insect assemblage of sample 6, collected from underlying sandy loam at the depth of 350 cm, considerably differs in species composition from samples collected in higher layers. It is dominated by arctoboreal

Table 3. Species composition and number of arthropod remains from peat bog section near Nyulsaveito Lake (analyzed by E.V. Zinov'ev and A.V. Gilev)

Class, order, family	Genus, species	Sample no. and depth, cm					
		1	2	3	4	5	6
		24–32	42–92	92–124	134–145	230–240	350
Class Insecta							
Order Coleoptera							
Family Carabidae	*Diacheila polita* Fald.						1
	Dyschiriodes cf. *globosus* (Hbst.)			2			
	Agonum sp.		1	3			
	Pterostichus cf. *tundrae* (Tsch.)						1
	Pt. ventricosus (Esch.)						1
	Pt. cf. *pinguedineus* (Esch.)						1
	Carabidae indet.	1				1	1
Family Dytiscidae	*Agabus* sp.				1		1
	Hydroporus sp.		1	9	1		
	Dytiscidae indet.			1			
Family Hydrophilidae	*Enochrus* sp.			5			
Family Silphidae	*Thanatophilus* sp.						1
Family Staphylinidae	*Acidota quadrata* Mnnh.					3	
	Olophrum cf. *rotundicolle* C. Sahlb.			1	1		
	O. sp.	1		4	4		
	Omaliinae gen. sp.			1			
	Lathrobium sp.			1		1	
	Stenus sp.	1		1			
	Quedinus sp.					1	
	?*Lotridon* sp.					1	
	Oxythelinae indet.					1	
	Staphylinidae indet.				1		
Family Helodidae	?*Cyphon* sp.	1		4	2	3	
Family Elateridae	*Sericus brunneus* (L.)			1			
	Hypnoidus arcticus (Hbst.)			1			
	Elateridae indet.					1	
Family Chrysomelidae	*Galerucella* sp.			1			
	Altica sp.				1		
Family Rhynchitidae	*Temnocerus* sp.					1	
Family Curculionidae	*Dorytomus* sp.					1	
	?*Dorytomus* sp.					1	
	Curculionidae indet.			1			
Family Brentidae	*Betulapion simile* s/sp. *simile* Kby				1		
	Coleoptera indet.			3	1		
Order Hemiptera							
Family Saldidae	*Chiloxanthus* sp.			2			
Family Lygaenidae	Lygaenidae indet.			10		1	
Order Hymenoptera							
Family Formicidae	*Formica* cf. *gagathoides* (L.)			26	1	2	
	Lasius niger L.	1					
	Leptothorax acervorum (L.)			5	1		
Order Trichoptera	Trichoptera indet.				2		
Order Diptera							
Family Tipulidae	Tipulidae indet.			3			
	Diptera indet.	1		3	2		
	Insecta indet.			3			4
Class Arachnida							
Order Oribatei	Oribatei indet.		1	1		1	
	Arachnida indet.		1	1	1		
Number of individuals/fragments		6/8	4/8	93/126	20/31	19/26	11/13

beetle species, inhabitants of southern tundras and forest–tundras (ground beetles *Diacheila polita, Pterostichus* cf. *tundrae, P. ventricosus*, and *P.* cf. *pinguedineus*). Although these species may also occur in northern and middle taiga forests, they are most abundant in the tundras. Since the size of this sample is small, the fossils it contains apparently represent the most abundant beetle species. Specific features of this assemblage show that the corresponding deposits were formed in a colder climate, compared to the overlying peat layers.

Judging from entomological and radiocarbon data, the climate change probably took place between 9000 and 8000 years BP, since sample 6 was collected from deposits lying below the layer dated 8179 ± 231 years BP.

DISCUSSION

Comparison of the results obtained by different methods shows that their paleoecological interpretations are quite consistent with each other. Palynological spectra of bog plants agree with data on the composition of plant macrofossils in peat. Palynological and carpological complexes also show no contradictions, with differences between them being largely explained by specific conditions of their formation. The palynological spectra of peat bogs are more averaged. They represent mainly regional and subregional (rather than local) vegetation, while the assemblages of macroscopic plant remains in peat bogs are autochthonous and characterize local and sublocal vegetation. For instance, the carpological assemblage from the depth of 225–230 cm contains considerable amounts of spruce remains and indicates the period when the amount of forests in the study area reached a peak. The palynological spectrum of this sample is dominated by pollen of dwarf birches (up to 70%) and contains only 6% of spruce pollen. This ratio reflects forest–tundra conditions, as also does the composition of hypoarctic dwarf shrub macrofossils. Apparently, at early stages of paludification, spruce was growing in the depression, directly at the site of the developing peat bog, while plakor areas were dominated by dwarf birch. Along with subsequent increase in heat and moisture supply and intensification of bog formation and peat accumulation, tree vegetation (including spruce) concentrated in plakor areas.

In the upper layers of deposits, formed during a period of consistent warming, palynological and carpological assemblages show no significant differences. The depleted species composition of plant remains at the depth of 92–124 cm reflects the expansion of meso-oligotrophic cotton grass–sphagnum phytocenoses in the bog, which is confirmed by botanical characteristics of peat at this depth. Bog rosemary, which proved to be abundant in this layer, usually grows in communities with cotton grass and *Sphagnum angustifolium* in raised and transitional bogs (*Bolotnye sistemy*, 2001).

In general, the results of palynological and carpological analyses show that trees (spruce, birch, larch) were growing in the upper reaches of the Khadytayakha River during the entire period of peat bog formation, and the climate of this area was considerably warmer than today. Insect assemblages are indicative of conditions approaching those of the boreal and forest–tundra zones and confirm the conclusion that the climate was warmer.

Judging from the results of radiocarbon dating, most of the studied peat deposit was formed during the Atlantic period (5000–8000 years BP). The development of vegetation in this period was characterized by a gradual transition from the initial larch–spruce–birch forest–tundra to taiga spruce forests with birch and larch in the Holocene optimum (around 6000 years BP). These forests probably contained an admixture of fir. Regular (although scarce) occurrence of its pollen in all the spectra at depths from 170 to 50 cm is indicative of fir growth in situ. This possibility is indirectly confirmed by the fact that Sukachev (1922) found a branch of fir (*Abies sibirica*) about 1.5 cm in diameter amid trunks of larch, birch, and spruce in a peat bog on the shore of Khu-Lor Lake (southwestern Yamal).

Pine pollen is also represented by few grains in all samples, but this component is obviously extraneous. This follows from its high content in the upper (tundra) layers on the deposit, since the proportion of airborne extraneous pollen is known to increase with a decrease in the amount of forests in the area. Apparently, the pollen of Siberian stone pine (*Pinus sibirica*) is also extraneous, and its appearance in the upper layers of the deposit reflects the northward expansion of Siberian stone pine in Western Siberia during the post-Atlantic time. Kats and Kats (1946, 1948) had the same opinion, although Pyavchenko (1955) allowed the possibility that a special life form of Siberian stone pine could have grown in bogs of the southern Yamal Peninsula during the Holocene. Our data do not confirm this hypothesis: we have found no macroscopic remains of *Pinus* species in the peat bog near Nyulsaveito Lake.

Comparing recent meteorological data for the shrub tundra subzone of Western Siberia (Savina and Khotinskii, 1982) and data from the nearest Novyi Port weather station with those for the subzone of northern taiga spruce–larch forests (similar to forests that, according to our data, were growing in southern Yamal during the Middle Holocene), we may conclude that summer temperatures in Yamal in that period were probably 3–5°C higher, while winter temperatures and the precipitation–evaporation ratio were almost the same as today.

The highest rate of peat accumulation (over 3 mm per year) was characteristic of the first, more humid half of the period. The location of the peat bog in a narrow and deep depression, high moisture supply, and low rate of plant remains decomposition contributed to the rapid growth of the peat deposit.

Our conclusions concerning the development of vegetation and peat formation in southern Yamal during the Atlantic period agree with the opinion of Vasil'chuk et al. (1983). These authors relate the onset of forest development in the Yamal tundra to marine regression and climate warming during the second half of the Boreal period. This view is further confirmed by the results of dendrochronological and radiocarbon studies of fossil wood in Yamal (Hantemirov and Shiyatov, 1999). According to S.G. Shiyatov, numerous larch stumps and fragments of trunks up to 30 cm in diameter from deposits on the shore of Nyulsaveito Lake and in the Khadytayakha River floodplain date from the end of the Boreal period. Most of these trees probably died as a result of the so-called Novo-Sanchugovo cooling at the turn of the Boreal and Atlantic periods (Kind, 1974). During this cooling, larch forest was replaced by tundra and forest–tundra, with their vegetation pattern being reflected in the palynological spectra found in the basal layers of the peat deposit studied.

According to Hantemirov and Shiyatov (1999), the second half of the Atlantic time was one of the most favorable periods for the growth of trees, including spruce, during the Middle Holocene. This is in agreement with our conclusion that birch–spruce taiga forests with an admixture of larch were growing in southern Yamal during that period. The abrupt cooling in the second half of the Subboreal period resulted in retardation of peat formation and subsequent freezing of peat bogs not only in the southern Yamal Peninsula but also in the Polar Urals (Panova et al., 2003; Jankovska et al., 2006).

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