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TEMPERATURE STATE OF SOILS OF PEAT PLATEAUS IN THE SPORADIC PERMAFROST AREA (EUROPEAN NORTHEAST OF RUSSIA)

D.A. Kaverin, A.V. Pastukhov

Institute of Biology, Komi Science Center UB RAS,
28, Kommunisticheskaya str., Syktyvkar, 167982, Russia; dkav@mail.ru

The thermal regime of soils and underlying sediments in peat plateaus located in the northeastern margin of the Russian Plain (65–66° N) in the area of sporadic permafrost distribution has been characterized for the period of 2013–2016. The winter, summer and mean annual temperature regimes are found to differentiate significantly between soils in permafrost peat mounds and thawed fens. The warming and cooling coefficients have been evaluated in order to assess the seasonal variations of temperature in soils of peat plateaus. A comparative analysis of the calculated warming/cooling climatic coefficients and indices revealed the warming effect of the contemporary climatic variations on peat soils within the area of sporadic permafrost distribution in the north-east of European part of Russia.

Soil temperature regime, peat plateaus, sporadic permafrost distribution

INTRODUCTION

Climate change is one of the global challenges of the 21st century with inevitable implications for permafrost areas: it is expected that thawing of permafrost and subsequent advance of the tree line northwards will further affect soils and vegetation [*Kulikov et al., 1997; Hugelius et al., 2011*]. The data from geocryological observational and weather stations are widely used for evaluation of climate impact on the thermal state of soils in the permafrost areas [*Romanovsky et al., 2002; Pavlov, 2008*], and for the analysis of soil and climatic coefficients [*Klene et al., 2001; Throop et al., 2012*].

The subarctic zone of the northeast of European Russia is one of the most sensitive regions to climate change [*Mazhitova et al., 2004; Oberman and Shesler, 2009*]. The highest rates of permafrost degradation are observed along the southern boundary of the permafrost in the Urals part of the region [*Oberman and Shesler, 2009*]. In the European part of Russia, the southern limit of permafrost distribution coincides primarily with the southern boundary of the tundra landscapes. The presence of sporadic patches of high-temperature permafrost at the extreme southern limit of the NE European cryolithozone (the subzone of the northernmost taiga) is primarily associated with peatland plateaus [*Ershov and Kondratieva, 1998; Osadchaya and Tumel, 2012*].

Investigations of the thermal regime of permafrost-affected soils of peatlands in the southern part of the northern European cryolithozone (permafrost) were carried out mainly within the zone of massive-island permafrost [*Mazhitova, 2008; Malkova, 2010*]. Soils of petmafrost peatlands in the tundra and forest-tundra are characterized by the harshest thermal regime favorable for permafrost preservation [*Kaverin et al., 2014*].

The thermal regime of soils at the extreme southern border of the permafrost zone has been largely overlooked. Soils of permafrost peatlands were studied in the zone of island distribution of permafrost in Western Siberia. Despite their geographical location, they were ranked as very cold subtype within the cryogenic soils type [*Goncharova et al., 2015*]. In the north of European part of Russia, the thermal regime of soils was studied in the mid 20th century within the cultivated and virgin peatlands of the extreme northern taiga [*Kochetkova, 1966*]. The results and findings have demonstrated that reclamation of peat soils often leads to deterioration of their thermal properties, much as the development of peatlands – to the formation of permafrost patches in them.

Determinations of the thermal state and stability of permafrost-affected soils in the zone of sporadic distribution of permafrost (subzone of the extreme northern taiga) were carried out by the researchers from the Institute of Biology, Komi Science Center within the long-term temperature monitoring (launched in 2013) of soils of permafrost peat mounds with thawing fens (which is, technically, palsa peatland) and the underlying deposits within peat plateaus.

The monitoring results allowed to assess the response of permafrost-affected soils in the extreme southern part of the East European plain to interannual and seasonal air temperature variations, and ultimately, to climate change given longer series of observations. The purpose of this paper is to estimate the contemporary temperature state of soils of peat plateaus in concert with climate parameters characteristic of the southern limit of the NE European permafrost zone.

OBJECTS AND METHODS OF STUDY

The study area is subsumed into the extreme northern taiga subzone, whose northernmost part maintains sporadic (island) distribution of permafrost. This area has a temperate – continental moderate-cold climate (the key climatic parameters listed in Table 1). The studies of the thermal regime of soils of peat plateaus with developed hummocks and fens were carried out in 2013 through 2016 at three study sites in the Kosyu river basin (the Inta administrative district of the Republic of Komi) (Fig. 1). Table 2 provides a detailed characterization of the study sites with the conventional names given in accordance with their geographical relatedness to the Ural Mountains. The locations of the sites were carefully chosen proceeding from the gradually changing (from west to east) geology and geomorphology of the eastern part of the Pechora Plain bordering the Ural Mountains. Given their topographic differentiation represented by low lake-glacial plain, elevated moraine plain, and undulated-blocky relief the sites were marked as the Plain study site, the Foothill study site, and the Low-mountain study site, respectively [*Kalesnik, 1964*].

Soils classification and indices of the horizons are given in accordance with [*Shishov et al., 2004*] and "Field Indexing of Soils in Russia" [*2008*]. Table 1 lists the types of soils used further in the text. In this work, the term "soils" refers to a layer consisting of topsoil and the underlying sediment totaling from 2 to 10 m in thickness [*Parmuzin and Karpov, 1994*]. Soil temperatures were measured using HOBO U-12-008 data loggers placed in the soil (depths: 0, 0.2, 0.5, 1.0 m) and in the underlying deposits (depths: 2.0, 3.0, 5.0, 10.0 m) and set for 8 measurements per day; the measurement accuracy of the logger sensors is up to 0.1 °C. The loggers' sensors placed in the soil are fixed on a wooden batten plunged into a hole (3 cm in diameter) to a depth of 1 m.

In the underlying sediments, the loggers are placed in the well drilled to a depth of 10 m and cased by a steel pipe 7 cm in diameter, with a capping attached to its tip to provide for logger installation. The loggers were installed at two points: at the top of peat mound and in the fen at each of the three study sites, the temperature observationbs were thus carried out both in the soil profile (including the active layer) and in the upper horizon of the underlying deposits (including permafrost). Our calculations of climatic parameters – mean annual air temperature, sum of positive (thawing degree days, TDD) and negative air temperatures (freezing degree days, FDD), and average annual precipitation – were underpinned by the Petrun weather station data located at a distance of 50 km north of the Plain and Foothill study sites (Table 1). The air temperatures for these areas measured by the installed loggers are comparable with the weather station data.

The climatic characteristics of the Low-mountain site were derived from the temperature logger data installed at a height of 2 m within the boundar-

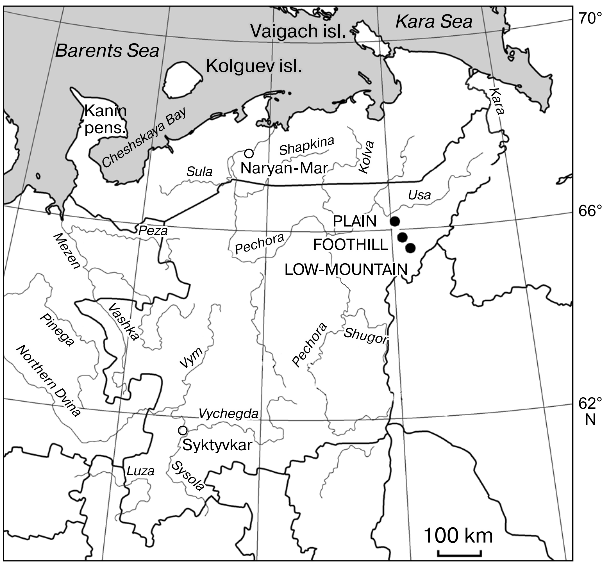

Fig. 1. Geographical position of the study sites.

Table 1. **Climate indices (according to the Petrun WS data)**

The water year (01.10–31.09)	Mean annual air temperature (MAAT), °C	Sum of diurnal mean air temperatures		Annual precipitation, mm	Total precipitation, mm	
		>0 °C	<0 °C		June–September	December–February
2013/14	–3.8	1215	–2648.1	734.8	330	112
2014/15	–2.4	1410	–2313.0	616.0	242	127
2015/16	0.1	1962	–1894.1	508.8	259	58
Average over 2013–2016	–2.0	1529	–2285	620	277	99
Norm (1961–2016)	–3.9	1299	–2687	532	238	93
Range (1961–2016)	0.1...–8.5	897...1962	–1170...–3809	341...735	122...402	24...141

Table 2.

Characterization of the objects of study

Study site (topography element)	Space co-ordinates	Landscape boundaries	Landscape characterization	AL thickness, cm	Average snow cover depth, cm	Soil profile structure	Soil class*	Soils description**
1. Plain (peat mound)	66°05′ N 59°58′ E	Waterlogged interfluve of the Bolshaya Inta and Malaya Inta rivers. Large peat mounds-fens peat bog complex	Peat mound summit. Shrub-moss-lichen vegetation: ledum, cow-berry, bog blueberry, dwarf birch thicket, cloudberry, true mosses, lichens. Bare spots occupy up to 10 % of the area	35	21	O (0–5) – T_1 (5–15) – T_2 (15–25) – $T_3^{\perp}$ (25–87) – T_4 (87–94) – T_5 (94–106)	Peaty oligotrophic permafrost-affected soil	Soils of peat mound / the Plain site
2. Plain (fen)	66°05′ N 59°58′ E		Cottongrass-sphagnum fen: cranberry, cotton grass, sphagnum moss	Unfrozen	117	O (0–5) – T_1 (5–10) – T_2 (10–20) – T_3 (20–40)	Peaty oligotrophic soil in fens	Soils of fen / the Plain site
3. Foothill (peat mound)	65°54′ N 60°26′ E	Niche-Kulitsanyur natural boundaries, the Chyornaya and Bolshaya Inta interfluve. Large peat mounds-fens peat bog complex	Peat mound summit. Shrub-moss-lichen vegetation	50	46	O (0–3) – T_1 (3–20) – T_2 (20–40) – T_3 (40–50) – $T_4^{\perp}$ (50–100)	Peaty oligotrophic permafrost-affected soil	Soils of peat mound / the Foothill site
4. Foothill (fen)	65°54′ N 60°26′ E		Cottongrass-sphagnum fen: dwarf birch thicket, ledum, cloudberry, cow-berry, bog blueberry, cotton grass, sphagnum moss	Unfrozen	109	O (0–6) – T_1 (6–23) – T_2 (23–33) – T_3 (33–48) – T_4 (48–55)	Peaty oligotrophic soil	Soils of fen / the Foothill site
5. Low-mountain (peat mound)	65°25′ N 60°49′ E	The Kozhim and Lemva interfluve, the natural boundaries of the Vode-Ty bog circumference. Foothills of the Polar Urals. Hummock-fen peat bog complex	Peat mound summit. Shrub-moss-lichen	55	Data n/a	O (0–10) – T_1 (10–25) – T_2 (25–32) – T_3 (32–50) – $T_4^{\perp}$ (50–70) – $T_5^{\perp}$ (70–95)	Peaty oligotrophic permafrost-affected soil	Soils of peat mound / the Low-mountain site
6. Low-mountain (fen)	65°25′ N 60°49′ E		Dwarf birch graminous –moss-covered fen	Unfrozen	Data n/a	O (0–5) – T_1 (5–20) – T_2 (20–40) – T_3 (40–50) – T_4 (50–60)	Peaty oligotrophic soil in fens	Soils of fen / the Low-mountain site

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* After: Russian Soils Classification... [*Shishov et al., 2004*].

** This paper.

ies of the studied peat plateau, with key parameters of air and soil temperature profiles over the water year (October 1 through September 30). The values for the mean annual temperatures, FDD and TDD were calculated for characterization of the thermal regime of soils. The current thermal condition of soils was estimated by calculating the air-freezing index (AFI) and soil-freezing index (for a depth of 0.2 m), and coefficients of warming and cooling of the investigated soils.

The values of soil cooling coefficient were taken as a relationship between the *FDD* for air and those for soil (*FDDs*):

$$K_f = \frac{FDD}{FDDs},$$

where K_f is coefficient of soil cooling; *FDD* is the sum of negative air temperatures (freezing degree days); *FDDs* is freezing degree days for soils. Likewise, we calculated the coefficient for soil warming (with sums of positive air and soil temperatures as *TDD* and *TDDs*, respectively)

$$K_w = \frac{TDD}{TDDs},$$

where K_w is coefficient of soil warming; *TDD* is the sum of positive air temperatures (thawing degree days); *TDDs* is thawing degree days for soils.

The air freezing index takes the form of the relationship written as

$$F = \frac{FDD_+^{1/2}}{FDD_+^{1/2} + TDD^{1/2}},$$

where *F* is air freezing index; symbol “+” implies the use of sums of negative temperatures as positive values.

Similarly, the calculation of soil freezing index at a depth of 0.2 m took the form of formula:

$$Fs = \frac{FDDs_+^{1/2}}{FDDs_+^{1/2} + TDDs^{1/2}}.$$

RESULTS AND DISCUSSIONS

Winter temperature regime of soils. Seasonal freezing of the topsoil in peat plateaus begins in October with the onset of steady negative air temperatures. Soil freezing proceeds from the surface downwards. In October–November, the mean monthly temperatures in the upper horizons (0–0.2 m) of active layer (AL) of peat mounds gradually turn to negative values (Fig. 2). The rate of freezing slows down along the profile due to the so called “zero curtains” documented the depth of 0.2 m whose duration may be as long as two months.

On peat mounds’ tops with a relatively thin snow cover (0.1–0.2 m) the range of total negative temperatures of topsoil surface amounted to −655...−1567 °C·day, at a depth of 20 cm range −303...−1092 °C·day (Table 3). Soils of peat mound at the Low-Mountain site appeared to be the coldest profile, which is associated with the harsh climatic conditions of the polar Urals and insignificant snow depth. The sum total negative temperatures at a depth of 1 m vary within −138...−624 °C·days, and from −22 to −425 °C·day at a depth of 10 m. Seasonal temperature variations, most pronounced within the AL, gradually attenuate in the underlying permafrost (Fig. 2). At a depth of 10 m they are practically not expressed. Soils of peat mounds show the lowest temperatures within the AL in February (Fig. 2). The cooling of permafrost has two peaks: in the period spanning March–April (depth: 1–3 m), and May–June (depth: 5 m).

The mean monthly temperatures for the coldest month range from −8 to −17 °C (topsoil surface) and between −2 and −7 °C in permafrost (at a depth of 1 m), with the snow cover depth being major control of the winter climate severity with respect to soils. Thus, in 2015, the maximum snow depth averaged 0.44 m at the warmest Foothill study site, and 0.21 m at the colder Plain site, whilst soils of peat mound from the Low-mountain site produced the coldest

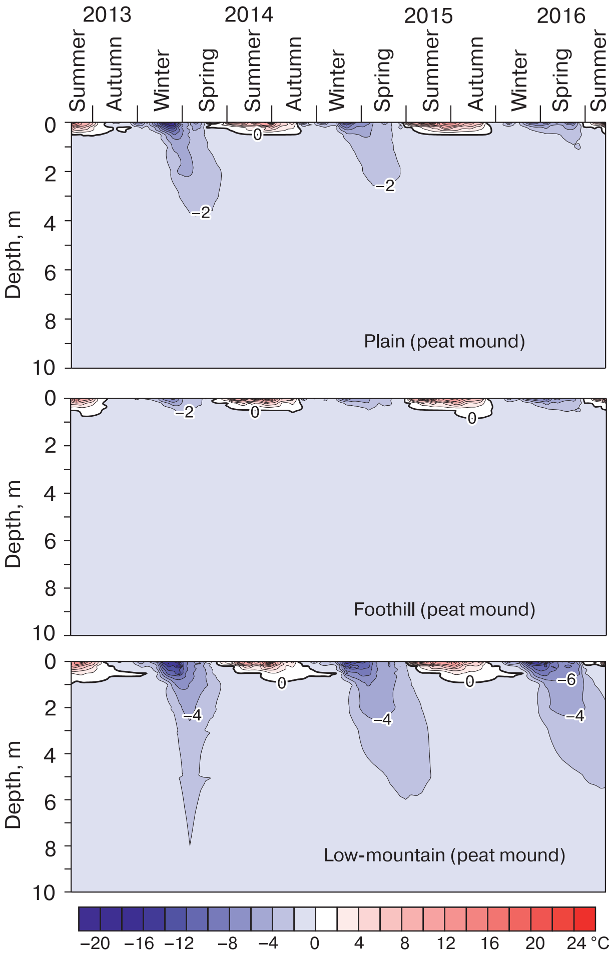

Fig. 2. Temperature dynamics over the period of 2013–2016 in soils of permafrost peat mounds.

Table 3. **Freezing degree days (FDD) for soils (°C·days)**

Soils	The water year	Depth, m							
		0.0	0.2	0.5	1.0	2.0	3.0	5.0	10.0
1. Soil of peat mound / the Plain studysite	2013/14	–1390	–808	–462	–424	–455	–342	–216	–102
	2014/15	–1134	–615	–403	–369	–403	–352	–299	–166
	2015/16	–1027	–426	–226	–226	–231	–232	–241	–151
2. Soil of fen / the Plain study site	2013/14	–11	–2	0	0	0	0	0	–23
	2014/15	–1	0	0	0	0	0	0	–35
	2015/16	0	0	0	0	0	0	0	–32
3. Soil of peat mound / the Foothill study site	2013/14	–655	–317	–163	–173	–269	–198	–94	–28
	2014/15	–697	–303	–148	–158	–77	–64	–53	–22
	2015/16	–912	–382	–159	–138	–221	–203	–135	–42
4. Soil of fen / the Foothill study site	2013/14	–14	0	0	0	0	0	0	0
	2014/15	–9	0	0	0	0	0	0	0
	2015/16	–27	–9	0	0	0	0	0	0
5. Soil of peat mound / the Low-mountain site	2013/14	–1346	–1073	–836	–616	Data n/a	Data n/a	Data n/a	Data n/a
	2014/15	–1379	–1058	–815	–624	–714	–620	–542	–401
	2015/16	–1567	–1092	–838	–612	–717	–634	–573	–425
6. Soil of fen / the Low-mountain site	2013/14	–230	–85	0	0	Data n/a	Data n/a	Data n/a	Data n/a

profile, which is associated with a minimum snow depth (0.2 m) there. According to the winter temperature profile parameters, soils of waterlogged fens differ principally from those of peat mounds. In the fens, its only the topsoil layer (from which subfreezing temperatures are reported) that experiences freezing during the winter (Fig. 3).

Accordingly, soils of fens on the surface are characterized by low values of negative diurnal temperatures (Table 3). At a depth of 0.2 m, the FDDs values are either unidentifiable or tending to be zero. The minimal mean monthly soil temperatures (–0.1...–2.3 °C) in the fens are usually reported in February, progressively decreasing from the Plain site towards the Low-mountain site.

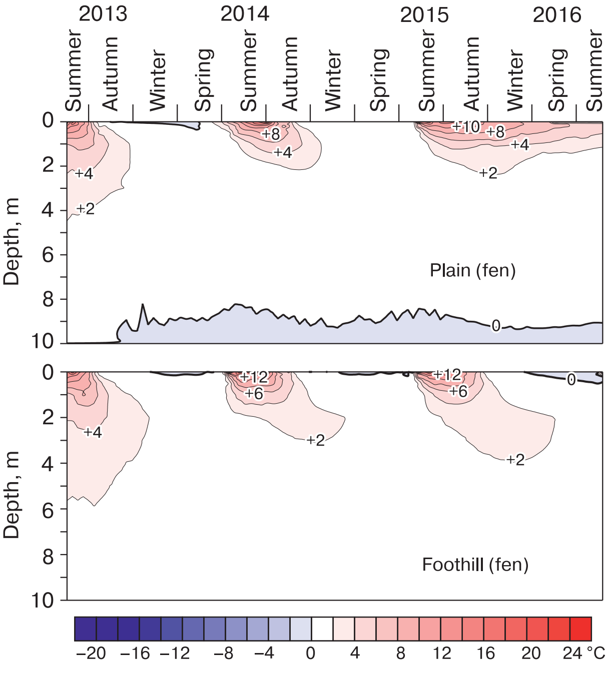

Fig. 3. Temperature dynamics over the period of 2013–2016 in soils of fens.

In the winter season, positive mean monthly temperature only as low as +0.1 °C is reported in soils of fens at a depth of 0.2 m at the Plain and Foothill study sites. While at the coldest Low-mountain study site, average monthly winter temperatures in soils on the surface of fens vary in the range of –0.1...–1.2 °C. The warmest peaks for mean monthly soil temperatures at a depth of 2–3 m are shifted to May–June, and constitute from +0.3 to +1.4 °C.

Summer temperature regime of soils. The seasonal thawing of the upper horizons of the studied soils usually begins in May. During the summer, soil temperatures on peat mounds are lower compared to that of fens. This is accounted for the cooling effect from the permafrost table due to its shallow occurrence in drained summits. The TDDs values for the AL of peat plateaus are generally comparable with those of permafrost-affected peaty soils of the tundra and forest tundra [*Kaverin et al., 2014*]. The mean monthly temperatures of the warmest month (July or August) on the surface of peat plateaus vary in a narrow range from +10 to +11 °C (Fig. 2). In the upper horizons of peat plateaus (depth: 1 m) maximum mean monthly temperatures (–0.1...–1.2 °C) are reported for the period spanning from September to December.

The soils of fens warm up much better compared to peat mounds due to either the absence or very deep occurrence of permafrost and very poor "accumula-

Table 4. **Thawing degree days (TDD) for soils (°C·days)**

Soils	The water year	Depth, m							
		0.0	0.2	0.5	1.0	2.0	3.0	5.0	10.0
1. Soil of peat mound / the Plain study site	2013/14	950	389	1	0	0	0	0	0
	2014/15	1355	558	0	0	0	0	0	0
	2015/16	1602	760	0	0	0	0	0	0
2. Soil of fen / the Plain study site	2013/14	535	618	1020	846	186	146	82	0
	2014/15	1406	1233	1075	820	457	301	140	0
	2015/16	1689	1498	1317	999	531	356	168	0
3. Soil of peat mound / the Foothill study site	2013/14	977	340	11	0	0	0	0	0
	2014/15	1287	499	1	0	0	0	0	0
	2015/16	1646	720	48	0	0	0	0	0
4. Soil of fen / the Foothill study site	2013/14	1282	1246	1202	1099	377	359	314	262
	2014/15	1390	1286	1066	750	703	606	483	405
	2015/16	1646	1460	1171	775	802	696	548	433
5. Soil of peat mound / the Low-mountain study site	2013/14	1125	572	125	0	0	0	0	0
	2014/15	1379	700	106	0	0	0	0	0
	2015/16	1597	812	179	0	0	0	0	0
6. Soil of fen / the Low-mountain study site	2013/14	1147	1035	937	783	Data n/a	Data n/a	Data n/a	Data n/a

tion of winter cold" (Fig. 3). A remarkable increasing trend for the entire soil temperature profile shows up in June. The fens are characterized by very large TDDs values both for soils and the underlying sediment (Table 4). The maximal mean monthly temperatures vary from +12 °C on the soil surface to +6...+7 °C at a depth of 1 m (August). The period of maxima in the mean monthly temperatures (+1...+2 °C) at a depth of 2–5 m is shifted to December. Seasonal temperature fluctuations in the fens encompass a thickness of up to 5 m, which is associated with high thermal conductivity of highly waterlogged soils. In the case of completely permafrost-free fens, relatively high TDDs values persist in the layer of attenuation of annual temperature fluctuations (soils of fens, the Foothill site).

Annual fluctuations of soil temperature regime. The total mean annual temperatures within the soils AL in mounds at depths of 0, 0.2, 0.5 m varied from +2.0 to −2.0 °C, while in the upper permafrost horizons (depth: 1.0–5.0 m) they ranged within −0.3...−2.2 °C (Fig. 4). The lowest mean annual temperatures of permafrost in peat mounds were documented within the 1–3 m depth interval, which is associated with seasonal cooling of the upper permafrost horizon. Temperature fluctuations at the depth of zero annual amplitudes (10 m) exhibited annual variations between −0.1 and −1.2 °C. These indicated that the warmest soils of peat mounds are confined to the Foothill study site, where persist positive (in the seasonally thawing horizons) and subfreezing annual temperatures (in the underlying permafrost at a depth of 10 m).

Temperature profiles of soil of peat mounds at the other study sites have exhibited positive mean an-

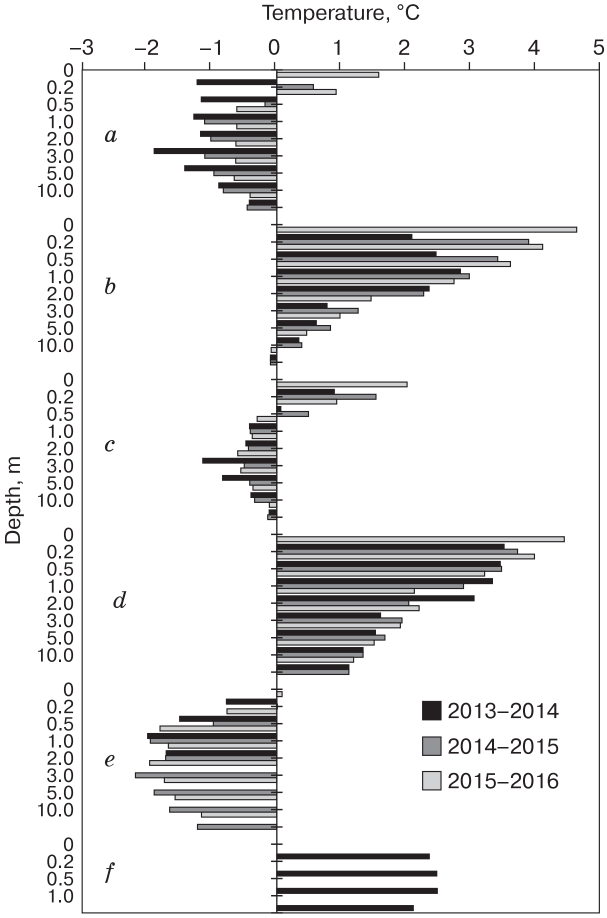

Fig. 4. Mean annual soil temperature of peat mounds and fens.

a – peat mound of the Plain site; *b* – fen of the Plain study site; *c* – peat mound of the Foothill study site; *d* – fen at the Foothill study site; *e* – peat mound at the Low-mountain study site; *f* – fen at the Low-mountain study site.

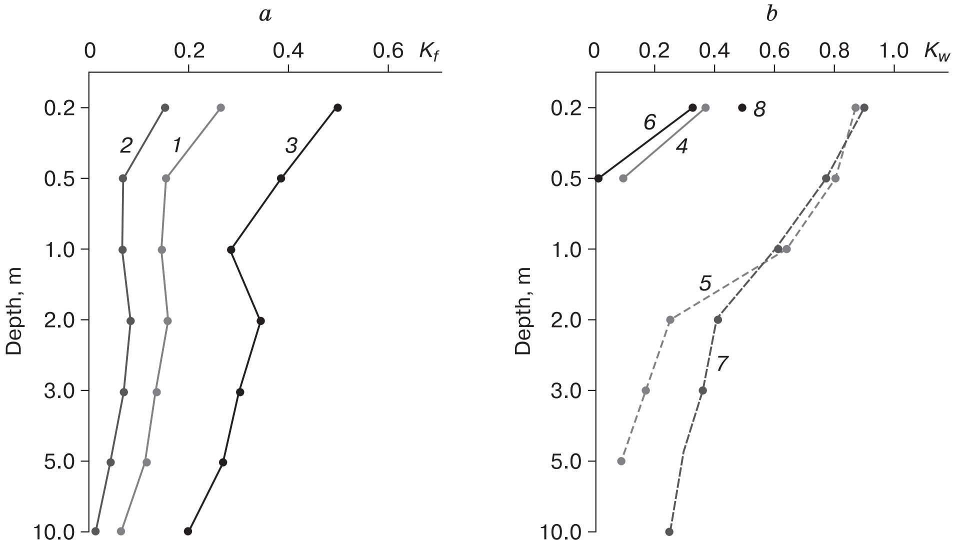

Fig. 5. Soil cooling K_f (*a*) and warming K_w (*b*) coefficients.

1 – peat mound of the Plain study site; *2* – peat mound of the Foothill study site; *3* – peat mound at the Low-mountain study site; *4* – peat mound of the Plain study site; *5* – fen of the Plain study site; *6* – peat mound of the Foothill study site; *7* – fen of the Foothill study site; *8* – peat mound at the Low-mountain study site.

nual temperatures at the topsoil horizon in two of the three years of monitoring observations. Whilst temperature offset in the context of the peaty permafrost-affected soils is characteristic of bare peat surfaces in the forest-tundra [*Burn, 2004; Kaverin et al., 2016*]. It stands to reason that at the extreme southern limit of the East European cryolithozone, positive mean annual temperatures are tending to become typical of the AL peaty soils, given that climatic conditions aggravated by the fairly intense processes of water erosion are unfavorable for preservation of permafrost [*Pastukhov et al., 2017*].

Soils are characterized by relatively high positive mean annual temperatures (Fig. 4). In the unfrozen deposits underlying the fens, the mean annual temperature gradually decreases within the range of positive values. The deep occurrence of permafrost (9 m) in the fen of the Plain study site affects its entire temperature profile, whose mean annual temperatures are reduced to the zubfreezing values at a depth of 10 m. The analysis of cooling and warming coefficients allows comparing the rate of temperature wave attenuation in the studied permafrost-affected and non-permafrost soils. The analysis of averaged cooling coefficients of permafrost soils has revealed the differences caused primarily by the snow cover depth. A relatively weak attenuation of negative temperatures is typical of peat mounds at the Low-mountain study site: the cooling coefficient is 0.2 at a depth of 10 m (Fig. 5).

At the Foothill site, on the contrary, the cooling coefficient value at this depth is close to zero, which is probably due to low thickness (10–15 m) of permafrost underlying the peat mound. Permafrost thickness within the key sites varies from 0 to 30 m [*Ershov and Kondratieva, 1998*]. The warming coefficient is more applicable to the comparative study of the positive temperatures propagation in the thawed soils of fens. In the absence of deep-seated permafrost, the fen at the Foothill study site is characterized by high values of this coefficient. At this, the cooling effect of the deep-seated permafrost base in the fen (the Plain study site) exerts its affect from the depth of 2 m and more (Fig. 5).

Estimation of the current thermal condition of soils. The contemporary thermal state of the studied soils was estimated from the comparative analysis of the freezing indices of the air (F) and soil (Fs) at a depth of 0.2 m. According to the authors, the interplay of these indices is suggestive from the perspective of searches for the universal "common ground" bridging climate modeling and cryopedology.

Calculations of the air freezing index are used for the purposes of climate modeling for mapping the "climatic" areas of permafrost distribution [*Sazonova and Romanovsky, 2003*]. During the so-called background period of a relatively stable state of the permafrost (1960–1990), the air freezing index for the region averaged 0.60. Understandably, such climatic conditions favored preservation of sporadic (island) pattern of permafrost (as ecosystem-protected) in peat plateaus [*Shur and Jorgenson, 2007*].

Given a linear downward trend F ($y = -0.0012x + 0.6209$; $R^2 = 0.2688$) manifest within the past 50 years, the air freezing index averaged over the study period (2013–2016) is equal to 0.55. While during the "background period", such values were typical only of the permafrost-free southern half of the subzone of the northernmost taiga. As such, the air freezing index dynamics indicates a gradual "deterioration" of climatic conditions that ensure preservation of permafrost at the extreme southern limit of its distribution.

The soil freezing index is similar to the soil-permafrost index (*Fn*) for soil surface used in model calculations of soil temperature conditions [*Anisimov et al., 2012*]. The calculation of the soil freezing index for the depth of 0.2 m, rather than for the soil surface, is enabled by greater stability of thermal conditions and the impact from the underlying permafrost strata. Additionally, this index can be used for estimating the continentality of the soil climate of permafrost-affected soils [*Dimo, 1972*]. The utility of soil freezing index is associated with defining indicators of temperature stability, including those adapted for the region with distribution of high-temperature permafrost, and permafrost-affected soils. A comparative analysis of air and soil freezing indices is additionally proposed for estimation of the current thermal state of permafrost-affected soils.

Comparison of the soil and air freezing indices values revealed a relative mildness of the climate of AL soils of peat mounds at the Plain and Foothill study sites (Fig. 6). Significantly lower soil freezing indices already report the "warming" in the upper horizons of permafrost-affected soils in peat plateaus, where the projected climate warming will further promote an increase in the AL depth [*Rivkin et al., 2016*].

Thus, in the context of the permafrost ecosystems of isolated peat plateaus further growth of soil temperature will only contribute to the erosion processes activation and further thawing of permafrost [*Pastukhov et al., 2017*].

CONCLUSIONS

In the area of sporadic (island) permafrost distribution in the European North-East of Russia, soils of peat mounds and fens differ strikingly under summer and particularly winter thermal regime. The insignificant snow cover depth (0.2–0.4 m) on peat mounds contributed to strong cooling of soils during the winter (–22...–1567 °C·days).

In fens with a relatively thick snow cover (1.0–1.5 m), winter freezing affects only the soil surface layer characterized by subfreezing temperatures (0...–0.2 °C). A sharp decrease in summer temperatures (1600–0 °C·day) within the thin (0.4–0.6 m) AL of peat mounds was caused by a high heat-insulating ability of peat on the drained mounds and strong cooling effect from the shallow depth of the permafrost table.

The deep penetrating summer warming (up to 5–6 m) into thawed soils of fens is accounted for high thermal conductivity of their strongly waterlogged horizons.

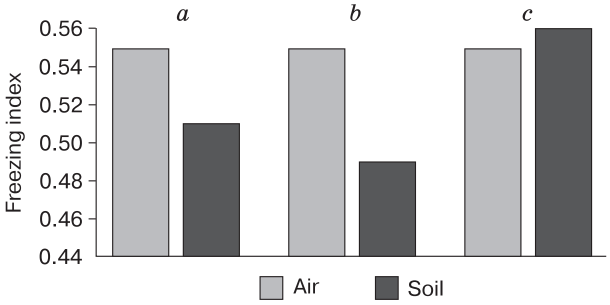

Fig. 6. Averaged over the study period air and soil freezing indices (depth: 0.2 m) at the Plain (*a*), at the Foothill (*b*) and at the Low-mountain (*c*) sites.

Soils of peat mounds within the AL are characterized mainly by positive or "warm" negative mean annual temperatures (–1...+2 °C), forming the warmest "link" within the permafrost-affected soils of the East European plain. Only positive mean annual temperatures (+2...+3 °C) gradually decreasing down the profile in the unfrozen underlying sediments (with positive temperatures, 0...+2 °C) are therefore reported from thawed soils of fens.

Analysis of cooling and heating coefficients within the depth of zero amplitudes showed that in the studied areas with sporadic (island) distribution of permafrost, the degree of summer heat penetration in soils of fens (K_w = 0.1–0.9) exceeds that of winter cooling of peat mounds (K_f = 0–0.5).

Comparative analysis of air and soil freezing indices is proposed for estimation of current temperature state of permafrost-affected soils in the northeast of European part of Russia. Relatively low freezing index values for air (F = 0.55) and soil (Fs = = 0.49–0.56) reflect the impact from modern climate warming on permafrost-affected soils of the region.

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