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Microbiological characteristics of the profile of Cryic Fibric Histosol (Turbic) soil in Western Siberia

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Abstract. The paper presents the results of comparative microbiological analysis of the samples extracted from the upper part of the profile of permafrost soils in the tundra and forest tundra exposed to the thawing and freezing processes, and the lower part of the profile, formed under the influence of permafrost. The comparative analysis revealed the key effect of seasonal temperature fluctuations on the nature of distribution in the soil profile of the number of microorganisms of the main ecological and trophic groups involved in maintaining the cycles of nitrogen and carbon.

1. Introduction
The nature and intensity of the response of terrestrial ecosystems to climate change has become one of the priority areas of research of the world scientific community over the past decade. The currently developed climate models show that an increase in temperature, humidity and a change in the nutrient regime in the soil can substantially modify microbial communities and indirectly affect through their response greenhouse gases’ flow [1]. The question of the influence of climate changes on the stimulation of the activity of soil microorganisms and the rate of organic matter decomposition in the soils of the cryolithic zone remains open [2]. As it is known, partially decomposed plant phytomass and animal remains accumulate in organic soils for millennia, that makes them the largest carbon bank on the planet. According to Hugelius et al. [3] the permafrost soil stores more carbon than the atmosphere currently contains. For this reason, the scientific community is becoming increasingly concerned that, in the conditions of climate change, the growing metabolic activity of soil microflora will contribute to increased CO₂ emissions and even more global climate changes [4-7]. At the same time understanding the consequences of climate change for the functioning of microbial communities of tundra soils remains limited [8]. This determines the high urgency of studying the nature of microbiological processes in the profile of Cryic Fibric Histosol (Turbic) soil and the effect the climate factors on these processes, causing the periodic changes in the physical and chemical parameters of the soils.

2. Materials and methods
The research was conducted in the typical bog massifs in the tundra and forest-tundra zones located at a distance of more than 200 km from each other (Table 1, figure 1). The climate conditions in the area are severe. According to the data of NASA (https://eosweb.larc.nasa.gov/sse/RETScreen/) average annual temperature in the area S1 (Pangody) is -4.6 °C, in the area S2 (Tazovsky) -8.2 °C.
In bogs, wells were drilled to a depth of 120 cm, from which peat cores were extracted. Peat samples immediately after extraction were cleaned with disposable sterile blades and placed for storage in sterile bags. The samples were transported and stored at a temperature of -20 °C. Before inoculation, the samples were not thawed to prevent possible distortion of the analysis results.

To assess the contribution of the microbial community of peat permafrost soils into the nitrogen cycle, the number of ammonifying microorganisms transforming nitrogen-containing organic compounds to ammonium and microorganisms that assimilate mineral forms of nitrogen were calculated.

Table 1. Characteristics of the landscape

| №  | Coordinates                  | Temp. January, °C | Temp. July, °C | Ecosystem       | Plant community       |
|----|------------------------------|-------------------|----------------|------------------|-----------------------|
| S1 | N 65°52'24,8" E 74°57'38,6" | -20,5             | 15,8           | Palsa            | Dwarf shrub-moss-lichen |
| S2 | N 67°21'25,2" E 78°42'11,8" | -27,5             | 14,4           | Poligonal bog    | Dwarf shrub-moss-lichen |

To assess the contribution of the microbial community of peat permafrost soils into the carbon cycle, the number of clostridia, humus-destroying and oligotrophic microorganisms, microscopic fungi was accounted. Determination of the number of microorganisms in peat permafrost soils was carried out in three replications by the Koch method, by inoculation on agarized elective media. The number
of ammonifiers was calculated in the pancreatic digest of fish flour agar (DFF), the utilizers of nitrogen-containing organic substances - in starch-and-ammonia agar (SAA), oligotrophic microorganisms - in peat agar, microscopic fungi - in Chapek's medium. The number of clostridia was determined by the method of limiting dilutions by inoculation on Vinogradsky's medium.

By means of correlating the number of microorganisms, mainly assimilating inorganic sources of nitrogen and nitrogen-containing organic matter, and the number of ammonifiers focused mainly on the assimilation of organic nitrogen, the mineralization coefficient was calculated. The coefficient of oligotrophication was calculated as the ratio of the number of oligotrophic microorganisms capable of assimilating insignificant concentrations of nutrients to the number of eutrophic ammonifiers actively developing on relatively rich organic substrates. This indicator gives an idea of the degree of soil enrichment with organic matter available to eutrophic microorganisms and allows an indirect assessment of the degree of species diversity of the microbial community.

3. Results and discussion

The microbiological analysis of the profiles of Cryic Fibric Histosol (Turbic) soil in the investigated sites in the forest-tundra (S1) and tundra (S2) showed that both soils are characterized by rather a low number of microorganisms. It was revealed that the number of ammonifiers significantly correlated with the number of microorganisms assimilating nitrogen-containing organic matter ($r=0.95$, $p<0.05$), and the number of humus-destroying microorganisms ($r=0.7$ $p<0.05$). Also, a direct correlation between the number of fungi and the number of humus-destroying microorganisms was identified ($r=0.88 = p<0.05$).

It is noteworthy that the zones of "optimum" for the considered ecological-trophic groups of microorganisms in the profile of the two investigated soils are confined to the same regions. Microbiological profiles are distinctly divided into two zones: the upper zone, susceptible to seasonal temperature fluctuations, and the lower one, formed under the influence of permafrost (Figure 2, 3, 4). The maximum number of all ecological-physiological groups of microorganisms is found in the upper, most aerated and least decomposed horizons of the profiles. The studies done by M. Clarholm et al. [9], P. Widdens [10], F.L. Bunnell et al. [11], A.J. Holding [12] and O.M. Parinkina [13] provide the evidence for the decrease in the amount of bacteria with the depth of the permafrost peat. Most authors relate this fact to the peculiarities of water-air regime of the soil profile, but not to the organic matter available in it.

The second zone of the optimum for some groups (oligotrophic microorganisms, microscopic fungi and humus-destroying microorganisms) is the suprapermafrost layer located directly above the “freeze-thaw” boundary (Figure 2, 3). Similar patterns are revealed by O.M. Parinkina [13] for soil microflora in the subzone of the Arctic tundra of Taimyr and Morgalev et al. [14] for soils in the northern taiga of Western Siberia. The microbial communities of the investigated permafrost peat soils contain metabolically active representatives of both the eutrophic and oligotrophic microbial communities. The distribution curves of the number of oligotrophic and eutrophic microorganisms in the soil profile have mirror nature, which probably indicate the presence in the profile of peat soils of spatially separated zones of the optimum for microorganisms belonging to the eutrophic and oligotrophic ecological strategy. In the upper layer of peat soils of the forest-tundra, the number of the investigated groups of microorganisms, except oligotrophic microorganisms, is higher than in the soils of the tundra. However, in general, such correlation in the profile is observed only for humus-destroying microorganisms and fungi. The number of oligotrophic microorganisms, ammonifiers and utilizers of nitrogen-containing substances is higher in the soil of the tundra. The number of clostridia in the permafrost layer of peat soils at two sites is approximately the same and almost doesn’t vary with depth (Figure 1, 2, 3).
The curve of changes in the values of the oligotrophication coefficient in the profile of peat soil in the forest-tundra site indicates a relatively weak enrichment of the upper soil layer (0-10 cm) with organic matter available for the eutrophic microbial community. Further, a gradual increase in the value of the oligotrophication coefficient is observed downward along the profile, and at a depth of 35-40 cm, in the upper layer it increases three-fold to 3.15 (Figure 4a).

A significant increase in the oligotrophication of the peat deposit, in accordance with the basic ecological laws, should be accompanied by an increase in the number of ecological niches in the suprapermafrost layer, and, consequently, an increase in the degree of species diversity of the soil microbial community. In the peat soil in tundra zone, an increase in the coefficient of oligotrophy is observed in the frozen layer at a depth of 70-80 cm (Figure 4 b).

In the profile of the soil in forest-tundra, the change in the number of microorganisms, mainly assimilating mineral forms of nitrogen and nitrogen-free organic substances, has a character close to the character of distribution of ammonifiers in the profile.
The mineralization coefficient reaches its maximum values in the upper layer of the soil (Figure 4a). Further, downward the soil profile, an insignificant decrease in the mineralization coefficient is observed. In the tundra soil, a slight increase in this coefficient was noted in the permafrost layer at a depth of 80 cm (Figure 4b). In general, the mineralization coefficient along the soil profile varies insignificantly.

4. Conclusions
The profiles of the investigated permafrost peat soils of the forest-tundra and tundra are characterized by fairly low values of the number of metabolically active forms of microorganisms of all studied ecological-trophic groups. Moreover, the representatives of both the eutrophic and the oligotrophic microbial groups are present in the microbial communities of the investigated permafrost peat soils. The optimum zones for the representatives of the eutrophic and oligotrophic ecology-trophic strategy were identified in the profile of the investigated soils. In this case, the optimum zone for the oligotrophic microflora is the boundary layer located above the active layer, depleted by dissolved organic and mineral compounds as a result of their washing out into the underlying layers of the peat thickness. The optimum zone for the eutrophic microflora is the upper, oxygen-enriched layers of the soil profile, as well as the layers located below the "freeze-thaw" boundary. Given the considerable similarity of the profile distribution of the number of microscopic fungi and oligotrophic microflora, as well as a significant proportion of microscopic fungi in the composition of oligotrophic microbial communities, the fungal population of the investigated peat permafrost soils is likely to belong to the oligotrophic strategy. The high abundance of microorganisms in the investigated soils that can use humus as the only available source of carbon, comparable to the number of ammonifiers and utilizers of nitrogen-containing organic matter, indicates the probable belonging of this ecological-trophic group of microorganisms to the eutrophic strategy.

The revealed tendency to an increase in the number of heterotrophic microorganisms in the lower permafrost horizons of peat soils makes it possible to forecast that an increase in average annual temperatures in the region under investigation is likely to cause a significant acceleration of microbiological degradation of organic matter and as a consequence of CO$_2$ emission, which corresponds to the assumptions of most researchers of Arctic soils [5, 7, 15].

**Figure 4.** Changes in the values of mineralization coefficients (k min) and oligotrophication (k olig) in the profile of permafrost peat soil of forest-tundra (a) and tundra (b)
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