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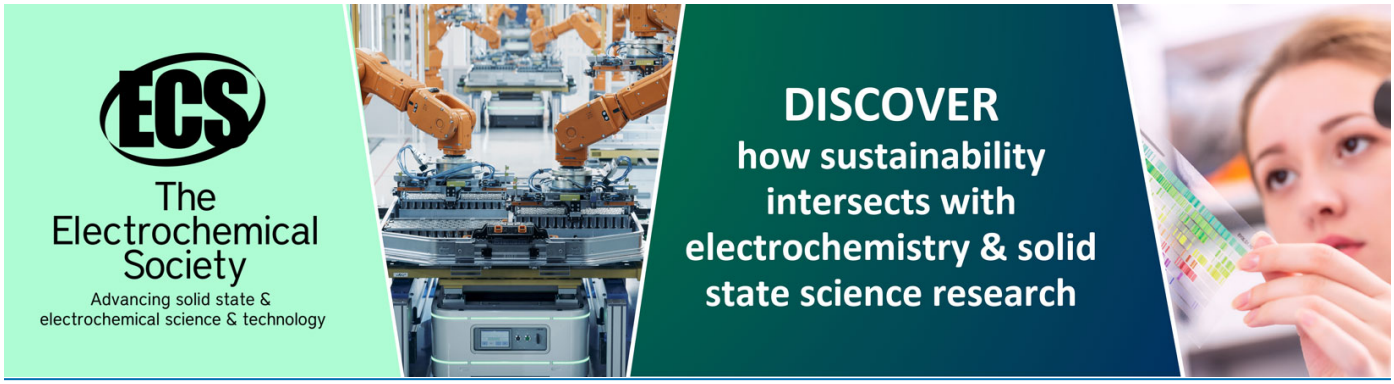

Peat deposits and peat-forming plants in the mires of the West Siberian northern taiga (based on studies of the Khanymei site)

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Abstract. The botanical composition of peat from upper (over-permafrost) layers of the peatland, a part of the peat-podzol soil profile, was analysed. It was discovered that peat deposits in the Khanymei site are characterised by large-scale diversity, and mosaic structure and composition of peats constituting them.

1. Introduction

Mires and peatlands occupy huge areas on the globe – about 350 million hectares. They are mostly widespread in the countries with a cold and temperate climate. Russia accounts for about 73% of the world's peatland area and 60% of the world's peat reserves. Different climate conditions, terrain types and underlying rocks determine the development of various types of peatlands, which differ in types of water supply and chemical composition, and, consequently, in the composition and structure of the peat deposit. After the death of peat-forming plants their organs and tissues (mainly underground ones) in conditions of excess moisture and lack of oxygen in a temperate climate decompose incompletely and form peat. Peat, thus, can be defined as a mixture of incompletely decomposed plant residues and the products of their decomposition, formed with the withering of plants and incomplete decay of their tissues in conditions of high humidity and lack of oxygen.

As noticed by H. Joosten and D. Clarke [1], peatlands record their own history, which is of particular importance for the reconstruction of long-term human and environmental history. Macro-remains of peat-accumulating plants provide data stored in the peat archives that have been used for scientific purposes since the first palaeo-ecologic reconstructions of vegetation and climate [2, 3, 4]. Today, the palaeo-ecological research, based on a peat plant remains analysis and peat deposit stratigraphy, is undoubtedly prospective [5-12], having the new developments including a detailed reconstruction of human life [13-16], of atmospheric deposition of heavy metals [17, 18, 19], of atmospheric CO2 concentrations [20, 21], and of climatic change [22, 23]. A special role of peatlands and peat-based palaeo-reconstructions increases at the littleknown geographical areas, one of which is the southern border of the permafrost zone in West Siberia, where peat deposits are still at the initial stage of investigation and the number of the studied peat cores is scarce [24]. At the same time, a detailed study of long-term dynamics of peat accumulation and decomposition near the southern boundary of the permafrost zone was performed in northeast Europe [25].

A large number of plant species that occur in mires, such as sedges, grasses, Sphagnum and other mosses, as well as woody plants, contribute to peat formation. Peat-forming bryophytes and vascular plants were described in some papers [26, 27]. Some plant species, organs, and substances are more inclined to accumulate peat than others. Consequently there exists a wide variety of "botanical" peat types [28, 1]. Peat types are furthermore distinguished on the basis of their degree of decomposition, nutrient content, acidity, ash content/content of organic material, pedogenic alteration, fibre content and other characteristics [29, 30, 31].

2. Material and methods

Peat deposits of the Khanymei site located in the northern taiga sub-zone of West Siberia (Figure 1), on the southern boundary of distribution of permafrost rocks, are characterised by a large variety of composition and structure of peats that form them. Using a macrofossil analysis method, we analysed a botanical composition of peats of the upper (above-frozen) layers of deposits and peat deposits, which are part of the profile of peat-podzolic soils.

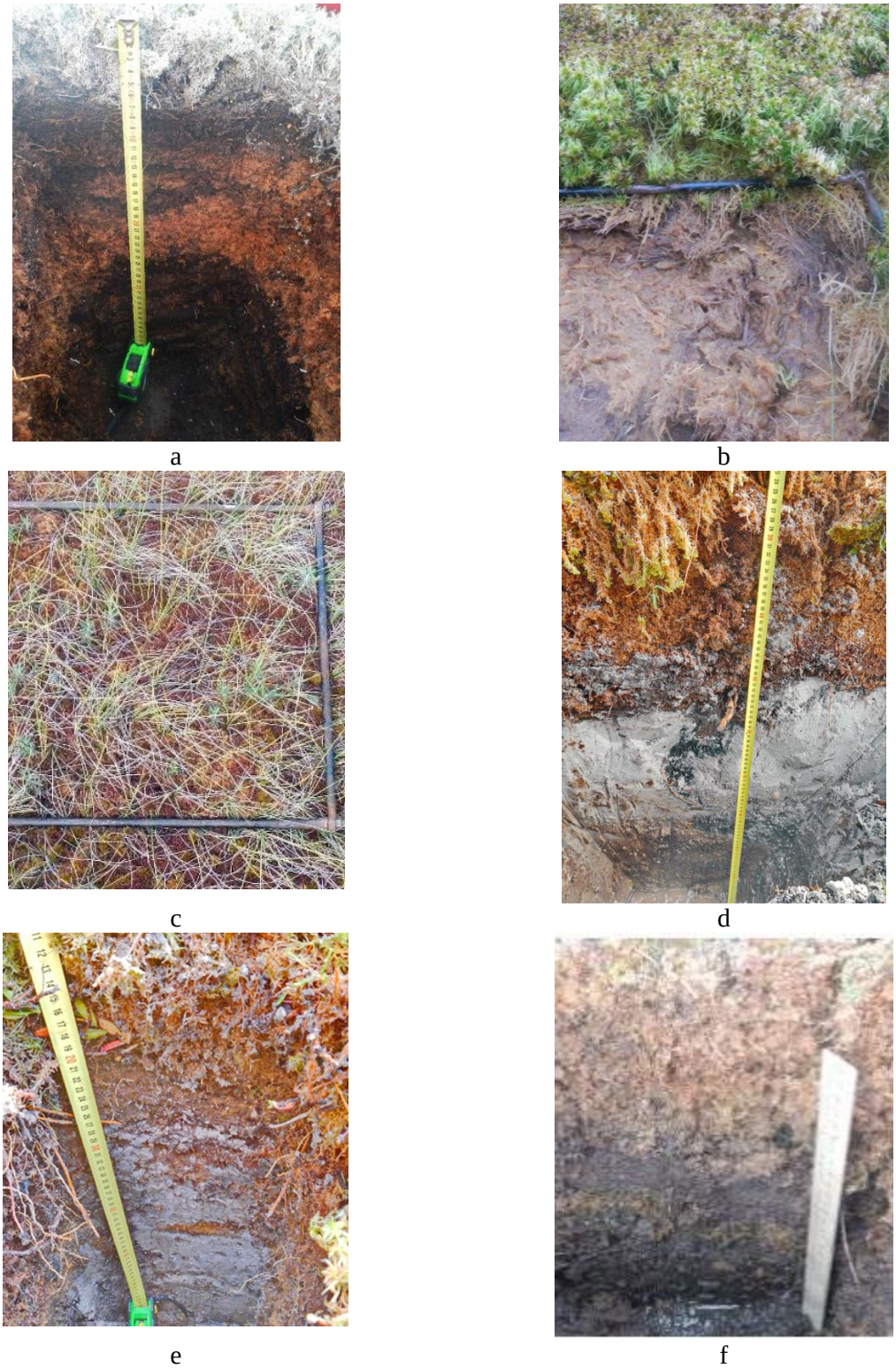
Figure 1. Study area a) on the map of Eurasia, b) on the satellite image

The peat sampling with 10 cm interval was performed. Each coring and sampling point is supported by geobotanical descriptions (relevees). Peat macrofossil analysis was performed according to the standards of Protocol [32].

3. Results

The analysis showed the distribution of peat-forming plants in peat deposits. These plants are described below.

Dwarf shrubs. Raised bogs supply nourishment to waters that are very poor in mineral salts, which determines a set of plant species characteristic of this mire type. There are several layers in the vertical structure of raised bog vegetation (Figure 1).



a – core 1, Glacic-Fibric Histosols (Dystric) soil, b – core 2, Fibric Histosols (Dystric) soil, c – core 4, Fibric Histosols (Dystric) soil, d – core 7, Histic-Albic Podzols, e – core 8, Histic-Albic Podzols, f- core 20, Glacic-Fibric Histosols (Dystric) soil

Figure 2. Cores of the investigated soils

One of the major peat formers in mire deposits of the Khanymei site is oligotrophic dwarf shrubs from the Ericaceae Juss. family. They are wild rosemary *Ledum palustre* L., *chamaedaphne* (*Chamaedaphne calyculata* (L.) Moench) and bog rosemary (*Andromeda polifolia* L.). Besides, in abundance are crowberry (*Empetrum nigrum* L.), lingonberry (*Vaccinium vitis-idaea*), marsh cranberry (*Oxycoccus palustris* Pers.) and small cranberry (*O. microcarpus* Turcz. ex Rupr.). Dwarf birch (*Betula nana* L.) is also common there. Now and before, a dense dwarf shrub layer formed mainly by the aforementioned plant species is a very characteristic feature of the peatland landscape of this area occupied predominantly by oligotrophic mires. The dwarf shrub subtype of the oligotrophic peat type predominates in core 20, overlapping with fuscum peat in the upper part of a deposit. This peat subtype is also found at a depth of 40-50 cm in core 1.

A peculiar feature of dwarf shrub remains decomposition in the studied peat deposits is good preservation of leaves in peat, especially wild rosemary leaves.

Trees and shrubs. Siberian pine (*Pinus sibirica* Du Tour) and Siberian larch (*Larix sibirica* Ledeb.), scarce in number and sometimes badly depressed, are typical elements of the tree layer of raised bog vegetation in Siberia. Remains of these conifers (pollen, fragments of bark and wood) are also found in peat deposits. Occasionally fragments of birch (*Betula pubescens* Ehrh.) are found. However, Scots pine (*Pinus sylvestris* L.) is the most constant element of the tree layer of bog vegetation and its remains are more frequently found in peat. However, the tree layer is not characteristic for the present-day vegetation cover of Khanymei peatlands. Low stands occur on peat-podzolic soils with deep permafrost; the tree layer is formed by pure plantations of *Pinus sylvestris* of two ecological forms (according to [33, 34]): *Pinus sylvestris* f. *litvinowii* (the height of trees is 4-6 m, the canopy is located in the upper and middle parts of the trunk) and *Pinus sylvestris* f. *wilkommii* (exemplars of this pine form do not exceed 3 m in height, the trunks are twisted and the canopy is located along the entire trunk). The shrub layer of vegetation is absent on raised bogs.

Herbaceous plants. Cloudberry (*Rubus chamaemorus* L.) is found most often in peat deposits of Khanymei peatlands. Remains of cotton grasses (*Eriophorum vaginatum* L., *E. polystachion* L.), *Scheuchzeria palustris* L. and mire sedges (*Carex limosa* L., *Carex rotundata* Wahlenb., *Carex chordorrhiza* Ehrh., *Carex globularis* L.) are constantly found in the investigated peats. *Carex limosa*, *Eriophorum polystachion* and *Scheuchzeria* tend to occur on the constantly water-covered areas of the bog surface – hollows, indicating flooded stages of peatland development.

Bryophytes and lichens. The moss layer of raised bog vegetation is very well developed and generally formed by sphagnum mosses. In fact, these plants are edificators of plant communities and create a special environment of raised bogs. Brown sphagnum (*Sphagnum fuscum* (Schimp.) Klinggr, Magellan sphagnum (*Sphagnum magellanicum* Brid.), long-leaved sphagnum (*Sphagnum angustifolium* (Russ.) C. Jens.) and *Sphagnum nemoreum* Scop. are most often found in peat deposits of Khanymei (up to 90% of the peat sample volume). In addition to these species that show the highest abundance in peat and in the current vegetation, the peat of Khanymei contains remains of *Sphagnum lenense* H. Lindb. (up to 20% of the peat sample volume); *Sphagnum jensenii* H. Lindb. and *Sphagnum fimbriatum* Wils. (40% and 10% of the sample volume from a depth of 15-25 cm in core 21, respectively); *Sphagnum rubellum* Wils. and *Sphagnum russowii* Warnst. (correspondingly up to 50-60% and 20% of the volume of the near-surface peat sample from core 8). In the same core 8, at a depth of 30-40 cm, the remains of *Sphagnum balticum* (Russow) C.E.O. Jensen), which is common in hollows and fens of northern oligotrophic bogs, reach up to 70-75% of the sample volume. Remains of dwarf shrubs – wild rosemary, dwarf birch, and to a lesser extent – *Andromeda*, *Chamaedaphne* and crowberry (*Empetrum*) account for 10-30% of the plant fibre volume of the complex sphagnum upper peat, fuscum- and magellanicum-peat, and for most other types of peat. Particularly rich in fragments of dwarf shrub roots and leaves are the upper horizons of peat deposits.

Special attention should be paid to core 2, almost completely composed of remnants of *Sphagnum riparium* Aongstr. Only in the lower part of the core, cotton grass becomes more noticeable in sediments. The pure type of peat formed by remains of *Sphagnum riparium* is not described in known classifications. The occurrence of this sphagnum at this particular site of the landscape is connected

with the bed of the old swampy watercourse. The slow water flow inside the moss turf, which creates conditions for richer plant nutrient, apparently still occurs here, which allows *Sphagnum riparium* growing among the oligotrophic plant communities and depositing in peat, although this species is known as a usual peat former of the fen and transitional peat types of the tundra zone and an inhabitant of swamps. The degree of peat decomposition is minimal.

Green mosses in peat deposits can, depending on a specific species of moss, characterise completely opposite environmental conditions. Thus, after discovering in peat the remains of psychrophilous mosses such as *Polytrichum strictum* Brid. (core 7, at a depth of 20 cm and below) and *Dicranum congestum* Brid. (core 1, from the surface and to the bottom), one can imagine a plant community of dry top of a hillock or ridges of an oligotrophic bog with signs of mire regression and degradation of a peat deposit. On the contrary, common moss peat forming oligotrophic *Warnstorfia fluitans* (Hedw.) Loeske and eutrophic *Drepanocladus aduncus* (Hedw.) Moenk. as well as quite rare moss *Calliergon richardsonii* (Mitt.) Kindb. indicate high humidity because they usually grow in swamps and hollows. In peat bogs of Khanymei, remains of these mosses were found in core 4, from the surface and across the entire core. The amount of green moss residues in peat composition does not exceed 10% of the sample volume.

With the accumulation of peat and the growth of the bog dome, the habitat conditions of sphagnum mosses deteriorate, they get oppressed; and lichens (mainly species of the genera Cetraria and Cladonia) settle on the surface of the moss turf. In the north of the taiga zone, they are very abundant. Being deposited at peat layers in significant quantities, they do not decompose completely after withering, as is usually the case in more southern areas where lichens are not peat formers under any conditions, but form very distinct interlayers with a thickness of 1-2 cm in the peat deposit. Thus, we are dealing with the phenomenon of the formation of a unique lichen type of peat. This peat type was also found by E. Ya. Muldiyarov in peat deposits in the vicinity of Noyabrsk (oral report). Lichen peat is identified and described for the first time. Fragments of lichens have an amorphous appearance, black when examined visually, and cherry or gray-beige colored under a microscope, opaque, multilayered. The cellular structure is not visible. Perhaps the presence and location of lichen interlayers in peat deposits is associated with the phenomenon of cryoturbation of soils. In addition to the entire interlayers of lichen peat, lichens are found as an impurity in the upper layers of raised bog deposits of Khanymei, in the dwarf-shrub, fuscum-, and magellanicum-peat subtypes.

4. Conclusions

A microscopic analysis of Khanymei peat deposits showed the following features: 1) all samples are heavily polluted with mineral inclusions (transparent, colorless and gray-blue, less often yellowish coarse particles – sand, apparently of aeolic origin); 2) a majority of samples show a small degree of peat decomposition, with the exception of peat of grass species from core 4, with their average/above average degree of decomposition reaching 40%; 3) very often in peat there are traces of fires – fire horizons, manifested by embers, less often – by shiny black balls; 4) the regularity of the classical change in the layers of peat deposit, as bogs develop from eutrophic peat into oligotrophic peat, is disturbed for at least three reasons:

– the underlying soils lacking elements of mineral nutrition of plants, which triggers the development of the peatland following the oligotrophic pattern;

– fires that constantly restart the succession of vegetation;

– cryoturbation, cryogenic punching, subsidence of soil and other phenomena and processes caused by permafrost.

Acknowledgments

This research was supported by the RF Federal Target Program, project RFMEFI58717X0036. We express gratitude to Large-scale research facilities «System of experimental bases located along the latitudinal gradient» for fruitful cooperation (http://www.secnet.online/megaustanovka-ru.html).

References

[1] Joosten H and Clarke D 2002 Wise Use of Mires and Peatlands *International Mire Conservation Group and International Peat Society* 304
[2] Dau JHC 1823 *Neues Handbuch über den Torf, dessen Natur, Entstehung und Wiederezeugung. Nutzen im Allgemeinen und für den Staat* ed Hinriches J C (Buchhaundlung: Leipzig) 244
[3] De Chamisso A 1824 *Untersuchung eines Torfmoores bei Greifswald und ein Blick auf die Insel Rügen* Archiv für Bergbau und Hüttenwesen vol 8 (1) pp 129-39
[4] Steenstrup JJS 1842 Geognostiskgeologisk undersögelse af skovmoserne Vidnesdam- og Lillemose i det nordlige Sjelland. *Vid. Sel. naturvid. og mathem*. Afh.vol 9 17-120
[5] Overbeck F 1975 *Botanisch-geologische Moorkunde* (Wachholtz: Neumünster)
[6] Birks HJB and Birks HH 1980 *Quaternary Palaeoecology* ed Edward Arnold (London)
[7] Godwin H 1981 *The Archives of the Peat Bogs* (Cambridge University Press: Cambridge)
[8] Frenzel B 1983 Mires - repositories of climatic information or self-perpetuating ecosystems *Mires: Swamp, Bog, Fen and Moor. Ecosystems of the World 4 A General Studies. Elsevier* ed APJ Gore (Amsterdam) pp 35-65
[9] Berglund B E (ed) 1986 *Handbook of Holocene Palaeoecology and Palaeohydrology* (Wiley: Chichester)
[10] Franklin J F 1989 Importance and justification of long-term studies in ecology *Long-Term Studies in Ecology. Approaches and Alternatives Springer* ed G E Likens (New York) 3-19
[11] Barber K E 1993 *Peatlands as scientific archives of biodiversity*. Biodiversity and Conservation **2** 474-89
[12] Joosten H 1995 *Time to regenerate: longterm perspectives of raised bog regeneration with special emphasis on palaeoecological studies* Restoration of temperate wetlands ed B Wheeler ,S Shaw, A Robertson and W Fojt (Wiley: Chichester) 379-404
[13] Brothwell D 1986 *The bog man and the archaeology of people* (British Museum Press: London / Harvard Univerity Press: Cambridge)
[14] Coles B and Coles J 1989 *People of the Wetlands. Bogs, bodies and lake-dwellers* (Thames and Hudson: London)
[15] Fansa M (ed), 1993 *Moorarchäologie in Nordwest-Europa*. Isensee (Oldenburg)
[16] Turner RC and Scaife RG (ed) 1995 *Bog bodies. New discoveries and new perspectives* (British Museum Press: London)
[17] Shotyk W, Norton S A and Farmer J G 1997 *Peat bog archives of atmospheric metal deposition.* Water, Air, and Soil Pollution 100: 213-413
[18] Shotyk W, Weiss D, Appleby PG, Cheburkin AK, Frei R, Gloor M, Kramers JD, Reese S and van der Knaap WO 1998 *History of atmospheric lead deposition since 12,370 14C yr BP from a peat bog,* Jura mountains, Switzerland. Geological Institute, University of Berne, Switzerland. Science (Washington), 281 (**5383**): 1635-1640
[19] Volkova II, Baikov KS, Syso AI 2010 *Kuznetsk Alatau mires as filters for natural waters*. Contemp. Probl. Ecol. 3: 265-271
[20] Wagner F, Below R, De Klerk P, Dilcher DL, Joosten H, Kürschner WM, Visscher H 1996 *A natural experiment on plant acclimation: Lifetime stomatal frequency response of an individual tree to annual atmospheric CO2 increase*. Proc. Natl. Acad. Sci. USA 93: 11705-11708
[21] Wagner F, Bohncke SJP, Dilcher DL, Kürschner WM, Van Geel B, Visscher H 1999 *Century-scale shifts in early Holocene atmospheric CO2 concentrations*. Science **284** 1971-1973
[22] Mauquoy D, Barber KE 1999 Evidence for climatic deteriorations associated with the decline of Sphagnum imbricatum Hornsch. Ex Russ. in six ombrotrophic mires from Northern England and the Scottish Borders. The Holocene 9: 423-437
[23] Barber KE, Maddy D, Rose N, Stevenson AC, Stoneman RE, Thompson R 2000 Replicated proxy-climate signals over the last 2000 years from two distant UK peat bogs: new evidence for regional palaeoclimate teleconnections. Quaternary Science Reviews 18: 471-479

[24] Vasil'ev SV 2000 *Rate of peat accumulation in Western Siberia. Dynamics of Wetland Ecosystems in Northern Eurasia in the Holocene* (Karelian Scientific Center, Russian Academy of Sciences, Petrozavodsk) 56-59 (in Russian)
[25] Pastukhov AV, Marchenko-Vagapova TI, Kaverin DA, Kulizhskii SP, Kuznetsov OL, Panov VS 2017 *Dynamics of peat plateau near the southern boundary of the East European permafrost zone*. Eurasian Soil Sc. 50: 526-538
[26] Souto M, Castro D, Pontevedra-Pombal X, Garcia-Rodeja E, Fraga MI 2016 Characterisation of Holocene plant macrofossils from North Spanish ombrotrophic mires: vascular plants. Mires and Peat, 18(**11**), 1-21
[27] Souto M, Castro D, Pontevedra-Pombal X, Garcia-Rodeja E, Fraga MI 2016 Characterisation of Holocene plant macrofossils from North Spanish ombrotrophic mires: bryophytes. *Mires and Peat*, 19(**2**), 1-12
[28] Tjuremnov SN 1976 Peat Deposits, 3rd edition, Nedra Publications, Moscow, 488
[29] Fuchsman CH 1980 *Peat. Industrial chemistry and technology*. Academic Press, New York, 279
[30] Andriesse AJ 1988 Nature and management of tropical peat soils. FAO Soils Bulletin 59, FAO
[31] Succow M, Joosten H (Eds.) 2001 Landschaftsökologische Moorkunde 2nd ed. Schweizerbart, Stuttgart, 65-69
[32] Mauquoy D, Hughes PDM and van Geel B A 2010 Protocol for plant macrofossil analysis of peat deposits // Mires and Peat, Volume 7 (2010/11), Article 06, 1–5
[33] Sukachev VN 1905 About the mire pine *Forest journal, Saint-Petersburg*, 35 (**7**), 354-372 (in Russian)
[34] Abolin RI 2015 Mire forms of *Pinus sylvestris* L. Proceedings of botanical museums of Academy of science **14**, 62-84 (in Russian)