Article

The state of drained peatlands in the Middle Urals and prospects of their use for carbon farming

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Abstract

The global change of the planet's climate is associated with increased concentration of greenhouse gases in the atmosphere, which is the result of irrational human economic activity. Wetlands are a natural and efficient store of carbon dioxide. It covers only about 6% of the land surface. Peatlands contain one-third of all soil carbon, or 600 billion tons, which is two times more than the entire global forest biomass pool. Only ocean sediments contain more carbon. Peatlands in the boreal zone, characterized by snowy winters and short warm summers, contain on average seven times more carbon per hectare than any other ecosystem, and ten times more in the tropics. Restoration of drained wetlands to enable their use for carbon farming is also advisable, because it reduces carbon dioxide emission caused by microbial oxidation of peat and by wildfires in the drained areas. Therefore, comprehensive research on the role of drained wetlands in capturing and storing greenhouse gases is crucial for the sustainable management of these valuable ecosystems. Identifying the most promising areas for carbon farming is an important challenge for both global and regional studies. In 2022, the Basyanovsky and Koksharovsko-Kombaevsky drained peatlands located in the Sverdlovsk region (the Middle Urals) were studied as a part of reconnaissance work aimed at finding and selecting peatlands suitable for carbon farming. These peatlands are currently not used for peat harvesting and undergo active natural restoration. The area of secondary rewetting within the Koksharovskypeatland was also studied. On the territory of the Koksharovo-Kombayevsky peatland, the species composition of vegetation in both woody and grass-shrub strata, the composition of peat deposits, and the rate of carbon accumulation were evaluated. Based on the results of this research, the most promising peatland for carbon farming and further study of greenhouse gas emissions appeared to be the Koksharovsko-Kombayevsky peatland.

Keywords the Middle Urals; drained peatland; peat deposits; carbon farming.

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1 Introduction

Wetlands are a natural and efficient store of carbon dioxide (Valach et al., 2021). It covers only about 6% of the land surface. Peatlands contain one-third of all soil carbon, or 600 billion tons, which is two times more than the entire global forest biomass pool (Kirpotin et al., 2021).

One of the main reasons for the wetland drainage is peat extraction for energy needs, often accompanied by cutting down existing tree stands. In the studies of boreal peatlands, Swedish scientists showed that deforestation of pre-drained peatlands significantly increases the wash-out of dissolved organic carbon, dissolved organic nitrogen, and total nitrogen into surface waters and nearby boreal peatland catchments (Könönen et al., 2018). It is known that drainage of swamps often leads to hydrophobicity and high acidity of soil conditions, as a result of the release of a large number of humic acids, hydrophobic in their chemical nature (Szajdak and Szatylowicz, 2010).

Degradation of peatlands leads to a reduction in many ecosystem services, such as the provision of large quantities of high-quality water and the support of biodiversity. Most importantly, it causes a decline in global climate regulation due to reduced carbon deposition (Bonn et al., 2016). Moreover, degraded peatlands significantly dry out the adjacent areas making them more vulnerable to fire. Thus, the drainage of peatlands for large-scale farming and industrial plantations has lately become a global problem due to excessive CO2 emissions caused by peat oxidation, which contributes to global climate change (Hooijer et al., 2012; Salimi et al., 2021).

In recent decades, the rewetting of previously harvested peatlands has become increasingly important, not only in Russia, where wetlands cover about 10% of its territory (Xu et al., 2018). It should be noted that programs for the restoration of drained wetlands are also implemented in Germany, New Zealand, Iceland, Indonesia, the USA, Poland, Sweden, Scotland, and many other countries (FAO, 2012).

Some researchers report partial restoration of wetland ecosystems as a result of human interventions aimed at the area reconstruction (Bring et al., 2022). It is known that the drainage of wetlands often leads to hydrophobicity and high levels of acidity in the soil, as a result of the release of a large number of humic acids, which are hydrophobic in their chemical nature (Anshari, 2010). The rewetted soils are characterized by high levels of [total] nitrogen and dissolved organic carbon, associated with a higher rate of decomposition of organic components, which in turn is associated with a change in the faunal diversity of the rewetted areas (Frank et al., 2014).

The objective of our study was to assess the state of drained peatlands and their ability to absorb carbon in the soil and vegetation cover of wetlands and peat harvesting sites in the Middle Urals.

2 Material and Methods

The study of the soil and vegetation cover of the wetlands and peat harvesting sites was carried out at the Basyanovsky and Koksharovsko-Kombayevsky peatlands (hereinafter referred to as Koksharovsky) located in the Verkhnesaldinsky urban district of the Sverdlovsk region. Peat harvesting at the Koksharovsky peatland began in the 1930s of the XX century, the heyday of production was in the 60s-70s, and at the same time active drainage of wetlands, including the Basyanovsky fen, had been performed. By the 90s, active mining and drainage operations were discontinued.

The Basyanovskypeatland was formed on a drained fen with birch-spruce forest (8B2P). Currently, its landscape is a mosaic composed of relatively flat birch forest areas and wet sphagnum hummocks overgrown with ledum and sedge. These hummocks are most likely refugia of raised-bog species that were present before the drainage of this wetland, probably with a mixed type of peat deposit. Birch stand (*Betula pubescens* Ehrh.) is about 9–12 m high with an average trunk diameter of 15 cm. Occasionally there is a young growth of spruce (*Picea abies* (L.) H. Karst.) and cedar (*Pinus sibirica* Du Tour), with aspen (*Populus tremula* L.), mountain ash (*Sorbus aucuparia* L.) and alder (*Alnus incana* (L.) Moench) in the undergrowth.

The Koksharovsky peatland is forested with birch stands of various ages. Based on the vegetation, it can be assumed that before drainage, it was a fen receiving water from multiple sources with elements of lithogenous fen formed in the relief depressions. The birch stand contains a large number of trees of seed origin, and the quality class of the forest stand is generally lower than that of the Basyanovskypeatland: the height is about 8 m and the average diameter of the trunk is 8–10 cm. Pine (*Pinus sylvestris* L.), spruce, and young growth of cedar are extremely rare.

On the territory of the Koksharovskypeatland, there is a cutaway harvesting site, which was rewetted 25–30 years ago. At present, the relief of the former peat harvesting site is relatively flat with water-filled channels. Between the channels, there are sods overgrown with wetland vegetation. The birch stand is present only at the edge of the cutaway harvesting site, in the driest places there is a young growth of alder, *Betulapubescens*, arctic dwarf birch (*B. humilis* Schrank), and tea-leaved willow (*S. phylicifolia* L.). A lake has formed on the former peat harvesting site, where waterfowl and fish have settled.

Two study plots (SP) and an additional SP on the submerged cutaway site were laid in accordance with OST 56-69-83 (https://www.russiangost.com/p-122133-ost-56-69-83.aspx).

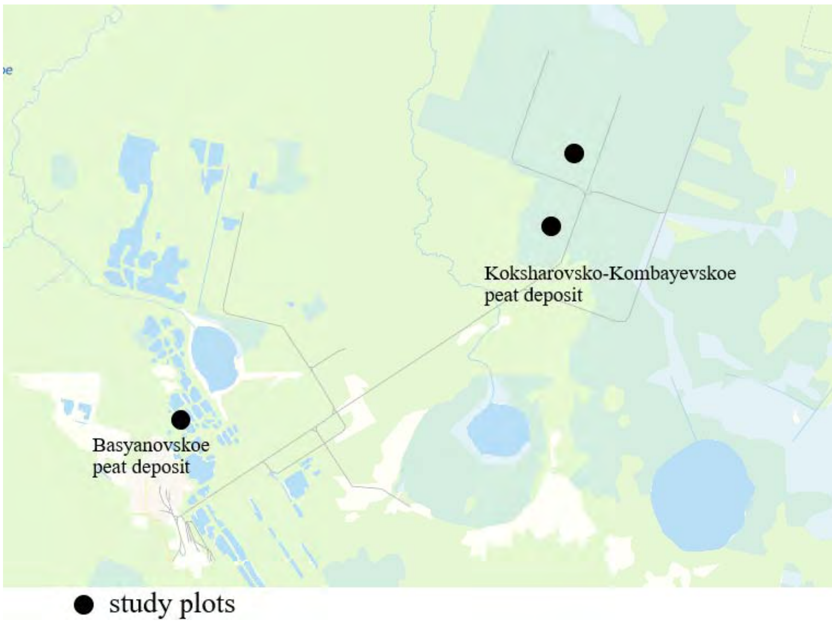

Fig. 1 Map of the study plots in the restored peat deposits of Basyanovskoye and Koksharovsko-Kombaevskoye.

A complete tree stand inventory by diameter at breast height (1.3 m) was conducted. Height measurements were made for model trees with diameters closest to the average. To determine the average age of the growing trees, core samples were taken with an increment borer. Based on the inventory data, the main taxation indicators of the forest stand were determined. The calculation of annual rings for the study of age in cores was carried out using the LINTAB complex.

To assess the aboveground phytomass, we used the allometric equation developed for the forests of the Ural region with the tree phytomass as a variable dependent on the trunk diameter (Chave et al., 2004; Usoltsev et al., 2022):

$$\ln Pi = a_0 + a_1 \ln D, \qquad (1)$$

where *Pi* – *i*-fraction of absolutely dry biomass (*Ps, Pb, Pf, Pa* – trunk, branches, foliage, aboveground phytomass, respectively), kg; *D* – trunk diameter at breast height, cm.

The regression coefficients of equation (1) were calculated using the Statgraphics software (for more information, see http://www.statgraphics.com/).

The species composition of the aboveground phytocoenosis and its productivity (aboveground and green phytomass of herbaceous plants and shrubs) were evaluated at each SP (Methods of study ..., 2002; Biological productivity ..., 2018). To evaluate the results of measurements of the phytomass reserve of the aboveground part of the ground cover, standard statistics were calculated: the total mass on the sample, the arithmetic mean, and the error of the average value. The humidity of the peat soil was determined by the thermostatic-weight method in 5-fold repetition from a depth of 15 cm.

To determine the type of peat and to reconstruct the history of forest phytocoenosis at the plots, peat samples were taken from each SP. The analysis of the botanical composition of the peat was carried out according to GOST 28245-89 (https://www.russiangost.com/p-56900-gost-28245-89.aspx) using the Zeiss Axio Scope A1 microscope at 100x magnification. The study of the degree of decomposition of peat consists of determining the relative area occupied by the structureless part when examining a thin liquefied layer of peat on a slide through a microscope. At the same time, the area occupied by the structureless part and plant residues is taken as 100%. The area occupied by the structureless part is expressed as a percentage and is taken as an indicator of the degree of decomposition. Plant tissues that have retained their cellular structure are taken for plant residues. The study of the botanical composition of peat consists of determining by using a microscope the quantitative ratio as a percentage of the residues of peat-forming plants composing plant fiber in a sample freed from humus. According to the botanical composition, the type, group, and type of peat are determined using the "key".

In order to assess the similarity of the botanical composition of peat, the principal component analysis (PCA) was applied, specially adapted for the detailed study of data with many variables and identification of leading environmental factors (Testolin et al., 2020). We have chosen this type of analysis, since the identified species, for the most part, are marked for both deposits. The analysis was carried out in the Statistica 8.0 software package. For correct analysis, the data were previously logarithmed, according to general recommendations (Kindt and Coe, 2005).

3 Results and Discussion

The analysis of the age of trees in core samples showed that in comparison with the Koksharovsky peatland (the average age is 22 years, with a maximum of 43 years), the forest stand of the Basyanovskypeatland is older with an average age of 38–41 years and a maximum of 46 years.

Table 1 provides an overview of the studied plant communities, reflecting the [total] projective cover and species composition in the vegetation. The names of the communities are given according to (Chindyaev, 2010). The moisture content of the peat from the Basyanovsky peatland is higher than that from the Koksharovsky (133% and 110%, respectively), which affects the projective cover of the living ground cover vegetation (78% and 65%, respectively). The forest on the Koksharovsky peatland is richer in species (5.8 pcs/m^2), including species of herbaceous plants (4.1 pcs/m^2). The subshrub spots at the Basyanovsky peatland are associated with sphagnum hummocks. The submerged cutaway site is characterized by extensive young growth of woody plants (up to 60 cm high).

A comparison of the total aboveground phytomass per SP presented in Table 2 revealed that a submerged cutaway site has the most productive plant community (1281.6 g/m^2), which can be explained by the large proportion of perennial Gramineae and Cyperaceae species. The birch forest with herb stratum on the

Koksharovsky peatland is more productive than that on the Basyanovsky peatland, despite the dry soil. This can be explained by the high proportion of tall large-leaved herbaceous plants (e.g. meadowsweet, stinging nettle, etc.) in the ground cover vegetation.

Table 1 Characteristics of the plant communities of the Basyanovsky and Koksharovsky peatlands.

Community	[Total] projective cover, %	Avg. number of species, pcs./1m^2	Soil moisture,%	Species composition, pcs/m^2				Dominants and co-dominants of the ground cover vegetation
				Woody plants	Shrubs and subshurb	Sedges, grasses	Forbs	
Basyanovsky peatland								
Birch forest with shrub and herb stratum	78	5,2	133±16	0,2	1,4	1,4	2,2	Bushgrass (*Calamagrostis epigeios* L.), raspberry (*Rubus idaeus* L.), eagle fern (*Pteridium aquilinum* (L.) Kuhn), yellow thistle (*Cīrsium setōsum* L.), dropwort (*Filipendula vulgaris* Moench). On the wet hummocks, there are marsh tea (*Ledum palustre* L.), bog bilberry (*Vaccinium uliginosum* L.), andromeda (*Andromeda* L.), cranberry (*Vaccinium oxycoccus* (Hill) A. Gray), sedge grass (*Carex* sp.). The moss stratum is represented by *Sphagnaceae.*
Koksharovsky-Kombayevsky peatland, birch forest								

Birch forest with herb stratum	65	5,8	110±27	0,2	–	1,5	4,1	Galium sp. predominant (*Galium* L., i.e, *Galium mollugo, G. palustre, G. Boreale), Rubus idaeus, Calamagrostis epigeios*. There are *Cīrsium setōsum, Filipendula vulgaris*, stinging nettle (*Urtica dioica* L.), woodland geranium (*Geranium sylvaticum* L.).
Koksharovsko-Kombayevsky peatland, submerged cutaway site								
Marsh and pond vegetation	72	4,6	187±11	1,2	–	2,2	1,2	Broadleaved cattail (*Typha latifolia* L.), common reed grass (*Phragmites communis* L.), wood bulrush (*Scirpus sylvaticus* L.), water plantain (*Alisma plantago-aquatica* L.), hard thistle (*Cirsium arvense* (L.) Scop.), forest anthriscus (*Anthriscus sylvestris* (L.) Hoffm.), rattleweed (*Rhinanthus alectorolophus* (Scop.) Pollich), floating manna grass (*Glyceria fluitans* (L.) R. Br).*Poa sp., Carex sp., Galium mollugo, Rubus idaeus, Geranium sylvaticum,* blister buttercup (*Ranunculus sceleratus* L.).

Table 2 The structure of phytomass and its summarized parameters per SP and per botanical group, where BGC — biogeocenosis; Phm — phytomass, g/m^2; Phm raw — raw phytomass before drying, g/m^2; Phm abvgr — aboveground phytomass, g/m^2; Phm green — green phytomass of shrubs, g/m^2; Dry matter yield — the dry to raw phytomass ratio.

BGC	Phm raw	Phmabvgr	Phm green	Dry matter yield	Phm green	Phmabvgr		
					Subshrubs	Tree seedlings	Sedges, grasses	Forbs
Basyanovsky peatland								
Birch forest with shrub-herb stratum	756,5 ± 25,9	380,7 ± 14,4	106,5 ± 20	0,50 ± 0,04	106,5 ± 20	1,42 ± 0,05	125,3 ± 29,3	110,6 ± 21,5
Koksharovsko-Kombayevsky peatland, birch forest								
Birch forest with herb stratum	1343,4 ± 205,6	556,7 ± 81,2	–	0,43 ± 0,06	–	2,6 ± 1,1	247,6 ± 63,1	306,52 ± 42,9
Koksharovsko-Kombayevsky peatland, submerged cutaway site								
Marsh and pond vegetation	–	1281,6 ± 78,9	–	–	–	256,38 ± 44,9	852,3 ± 106,9	72,1 ± 17,3

Peat samples were taken at each of the study plots. At the Basyanovsky and Koksharovsky peatlands, the peat is moderately and highly decomposed. At the submerged cutaway site, determining the degree of peat decomposition was difficult due to the mixing of soil horizons. To reconstruct the history of forest phytocoenosis at the given SP, a botanical analysis of the composition of peat was performed (see Table 3 for the results). The analysis showed that the Basyanovsky peatland is of a mixed fen/raised bog type passing through the raised bog successional stage or a sphagnum to hypnum-sedge successional stage. The raised bog evolved into a fen in the last wood-cottongrass successional stage, having passed through the sedge-sphagnum and wood-sedge successional stages during this wetland formation. Preliminary assessment of the age of peat under these conditions indicates that the thickness of 12–15 cm corresponds to 30–50 years [of peat accumulation], the predominance of the woody plants is probably related to drainage and the birth stand growth. The Koksharovsky peatland belongs to a mesotrophic type of habitat and is developed from a meso-eutrophic fen.

Table 3 Botanical analysis of the peat composition in the studied peatlands**.**

Basyanovsky peatland	
A sample taken at the border with sphagnum areas	0–3 cm: plant litter; 3–9 cm: decomposed woody peat with *Betula* sp., *Pinus sylvestris* plant material; 9–12 cm: wood/cottongrass peat with *Betula* sp., *Salix* sp., *Eriophorum vaginatum*; 12–15 cm: wood/sedge peat with *Betula* sp., *Carex cespitosa*, *C. lasiocarpa*; 15–21 cm: sedge/sphagnum peat with Cyperaceae: *Carex limosa*, *C. lasiocarpa*, etc. Sphagnum mosses: Sphagnum balticum, Sph. magellanicum; 21–25 cm: sphagnum peat: Sphagnum balticum, Sph. magellanicum; 25–34 cm: cottongrass/sphagnum peat Sphagnum balticum, Sph. magellanicum, *Eriophorum vaginatum*.
A sample taken on a typical relief	0–3 cm: wood/hypnum peat with *Betula* sp., *Salix* sp., *Alnus incana*, *Polytrichum strictum*, *Drepanocladus flavum*; 3–11 cm: wood/sedge peat with *Carex limosa*, *C. caespitosa*, *C. lasiocarpa* и др., *Drepanocladus flavum*, *Polytrichum strictum*; 12–16 cm: hypnum/sedge peat with *Carex limosa*, *C. caespitosa*, *C. lasiocarpa*, etc., *Drepanocladus flavum*, *Polytrichum strictum*; 17–27 cm: sedge/shavegrass/hypnum moss peat with Carex limosa, *C. caespitosa*, *C. lasiocarpa*, etc., *Equsetum palustre*, *Drepanocladus flavum*, *Cratoneuron* sp.
Koksharovsko-Kombayevsky peatland, birch forest with herb stratum	
0–3 cm: plant litter;	

3–10 cm: sedge/hypnum peat with *Carex limosa*, *C. caespitosa*, *C. lasiocarpa*, etc.. Green mosses *Drepanocladus flavum*, *Polytrichum strictum*;
10–15 cm: wood/cottongrass/subshrub peat with *Betula* sp., *Pinus sylvestris* L., *Eriophorum vaginatum, Ledum palustre*, *Chamaedaphne calyculata*, *Eriophorum vaginatum*;
16–19 cm: hypnum/green mosses peat with *Drepanocladus flavum*, *Polytrichum strictum*, *Campylium stellatum*;
19–25 cm: sedge/hypnumpeat with *Carex limosa*, *C. caespitosa*, *C. lasiocarpa*, etc. Green mosses *Drepanocladus flavum*, *Polytrichum strictum.*

Based on the allometric equation for the forests of the Ural region with the tree phytomass as a variable dependent on the trunk diameter, the phytomass of the tree stands on the SPs was determined. To evaluate the phytomass of the roots, we used a parameter relatively reflecting phytomass allocation by plants: root shoot ratio, which was equal to 0.25 ± 0.07 (Usoltsev et al., 2022). The total phytomass value (Pt) is the sum of the Pa and Pr values and is shown in Table 4.

Table 4 Results of calculation of forest taxation indicators and total phytomass of birch stands, where A — age of the stand, years; N — number of trees per hectare; D — average diameter of the stand, cm; H — average height of the stand, m; M — unbarked trunk wood, m3/ha; Ps, Pb, Pf, Pa, Pr and Pt — unbarked wood, branches, foliage, aboveground, root and total phytomass, respectively, t/ ha.

Composition of tree stand	A, years	N, pcs/ha	D, cm	H, m	M, m^3/ha	Ps, t/ha	Pb, t/ha	Pf, t/ha	Pa, t/ha	Pr, t/ha	Pt, т/га
Basyanovsky peatland. Birch forest with shrub-herb stratum											
9B1P	38	1550	13,6	13,7	152,0	91,2	11,6	1,8	101,1	25,3	126,3
Koksharovsko-Kombayevsky peatland. Birch forest with herb stratum											
10B	22	1767	14,1	11,5	195,4	130,4	15,4	2,1	142,1	35,5	177,6

To calculate the amount of carbon stored in the Basyanovsky and Koksharovsky peatlands based on the phytomass values of the forest stands, a coefficient of 0.50 was used (Matthews, 1993). The amount of carbon stored in the forest stands on the study plots at the Basyanovsky and Koksharovsky peatlands was 63.2 and 88.8 t/ha, respectively.

Based on the average values of 23 plant species selected from 10 samples taken to determine the botanical composition from two deposits, a PCA diagram was constructed, the first two axes of which account for 81.83% and 18.17% of the total dispersion, respectively (Fig. 2).

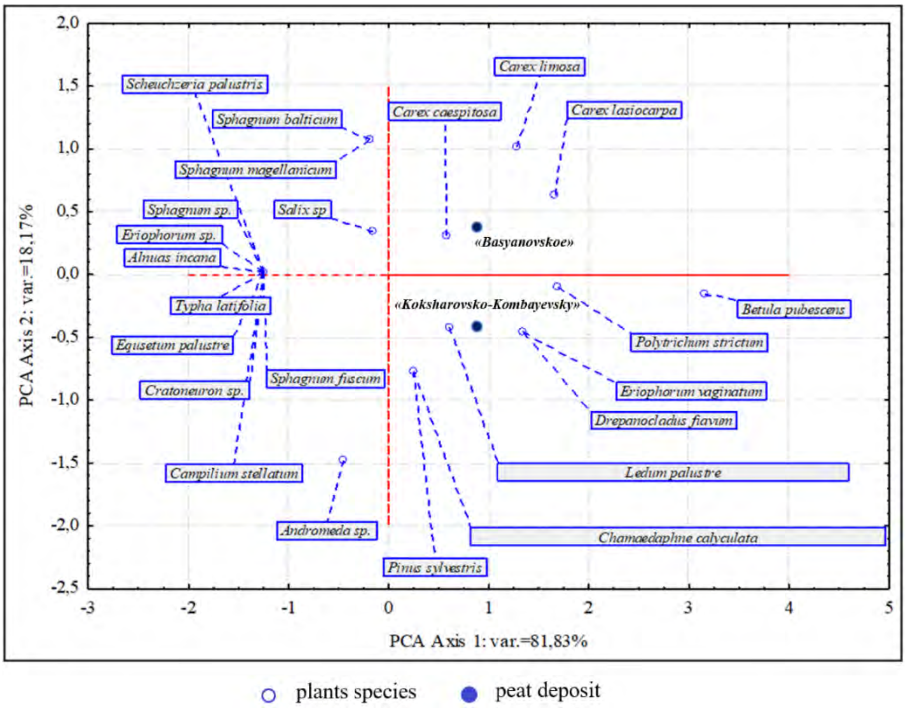

Fig. 2 PCA diagram showing the distribution of species identified in the framework of the botanical analysis of peat at two peat deposits.

For the studied deposits, a high index of species similarity of the botanical composition of peat deposits was obtained, which amounted to 0.64%. These deposits are located close to each other.

Drepanocladus flavum, *Eriophorum vaginatum*, *Polytrichum strictum*, *Ledum palustre*, *Betula pubescens*, and *Chamaedaphne calyculata* are species that are equally common in both deposits.

The Basyanovskoe peat deposits are characterized by: *Sphagnum balticum*, *Sphagnum fuscum*, *Sphagnum magellanicum*, *Typha latifolia*, and *Campilium stellatum*.

The Koksharovsky-Kombayevsky peat deposits are characterized by: *Andromeda* sp., and *Pinus sylvestris*. The remaining species intersect with the Basyanovskoe peat deposit.

4 Discussion

Sampling and the results of the study of the botanical composition of peat samples made it possible to reconstruct the dynamics of the succession pattern of the regional forest vegetation and to classify the current state of the Basyanovsky peatland as an oligo-mesotrophic habitat with a mesotrophic plant community. The Koksharovsky peatland is also a mesotrophic habitat with a plant community of higher productivity compared with that of the Basyanovsky peatland. Of particular interest is the secondary rewetted cutaway site within this fen. This abandoned peat harvesting site is a suitable model object for studying gas emissions in comparison with undeveloped peatlands and, especially, with those where peat harvesting is active.

The peatlands presented in this study are not currently being harvested. Further studies of greenhouse gas emissions from the surface of peatlands, the assessment of photosynthetic activity, and plant and soil respiration will require large-scale fieldwork. Compared to the Basyanovsky peatland, the amount of carbon stored in the forest stands of the Koksharovsky peatland is 29% higher, making it more promising for further research and development of carbon farming.

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