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RESEARCH ARTICLE

Drainage and pyrogenic influence alter the physicochemical properties and carbon storage of oligotrophic peatlands in Western Siberia

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Abstract
The study assesses the impact of drainage and pyrogenic exposure on the physical and chemical composition and properties of oligotrophic peat soils in the southern taiga of Western Siberia. These factors have been found to induce significant changes in phytocoenoses, resulting in soil degradation. Changes include alterations in vegetation cover, fluctuations in water table level, a decrease in acidity, increased peat ash content, total nitrogen content, and a reduction in the C/N ratio. Drainage and fires also lead to a change in the carbon sequestration potential of peatlands. In anthropogenically modified peatlands, carbon stocks in the 0 to 100 cm layer were 2.5 to 2.8 times higher than in undisturbed sites due to increased bulk density. These structural modifications in peat deposits indicate significant changes in their ecological function, particularly through altered carbon sequestration capacity, which may adversely affect regional carbon balance.

Keywords
Western Siberia, bog ecosystems, carbon stock, histosols, nitrogen stock, wildfire, carbon-nitrogen ratio

Introduction

Bog ecosystems play a critical role in biogeochemical cycling due to their ability to sequester carbon in peat deposits (Tyuremnov 1976; Zavarzin 1994; Inisheva et al. 2016). Organic matter in bog ecosystems accumulates in peat, which makes up a significant part of the global carbon stock. These reserves are estimated to contain 120–455 gigatons (Gt) of carbon (Gorham 1991; Vompersky 1994; Kudeyarov et al. 2007), with approximately 70 Gt stored specifically in Western Siberian peatlands (Sheng et al. 2004). Western Siberia is a unique region that leads the world in the rate of waterlogging (Kremenetski et al. 2003; Babeshina and Dmitruk 2009; Evseeva 2012). The wetlands area of Western Siberia is 32.5 million hectares, and currently the region continues to be waterlogged, especially in the subzones of the southern and middle taiga, where the vertical growth rate of peat is 0.39-2.62 mm/year, and the area growth rate is about 100 km^2/year (Neustadt 1977; Pologova, Lapshina 2002). According to research by Vompersky et al. (2024), the main contribution to the country's carbon reserves is made by bogs – 39% of the total carbon reserve of peat in the wetlands of the Russian Federation.

Due to low temperature, over moistening, and anoxia conditions, the decomposition of plant residues in bog ecosystems is slow. Therefore, carbon accumulated as a result of the photosynthetic activity of bog vegetation has been excluded from the biogeochemical cycling for a long time, being fixed in peat deposits. The peat formation process is influenced by many factors, such as hydrothermal conditions, topography, and vegetation (Courtwright 2011; Kirpotin 2021). Lowering the water table level (WTL) enhances aeration in the upper peat layers, resulting in significant ecological impacts including: peat consolidation, shifts in dominant vegetation species, suppression of *Sphagnum* mosses, increased stand height, and greater diversity of vascular plants (Maanavilja et al. 2014; Khaustova et al. 2018). Vegetation change, especially when induced by drainage and fires, directly redacts the balance between production and decomposition processes in peatlands, potentially impacting contemporary peat formation (D'Angelo 2021; Zalesov 2021). Therefore, even slight variations in the chemical composition can alter the activity of the decomposer microorganism and consequently the rate of plant residue decomposition (Moore, Basiliko, 2006; Nikitkin et al. 2023).

Land reclamation in wetlands for agricultural development and afforestation has been accompanied by drainage activities. In Europe, approximately 125,000 km^2 of peat soils are utilized for agricultural production (Page et al. 2016). In Fennoscandia, up to 35% of the 20 million hectares of peatlands have been drained since the early 20th century with the aim of increasing timber production (Tong et al. 2024). Extensive drainage activities were also conducted in the United Kingdom, Malaysia, and Indonesia (Couwenberg 2013). The consequences of such anthropogenic interventions are still evident today. Currently, significant areas of peatlands have been lost or greatly reduced due to drainage, leading to lowering of the height of the peatland surface (i.e., subsidence) and peat oxidation rates of 1–2 cm in temperate climates and 3–5 cm in tropical climates (Page et al. 1997). Peatland drainage frequently leads to wildfires (Sirin, Medvedeva 2022; Sinyutkina 2024). Drained peatlands exhibit increased fire risk: they ignite more readily and facilitate the spread of fire into deeper peat layers (Sirin et al. 2019). Largescale peat fires are documented across multiple global regions, including the United States, Canada, and Southeast Asia (Tarnocai et al. 2009; Page et al. 2016;Tong et al. 2024). These fires not only release substantial amounts of greenhouse gases into the atmosphere but also significantly impair the ecological function of peatlands as longterm carbon reservoirs. Studies (Ponomarev 2017; Jones 2020) indicate that fires have become increasingly prevalent in Western Siberia in recent decades too, damaging both forest and mire ecosystems. Therefore, this study aimed to assess changes in the quality of oligotrophic peat soils in the southern taiga subzone of Western Siberia resulting from drainage-induced and post-pyrogenic successions.

Materials and methods

Field and laboratory study

The study includes field and laboratory measurements. In 2019 at each research site, permanent 25 × 25-meter sample plots have been established to enable long-term monitoring of changes induced by anthropogenic impacts. Peat samples were collected using a peat corer "TGB-1" underneath with 10 cm intervals down to the underlying mineral horizon. In order to control for microtopographic effects, peat core sampling was conducted at representative locations across each experimental plot. In the laboratory, some physicochemical parameters were determined in peat samples using established methods: peat bulk density (Kaczynski 1965), pH, total nitrogen, carbon, and ash content. In previously dried, milled, and homogenized peat, the actual acidity of the samples by the potentiometric method using a pH meter (Metler Toledo, Switzerland) in a water extract (soil-to-water ratio = 1:25) (Vorobyeva 2006). The ashing was performed by heating at 550 °C overnight. (Bazin 1992). The total carbon and nitrogen content was quantified using high-temperature combustion with a CNSH-O EMA 502 elemental analyzer (VELP Scientifica, Italy). Carbon and nitrogen stocks were obtained by calculation using the formula (Vasenev et al. 2013; Leonova 2023):

$$S= X \times H \times d \times 0.1, \quad \textbf{(1)}$$

were S – carbon or nitrogen stock, kg C/ m^2 or kg N/ m^2; X – content of carbon or nitrogen, %; H – depth of peat, cm; d – peat bulk density, g/cm^3, 0.1 – conversion factor.

The carbon and nitrogen stocks were calculated in each 10 cm layer, then the values for the entire peat deposit of the studied phytocenoses were summed up. Since the depth of the peat deposit of the natural peat significantly exceeds the capacity of the anthropogenic transformed sites, the text of the article provides a comparison of the peat layer up to 1 m.

All measurements were made in three replicate. Basic statistical parameters (mean, mean error, Spearman correlation coefficient, Shapiro-Wilk test, Kruskal-Wallis test) were calculated using the MS Office Escel 2007 and StatSoft Statistica 12.0 software package. All statistical analyzes were performed at the significance level α=0.05.

Brief characteristics of the study areas

The measurement site is located in the south of Western Siberia (field station "Vasyuganye" (IMCES SB RAS) (Russia)). The study was carried out anthropogenically transformed and at different stages of the natural succession phytocenoses of the Bakcharskoe bog (Natural pine-shrub-sphagnum phytocenosis 56°52'31.7"N; 82°48'27.3"E (Natural), pine-shrub-sphagnum phytocenosis located near the drainage canal 56°53'33.3"N; 82°51'08.0"E (Drained)) and the Iksinskoe bog (pine-shrub-sphagnum phytocenosis with a well-defined undergrowth 56°51'42.1"N; 83°17'53.0"E (Restored) and pine-birch-sedge-sphagnum phytocenosis with a less pronounced degree of pyrogenic succession 56°52'03.4"N; 83°11'52.1"E (Burned)) (Fig. 1.). The bog belongs to the Bakcharsky and Shegarsky districts of the Tomsk Region and are the northeastern spurs of the Great Vasyugan mire, which lies on a thick layer of dense waterproof clay carbonate sediments (Evseeva 2012).

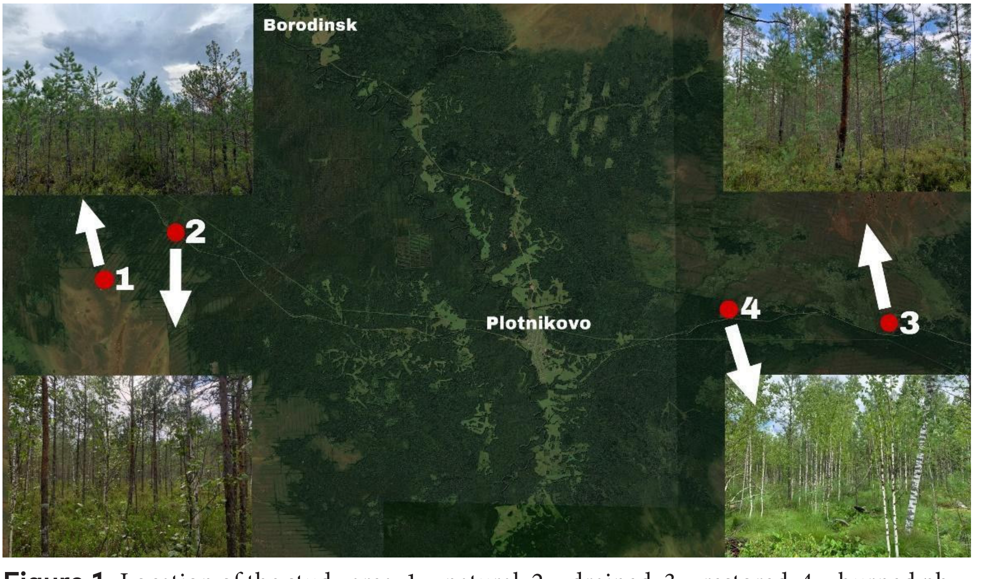

Figure 1. Location of the study area: 1 – natural; 2 – drained; 3 – restored; 4 – burned phytocenosis (Map data 2025 (C) Google).

The study area is located in the southern taiga subzone of Western Siberia and is characterized by a continental climate. The mean annual temperature is 0.50°C, with an annual precipitation of 497 mm for the years 1991-2020. Average air temperatures for January and July are -18.8°C and 18.2°C, respectively (RIHMI-WDC). Both peatlands are located on a watershed plateau: The Bakcharskoe bog lies within the interfluve of the Iksa and Bakchar rivers, while the Iksinskoe bog is situated between the Iksa and Shegarka rivers. The territory of the region is characterized by a high degree of swampiness, which has necessitated the implementation of drainage reclamation for its development. Since the 1970s, an improved canal network has been operating in these bogs, as a result of which cardinal changes in the natural environment occurred in the bogs, in particular, the drainage of significant bog areas, which caused massive forest and peat fires (Bazanov et al. 2002). Due to these impacts, the study sites have several unique characteristics that can have a significant impact on the peat formation process (Table 1).

Bakcharskoe bog is represented by both natural and anthropogenic-transformed phytocenoses. In 1975, a network of drainage channels was established on the territory of this bog. Natural phytocenosis is located outside the drain channel, traces of drainage appear in the form of drying of slight zones located sufficiently away from the point of study. Therefore, this site can be considered undisturbed. According to the morphological characteristic, the peat deposit belongs to typical oligotrophic peat soils. The depth of the peat deposit is reached on an average of 311±12 cm (mean ± error of mean), the upper layer of 10 cm has a low degree of decomposition – less than 5%. Natural phytocenosis, in terms of its main phytocenotic and hydrological characteristics, corresponds to the typical pine-shrub-sphagnum phytocenosis (ryam) of oligotrophic bogs in Western Siberia (Liss 2001). The water table level (WTL) determines the aeration of peat deposits and directly affects the conditions of peat formation. Under the conditions of a natural ryam, the average WTL during the growing season is -32±8 cm. Microtopography is represented by many moss hummock about 20 cm high and up to 2 m in diameter. The tree tier is formed by the swamp form of *Pinus sylvestris* f. *Litwinowii*, the average height of the trees is 1.7±0.1 meters (the projective cover is about 70%), the shrub level is well developed and consists mainly of *Chamaedaphne calyculata* Moench, *Vaccinium uliginosum*, less often *Ledum palustre* L., *Oxycoccus microcarpus*, among the mosses *Sphagnum fuscum* Klinggr is the absolute dominant, *Sphagnum divinum* Flatberg K. Hassel, and *Sphagnum angustifolium* C. Jens are found in the hollow between the hummocks, the herbs are singular, mainly such as *Eriophorum vaginatum*, *Rubus chamaemorus*, and *Drosera rotundifolia* L.

The drain ryam is located near to the drainage channel, determining a low WTL of the -51±7 cm, the depth of peat deposit is 97±12 cm, and represents a typical peat oligotrophic typical soil. In general, the vegetation cover is analogous to the natural ryam, but there are characteristic signs of drainage (Dashkevich and Smolyak 1993; Bragazza 2008): a more developed tree layer, mainly represented by *Pinus sylvestris* L. with an average height of 3.9±0.2 m, *Betula pubescens* Ehrh. is also rarely found, *Ledum palustre* L is the dominant species among shrubs, *Chamaedaphne calyculata* Moench is less common, sphagnum mosses are depress, representatives of bryidae mosses are often found.

Table 1. Characteristics of the phytocenoses of the Bakcharskoe and Iksinskoe bogs

Bog	Phytocenosis	Depth of peat deposit, cm	WTL, cm	Plant matter reserves, g/m²*	Stand height, m
Bakcharskoe	Nature	311±12	-32±8	3519±95	1.7±0.05
	Drained	97 ± 12	-51 ± 7	6327±129	3.9±0.15
Iksinskoe	Restored	105±3	-29±5	5151±109	3.2±0.19
	Burned	94±9	-26± 4	2097±75	3.7±0.21

Note. * - Includes moss litter up to 20 cm, but excludes the tree tier.

In the late 1990s, massive peat and forest fires were observed in the southern regions of the Tomsk Oblast. The causes of such large-scale fires were that drained bogs were abandoned and not used for forestry, industrial peat production, etc. (Evseeva et al., 2012). In 1998, a large part of the territory burned out in the drained area of the Iksinskoe bog. The vegetation cover from the near-surface peat layer in the bogs was completely destroyed (Bazanov et al. 2002). In early studies, before the fire, the area of the Iksinkoe bog that we selected for the study was referred to as raised bog (Kudryavtsev 1969; Khramov et al. 1977; Trifonova et al. 2010). Both phytocenoses located in the Iksinkoe bog are at different degrees of pyrogenic succession; unlike the phytocenoses of the Bakcharskoe bog, they are more watered and are represented by oligotrophic pyrogenic soils. The restored phytocenosis of the Iksinkoe bog is represented by a relatively well-naturally restored ryam, with an average WTL of -29±5, and a depth of peat deposit of 105±3 cm. The main tree layer consists of substorey and mid-sized *Pinus sylvestris*, with an average height of 3.2±0.2 m, and tall trees are singular. The shrub tier is abundant and is represented, for the most part, by *Ledum palustre*, less often by *Chamaedaphne calyculata*. The herb layer is less pronounced, represented mainly by *Carex rostrata* L. and some *Eriophorum vaginatum* L. The moss cover is dominated by *Sphagnum fuscum* Klinggr.

Burned phytocenosis is characterized by a slightly different phytocenotic composition, it is a pine-birch-sedge-sphagnum phytocenosis. The tree layer is very sparse and is formed mainly by *Betula pubescens* Ehrh., however, there are some rarely standing *Pinus sylvestris* L, the average height of the stand is 3.7± 0.2 meters. Shrubs are rare. A well-defined herb layer formed by numerous *Carex rostrata* and *Eriophorum vaginatum*. The moss layer is represented by a variety of sphagnum mosses; occasionally there are bryidae mosses. The depth of the peat deposit reaches 94±9 cm, WTL = -26± 4. Apparently, this site was more susceptible to fire than the above-described Restored, since there are traces of fire everywhere on the territory of the studied site: fallen trees, and burned bark of the surviving trees. Furthermore, according to an earlier assessment of plant matter reserves (Nikonova et al. 2023), low mortmass reserves (3 times less than in the phytocenoses studied), probably due to significant burning of the peat deposits.

Results and discussion

Oligotrophic peat deposits exhibit a relatively low ash content, a highly acidic pH, and significant carbon stocks (Lishtvan 1983; Loisel et al. 2014; Misnikov 2015; Titlyanova 2023). Drainage and pyrogenic effect can influence the properties of peat deposits, disrupting the ecological integrity of bog ecosystems, including their role as primary carbon pools (Inisheva 2006; Vompersky et al. 2007; Tynovets 2011; Sinyutkina 2020, 2024).

Data obtained in this study indicate that the ash content in oligotrophic peat soils under natural conditions averages 1.6%. These values are consistent with those obtained in other studies, for instance, the ash content in the peat soils of the central part of Western Siberia is 1.5 to 3.5% (Arkhipov, Maslov 1998; Moskvichenko et al. 2021) and 1.1 to 2% in the southern taiga (Golovatskaya, Nikonova 2013; Preiss et al. 2024). A global meta-analysis confirms that the average ash content of oligotrophic peat is about 2% (Loisel et al. 2014). Drainage increases the ash content to 6.5%, which is consistent with the data in the literature. According to A. Sinyutkina (2020), the ash content reaches 4.1% in drained oligotrophic peat soils in Western Siberia, and 8–10% in the European part of Russia (Akhmeteva et al. 2019). The increase in ash content is probably due to elements released as a result of the decomposition of organic matter after drainage, as well as the influx of minerals with groundwater (Chernik et al, 2005, Veretennikova et al, 2021). Peat fires contribute to an increase in the ash content (5.2% in the restored ryam and 10.5% in the Burnt). These data are consistent with those obtained in the studies by Vompersky et al. (2007) and Sinyutkina et al. (2024), which report an ash content of 6.5 to 14.8%. The changes in the water-air balance of the pyrogenic peat soil result in peat consolidation, which subsequently increases the rate of transformation of organic matter. The conversion of organic matter to fire-induced combustion products also increases the ash content. The results show that the minimum ash content is recorded in natural ryam soils (0.3% at a depth of 10–20 cm), and it increases in drained ryam (up to 10.1% at a depth of 20–30 cm) and in burned (up to 11.1% at a depth of 70–80 cm) (Fig. 2). Interestingly, drainage and the pyrogenic effect induce a marked increase in the ash content at a depth of 20–30 cm compared to the upper layers. Additionally, in the natural ryam area, the upper 100-cm soil layer dominated by sphagnum exhibits the minimum ash content (0.3–3.7%), which gradually increases with depth, reaching 32.8% at the interface with the mineral horizon (290–300 cm).

A high correlation was observed between the ash content and the acidity of the peat soils ($r = 0.72$, $p < 0.05$). The analysis showed that all of the soils studied are generally characterized by an acidic pH, with a shift to neutral pH values with depth. In natural ryam, the soil is strongly acidic with an average pH of 3.5, which is typical of oligotrophic soils where humification and organic acid accumulation processes predominate (Loisel et al. 2014). Drainage and fires lead to alkalization: the average pH is 4.1 in drained soils and 4.3 in pyrogenic soils. Acidity decreases likely due to accumulation of ash elements and changes in the hydrological regime, which facilitate organic acid neutralization by mineral components (Holden et al. 2004). In turn, an increase in ash content in the upper layer of peat, leading to an increase in pH, can inhibit the growth of sphagnum mosses (Marcotte et al. 2022, Sinyutkina 2024).

Decomposition and density significantly affect the carbon storage capacity. The peat soil in the natural ryam area is the loosest and least decomposed, with a density of the upper one-meter layer ranging from 34 to 53 kg/m³. The data obtained indicate an increase in peat density in post-fire and drained phytocoenoses in the order Natural ryam – Restored ryam – Burnt – Drained ryam. The consolidation with depth is observed in all disturbed phytocoenoses (Fig. 2). Typically, the pyrogenic effect and drainage trigger peat compaction due to the subsidence of cushion mosses (Velikanov 2015; Sinyutkina 2024).

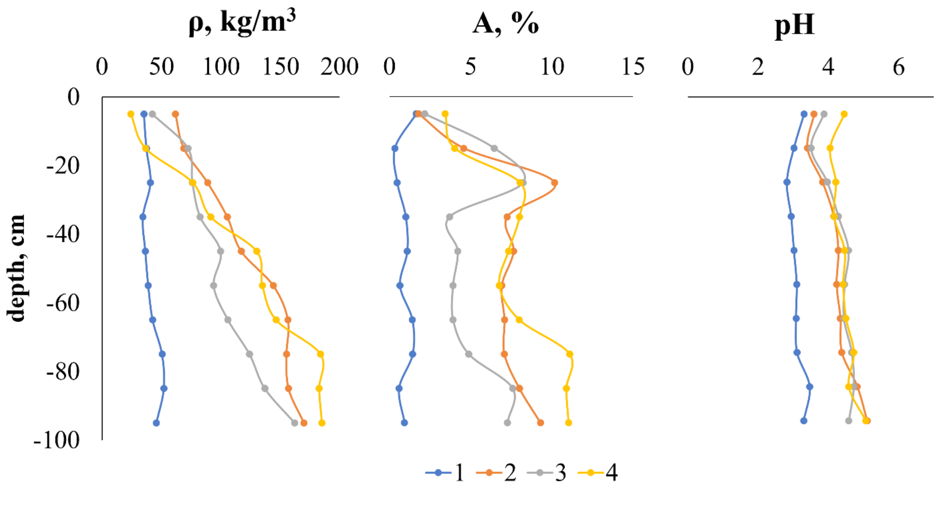

Figure 2. Density, ash content and pH (H_2O) of peat soils in the natural (1), drained (2), restored (3) and burned (4) areas of Bakcharskoe and Iksinkoe bogs.

The peat soils in natural ryam exhibit a high content of total organic carbon, averaging 47.8%, which indicates the dominance of organic matter over the mineral component. In the 290–300 cm layer, it decreases due to partial mineralization of organic matter at the interface with the bottom (mineral) horizon. The typical oligotrophic peat soils of drained ryam also shows a high carbon content, ranging from 46.8 to 53.9%. In the bottom horizon (70 to 100 cm), the carbon content decreases (by 24%) in a pattern similar to that observed for the area of Natyral ryam. In pyrogenic peat, the carbon content remains high (49.1%), which can be attributed to the formation of stable carbon compounds during combustion. The distribution of carbon content values down the soil profile is uniform (Fig. 3): restored – C=47.6–53.7%; burnt – C=43.5–52.7%.

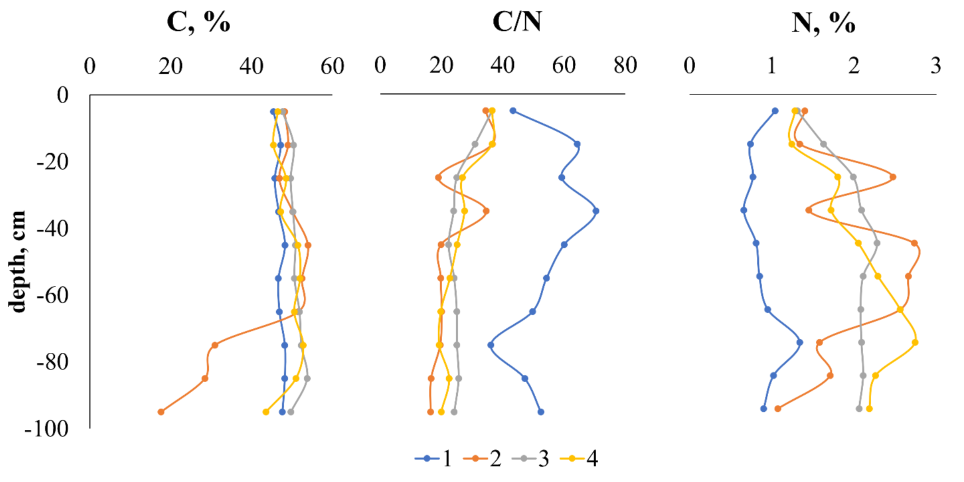

Figure 3. Distribution of total carbon, nitrogen, C/N ratio along the peat profile in the natural (1), drained (2), restored (3) and burned (4) areas of Bakcharskoe and Iksinkoe bogs.

The C/N ratio is a key indicator to assess soil biochemical activity. High C/N ratios (more than 30) indicate that microbial nitrogen sequestering is predominant in soil, significantly slowing mineralization and creating a deficiency of nitrogen available to plants (Bazilevich and Titlyanova 2008). In the natural ryam, this ratio averages 49.6±8.2, indicating slow mineralization of organic matter. In drained and pyrogenic soils, the C/N ratio decreases to 25.7±4.9 and 25.2±3.6, respectively, indicating accelerated decomposition of organic matter. In oligotrophic peat soils, upper layers generally tend to exhibit higher C/N values. A decrease in this ratio indicates higher rates of organic matter decomposition and carbon loss. However, variation in this indicator may be associated not only with carbon loss, but also with an increase in the nitrogen concentration per unit volume of peat due to nitrogen retention by microorganisms (Holden et al. 2004; Bazilevich 2008).

Nitrogen in natural ryam oligotrophic peat soils is found in small quantities, averaging 1.1%. In drained and pyrogenic soils, the nitrogen content increases to 1.8% and 1.9%, respectively, likely due to changes in biochemical processes and the accumulation of mineral nitrogen. Increased nitrogen content under postpirogenic conditions is also found in the literature, (Batjes 2002; Arisanty 2020). This is probably due to the massive influx of plant residues into peat after wildfires, the accumulation of hard to access forms of nitrogen over time, and changes in microbial communities of the nitrogen cycle (Gerasikina et al., 2021). It is also possible that substances are redistributed throughout the peat deposit, associated with an increase in the density and degree of peat decomposition and changes in plant diversity (Gashkova 2022). The total nitrogen content in soil profiles is predominantly polymodal, which can be attributed to the heterogeneous nature of peat accumulation during peat deposit formation. The total nitrogen content varies from 0.7 to 2.9% in the natural ryam, from 1.3 to 2.7% in the dried ryam, from 1.3 to 2.1% in the restored ryam, and from 1.2 to 2.7% in the burned bog area (Fig. 3). In studies by Szajdak et al. (2020) of undisturbed and drained wetlands in Poland, higher values were recorded than in our study, but the overall trend remained similar: drainage leads to a decrease in C/N (in its natural state, the average C/N value was 55.4, while in drained conditions it was 18.05) and an increase in total nitrogen content (2.5 times).

The nitrogen cycle is closely related to the carbon cycle. Data on the amount of carbon and nitrogen stored in the peat deposit (in the upper one-meter layer) and the bulk density were used to calculate the carbon and nitrogen stocks for all studied peat soils (Fig. 4). The total carbon stock is a crucial indicator to assess the status of an ecosystem that serves as a carbon pool and a potential source of greenhouse gas emissions (Zalesov 2021). The burned bog area exhibits the highest carbon stocks in the 0 to 100 cm layer (57.9 kg C / m^2), while the Natural ryam shows the lowest values (20.6 kg C/m^2). The dried and restored ryams occupy an intermediate position, with similar values of carbon stocks: 51.0 and 50.5 kg C/m^2, respectively. But the higher carbon stocks in these transformed peatlands mainly becouse of increase in carbon concentration due to changes in the structure and condition of the remaining peat deposit. While, the total carbon stock in the natural ryam peat soils is 250.0 kg C/m^2, indicating that the one-meter layer of the bog area contains only 8% of the total amount of carbon stock. The values obtained are consistent with literature data on carbon stocks in peat deposits, which demonstrate variation in peat soils from 36 to 81 kg/m^2 (upper layer 0 to 100 cm) (Boch et al. 1994; Vompersky et al. 1994; Efremov et al. 1994; Stolbovoi 2002; Chestnykh et al. 2004; Golovatskaya et al. 2022).

Assessment of nitrogen stocks in peat deposits shows a significant increase in total reserves in anthropogenic transformed peat bogs, by an average of 5.8 times. The restored peat deposit demonstrates slightly lower nitrogen reserves compared to the drained and Burnt bog areas, amounting to 2.0±0.1 kg N/m^2. In natural ryam with a loose upper layer of peat, the same trend is observed as with carbon stocks: only 3.6% of total nitrogen stocks throughout the deposit are concentrated in the layer 0–100 cm layer.

During the study, a comprehensive set of statistical analyses was conducted. This approach not only allowed for a quantitative characterization of differences in the distribution of key indicators across the study sites, but also enabled the identification of relationships between the variables under investigation. At the initial stage, the normality of data distribution within each phytocenosis was verified using the Shapiro-Wilk test (for samples <50). The results indicated that most physicochemical characteristics followed a normal distribution. However, some data sets exhibited non-normal distribution or a tendency to deviate from normality. Therefore, subsequent comparative analyses were performed using non-parametric methods that do not assume data normality. Due to the limited sample sizes and the presence of nonnormal distribution in some datasets, the nonparametric KruskalWallis test was used to assess differences, as it is more robust to violations of normality and homogeneity of variances. In cases where statistically significant differences were detected, a Dunn's post-hoc test with Benjamini-Hochberg (False Discovery Rate, FDR) correction was applied for pairwise comparisons. This procedure controlled for the proportion of false-positive findings.

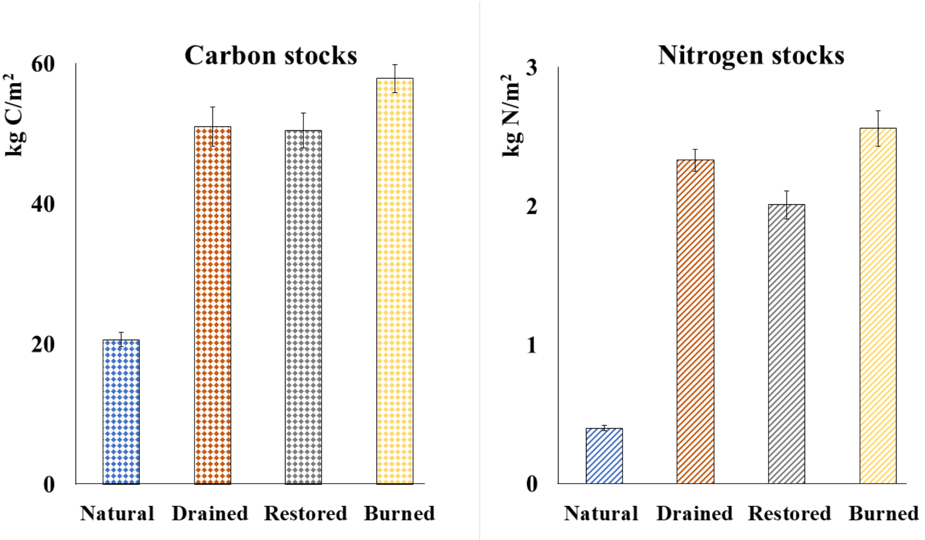

Figure 4. Carbon and nitrogen stocks in the 0–100 cm layer of peat deposits of the natural, drained, restored, and burned areas of Bakcharskoe and Iksinkoe bogs..

The Kruskal-Wallis test revealed statistically significant differences ($p < 0.05$) in multiple parameters across different site (Table 2). Among the assessed indicators, ash content, pH, and the C/N ratio emerged as the most sensitive to changes in condition, exhibiting significant variations in numerous comparisons. Furthermore, the post-hoc analysis revealed notable differences between natural and transformed conditions, while drained and burnt areas exhibit greater similarities in their parameters.

The Spearman's rank, which indicates the relationships among parameters, revealed a positive correlation between density and pH in the drained and pyrogenic peatlands (ranging from 0.84 to 0.96, $p < 0.05$). Furthermore, in the burnt, density was found to significantly influence other parameters, including nitrogen content ($r = 0.81$), C/N ratio ($r = -0.92$), and ash content ($r = 0.78$).

Table 2. Results of the Kruskal–Wallis χ2 test ((p) – the probability level is given in parentheses) with the post-hoc Dunn's test adjusted by the Benjamini–Hochberg (FDR) correction (statistically significant differences at $p < 0.05$ are highlighted in bold)

	N	C	C/N ratio	Ash	pH	Density
χ^2 (p)	**20.80 (<<0.01)**	**9.15 (0.03)**	**22.59 (<<0.01)**	**24.86 (<<0.01)**	**22.76 (<<0.01)**	**16.99 (<0.01)**
Comparison classes				p.adj		
1–2	**<<0.01**	0.27	**<<0.01**	**<<0.01**	**<0.01**	**<<0.01**
1–3	**<<0.01**	**0.02**	**<<0.01**	**0.01**	**<<0.01**	**0.01**
2–3	0.86	0.23	0.30	0.34	0.63	0.58
1–4	**<<0.01**	0.18	**<<0.01**	**<<0.01**	**<<0.01**	**<<0.01**
2–4	1.00	0.62	0.40	0.54	0.45	0.73
3–4	1.00	0.30	0.76	0.14	0.70	0.73

Note. 1 – natural 2 – drained 3 – restored 4 – burned areas.

Conclusions

The study confirmed that the drainage and pyrogenic effect induce complex changes in the properties of oligotrophic peat soils in Western Siberia. The order of Natural – Drained – Burnt bog areas demonstrates a 3.6 and 5.8-fold increase in the ash content, respectively, inducing a shift in actual acidity towards alkalization (r=0.72). Drainage and pyrogenic impacts result in peat compaction, increasing the bulk density of peat deposits by an average of 2.7 times. This leads to higher concentrations of carbon and nitrogen reserves in the remaining peat layer. As a result of these changes, carbon reserves in the upper 100 cm layer exceed those in undisturbed conditions by 2.5–2.8 times, while nitrogen reserves are 5.0–6.4 times higher. These changes cause to a decrease in the C/N ratio throughout the peat profile, which is a prerequisite for intensified decomposition of organic matter.

These changes indicate the degradation of disturbed peat soils and a reduction in their ecological significance, as carbon sequestration capacity is reduced. This could have a negative impact on carbon balance in the region and global climate regulation.

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