Middle-taiga ombrotrophic bogs as a source of DOC: Seasonal variations in concentration and spectral characteristics

Evgeny A. Zarov, Leonid V. Litvinov, Viktoria S. Shanyova, Sofia E. Rakhova, Irina S. Ivanova

UNESCO chair "Environmental dynamic and global climate changes", Yugra State University, Khanty-Mansiysk, Russia

SUMMARY

Peatlands are a major source of dissolved organic carbon (DOC) for inland waters in Western Siberia. Continuous hydrological and hydrochemical monitoring of these peatlands is essential for understanding the global carbon cycle. We investigated a pristine ombrotrophic bog in Western Siberia to determine the links between seasonal hydrological changes and DOC quantity and quality. Specifically, we analysed water table fluctuations, DOC concentrations and spectral characteristics ($SUVA_{254}$, E2:E3 and E4:E6 ratios). Our findings indicate that each peatland ecosystem exhibits distinct seasonal hydrochemical changes. The driest ecosystems (ryams) feature water with the highest DOC concentrations, characterised by high aromaticity and large molecular size, whereas the wettest ecosystems (pools) display the opposite trend. Surprisingly, the stream, which collects water from the entire peatland catchment, exhibits unique properties in that its DOC concentration is similar to that of wet ecosystems, while its spectral features more closely resemble those of dry ecosystems. Therefore, peatland ecosystems act as complex biogeochemical systems, modulating both the concentration and quality of dissolved organic carbon (DOC) based on prevailing environmental conditions.

KEY WORDS: hydrology, monitoring, Mukhrino, peatland, SUVA, West Siberia

INTRODUCTION

Peatlands represent a major terrestrial carbon (C) pool and play a crucial role in the global carbon cycle, directly influencing climate (Sirin 2022). Despite covering only 3 % of the Earth's land surface, they store approximately 30 % of global soil carbon and can sequester atmospheric carbon over millennia (Yu *et al.* 2014, Xu *et al.* 2018). The role of peatlands in the carbon cycle is determined by the balance between carbon uptake via photosynthesis and carbon loss through organic matter (OM) decomposition. In pristine conditions (i.e., undisturbed by human activity), this balance favours carbon accumulation, leading to the formation of peat—a resistant, weakly decomposed material that can persist for thousands of years (Clymo *et al.* 1998). However, peat OM is subject to biodegradation and photodegradation, driven by internal and external processes (Del Vecchio & Blough 2002), resulting in the release of greenhouse gases (methane and carbon dioxide), dissolved organic matter (DOM) and particulate organic matter (POM). However, key uncertainties remain regarding the dominant degradation pathways and the ultimate fate of the mobilised carbon. These uncertainties stem from the system's inherent biogeochemical complexity and are amplified by contemporary climate warming.

DOM serves as a key transport form for carbon from terrestrial ecosystems to aquatic systems (Urban *et al.* 1989, Freeman *et al.* 2004, Roulet *et al.* 2007). During transport, DOM can be transformed into greenhouse gases, converted into particulate or sedimentary OM, or transported downstream to marine environments. The reactivity of DOM structures determines its fate—whether stored in sediments, transported farther, or released into the atmosphere—and influences its turnover time (Bianchi 2007, Minor *et al.* 2014, Hansen *et al.* 2016). The chemical characterisation of DOM can be performed through spectrophotometric analysis, employing optical parameters including the specific ultraviolet absorbance (SUVA) and spectral absorbance ratios (E2:E3 at 250/365 nm and E4:E6 at 465/665 nm). The most active and mobile part of DOM is dissolved organic carbon (DOC), consisting of components ranging from simple amino acids and sugars to complex hydrophobic, aromatic and humic substances (Wallage *et al.* 2006). The ratio of these components depends on DOC origin—whether allochthonous or autochthonous (Broder *et al.* 2016, Robroek *et al.* 2016, Blanchet *et al.* 2017, Kellerman *et al.* 2018, Coble *et al.* 2019) and determines biochemical function and paths of DOC.

Peatland catchments are characterised by high DOC concentrations in runoff (Dawson *et al.* 2001, Freeman *et al.* 2004, Worrall *et al.* 2008, Dinsmore *et al.* 2010, Burd *et al.* 2020). The distinct sources of mineral input (precipitation, groundwater or a mix) determine the vegetation composition and, consequently, the peatland type, which in turn drives variation in DOC concentration. Minerotrophic peatlands (fed by groundwater) with dominance of brown mosses and grasses typically exhibit lower DOC concentrations (~ 20 mg L^{-1}), whereas ombrotrophic peatlands (rain-fed) with dominance of S*phagnum* mosses are characterised by higher DOC concentrations (~ 45 mg L^{-1}) (Fraser *et al.* 2001, Bengtsson & Törneman 2004, Webster & McLaughlin 2010).

In peatlands, the dominance of *Sphagnum* mosses contributes to DOC rich in aromatic compounds, which inhibit microbial degradation and reduce water transparency (Børsheim *et al.* 2001). This, in turn, can limit photosynthesis and biological activity in discharging waters (Karlsson *et al.* 2009). High-molecular-weight DOC consists primarily of humic substances—humic acids (HA), fulvic acids (FA), and humin (Bolin *et al.* 1979, Leenheer & Croué 2003, Bai *et al.* 2018)—which can comprise up to 50 % of DOM (Thurman 1985). These compounds generally have the most aromatic composition (Olk *et al.* 2019) and may regulate DOC mobility: HA, with their large molecular size, reduce mobility, whereas FA enhance solubility and transport. Both reflect the degree of OM transformation (Bai *et al.* 2018). Low-molecular-weight DOC components include oligopeptides, organic acids and sugars (Leenheer & Croué 2003), as well as sphagnan (a uronic acid found in cell walls; Børsheim *et al.* 2001) and sphagnol (a phenolic compound mixture; Verhoeven & Liefveld 1997), which suppress microbial activity, further slowing decomposition (Mellegård *et al.* 2009, Hájek *et al.* 2011).

In contrast to *Sphagnum*-derived OM, vascular plants produce DOC that is less resistant to degradation, consisting of aliphatic compounds, cyclic sugars, oligopeptides, lipids and lignin derivatives (Robroek *et al.* 2016). Among vascular species, woody plants contribute lignin-rich fractions (Mutch 1964), while shrubs reduce aromaticity and enhance OM export (Strack *et al.* 2019). Additionally, vascular plants promote peat aeration through root activity (Waldo *et al.* 2021), accelerating microbial decomposition and OM loss (Malik *et al.* 2020).

A key feature of peat-derived OM is its altered composition compared to the original plant material (Pinsonneault *et al.* 2016). External factors—such as temperature, water table and sunlight—further influence OM transformation. As dynamic, waterlogged systems, peatlands exhibit seasonal fluctuations in water tables, which affect local environmental conditions, plant and microbial diversity, and ecosystem functioning. The carbon balance of peatlands depends on multiple factors including biodiversity, temperature, humidity and pH (Freeman *et al.* 2001, Ågren *et al.* 2007, Worrall *et al.* 2008, Evans *et al.* 2012, Liu *et al.* 2022). Climate-induced shifts in these factors may alter peatland carbon cycling, potentially turning peatlands from carbon sinks into seasonal carbon sources (Dyukarev *et al.* 2019). Thus, continuous monitoring of water tables, physicochemical properties (pH, electrical conductivity (EC), temperature), along with DOC quantity and quality, is essential to understanding peatland behaviour and its interactions with climate and environment.

Globally, peatlands may contribute at least 91 ± 54 Tg of DOC to surface waters, representing 12–20 % of the DOC ultimately transferred to the ocean (Rosset *et al.* 2022). High DOC concentrations in wetland-dominated catchments—both upstream and within peatlands—have been observed across the Northern Hemisphere: 2–41 mg L^{-1} in Sweden (Laudon *et al.* 2011, Olefeldt & Roulet 2012), 15–140 mg L^{-1} in the UK (Clark *et al.* 2008, Freeman *et al.* 2001), and an average concentration of 6.3 ± 4.6 mg L^{-1} (Strack *et al.* 2015) reaching up to 44.6 mg L^{-1} in Canada (Prijac 2023).

In Western Siberia, peatlands cover up to 50 % of the landscape (Kremenetski *et al.* 2003, Savichev 2015), occupying floodplains and watersheds. DOC concentrations in the region's surface waters typically range from 20 mg L^{-1} to 50 mg L^{-1} in the south (Vorobyev *et al.* 2025), decreasing to 13–17 mg L^{-1} in the northern permafrost zone (Manasypov *et al.* 2015). Generally, DOC levels vary between 5 mg L^{-1} and 30 mg L^{-1}, with higher values in southern regions due to intensified peat decomposition (Pokrovsky *et al.* 2015). However, elevated DOC concentrations (33.7–81.6 mg L^{-1} for hollows and 50.6–90.2 mg L^{-1} for ridges, mounds and polygons) have been reported for high-latitude peatlands (Raudina *et al.* 2017).

DOC spectral characteristics for mires (open fens and tall ryams) and streams in Western Siberia show seasonal variations in specific ultraviolet absorption ($SUVA_{254}$) of 2.8–5.5 L mg^{-1} m^{-1} in southern regions (Raudina *et al.* 2022) and 3.5–4.5 L mg^{-1} m^{-1} in northern regions (Payandi-Rolland *et al.* 2020). However, data for the middle taiga zone remain lacking, particularly regarding long-term DOC variations across different peatland ecosystems and their role in shaping DOC chemical composition.

The Mukhrino International Field Station is located in a large ombrotrophic bog characterised by a thick aerobic layer (acrotelm) and minimal mineral input from precipitation only. These conditions result in low biodiversity and the dominance of oligotrophic vegetation, particularly *Sphagnum* species. The study area is representative of the middle taiga subzone and lies approximately 200 km south of the permafrost boundary (Baulin & Danilova 1984). Since 2009, the station has been conducting continuous climate and biodiversity monitoring (Dyukarev *et al.* 2021a). Its research focuses on environmental dynamics and global climate change, encompassing biodiversity (Kupriianova *et al.* 2022), greenhouse gas fluxes (Dyukarev *et al.* 2019, Kulik & Zarov 2023), climate (Dyukarev *et al.* 2021b), DOC (Zarov *et al.* 2022), hydrology (Bleuten *et al.* 2020) and palaeoenvironmental studies (Tsyganov *et al.* 2021, Lapshina & Zarov 2023, Zarov *et al.* 2023, Amon *et al.* 2025).

Understanding long-term changes of hydrology, biodiversity and—particularly—carbon balance in peatlands is critical for assessing their role in the global ecosystem. We hypothesise that middle-taiga bogs exhibit seasonal and ecosystem-dependent variations in dissolved organic carbon (DOC) concentration and spectral features driven by vegetation type, hydrological changes and climatic conditions. Our study provides the first high-frequency, multi-year dataset on DOC concentration across different microforms in a pristine middle-taiga bog of Western Siberia, which is an under-represented region in global peatland studies. These data reveal hydrological patterns and allow for an assessment of the bog's role in shaping hydrochemical composition at both local and regional scales. Our objectives were to: (1) quantify seasonal variations in DOC concentration; and (2) assess the qualitative composition of DOC (on the basis of its spectral properties) across distinct peatland landforms, aiming to elucidate how bog ecosystems differentially contribute to DOC export and quality.

METHODS

Study site

The research was conducted at the Mukhrino peatland in the middle taiga zone of Western Siberia (Russian Federation; Figures 1 and 2). This pristine bog has an average peat depth of 3.4 m, consisting predominantly of ombrotrophic peat with thin interlayers of mesotrophic peat and a basal layer of eutrophic peat (Zarov *et al.* 2023). The oldest peat deposits (~11,000–10,000 cal yr BP) occur in local depressions associated with an ancient riverbed and lake basin (Zarov *et al.* 2023).

The catchment area of the study stream is 0.88 km^2, with an annual discharge ranging from 10,000 to 187,000 m^3, based on field measurements and calculations. The main bog ecosystem types include typical ryam (treed bog with Scots pine, ericaceous shrubs and *Sphagnum* mosses) located in the most steeply sloping peatland zones with the thickest aerobic layer; the ridge-hollow complex (alternating treed ridges with vegetation similar to ryam and treeless hollows with sedges and *Sphagnum* mosses), where hollows work as paths for water movement and ridges retard runoff; and small ponds forming a stream (Filippov & Lapshina 2008).

The regional climate is moderately continental with a mean annual temperature of -1.0 °C (January: -21.5 °C; June: +17.4 °C). Annual precipitation totals

Figure 1. Oblique aerial view looking eastwards across the Mukhrino peatland

480 mm, with approximately 65 % occurring during August–September (Dyukarev *et al.* 2021a).

A hydrological model for the Mukhrino peatland was previously developed using the PCRaster-MODFLOW interface (Bleuten *et al.* 2020). The model showed that the calibrated acrotelm hydraulic conductivity was 0.6–1.2 cm s^{-1}, and the annual water table fluctuation had an amplitude of 10–20 cm. During snowmelt, the water table rose by 5–10 cm at the bog divide and 10–20 cm near the margin. In spring, 91 % of water discharge occurred through the hollows in the ridge-hollow complex. The mean dissolved organic carbon (DOC) concentration in the bog stream was 42.82 ± 10.48 g m^{-3}, resulting in an estimated DOC export of 7.7 g m^{-2} y^{-1}.

Sampling

Water samples were collected monthly from June to August 2021, and biweekly from May through October during 2022–2023. Minor sampling delays (5–10 days) occurred occasionally due to logistical constraints.

The sampling system included monitoring wells - three in each ecosystem (hollow, ridge, ryam and pool); the stream was not equipped with a well (Figure 2). The wells were constructed from perforated plastic pipes (50 mm diameter), sealed at the bottom and installed vertically to a depth of 150 cm below the peatland surface. The wells were completely evacuated the night before sampling to ensure water renewal.

Water samples were collected directly from the wells using a 160 ml plastic syringe and a 120 cm long, 8 mm diameter silicone tube, and transferred into pre-rinsed (three times with sample water) 60 ml amber glass bottles. Samples were transported to the UNESCO Chair "Environmental Dynamic and Global Climate Changes" laboratory (Yugra State University) within hours of collection. Without any preservatives added, all samples were refrigerated at

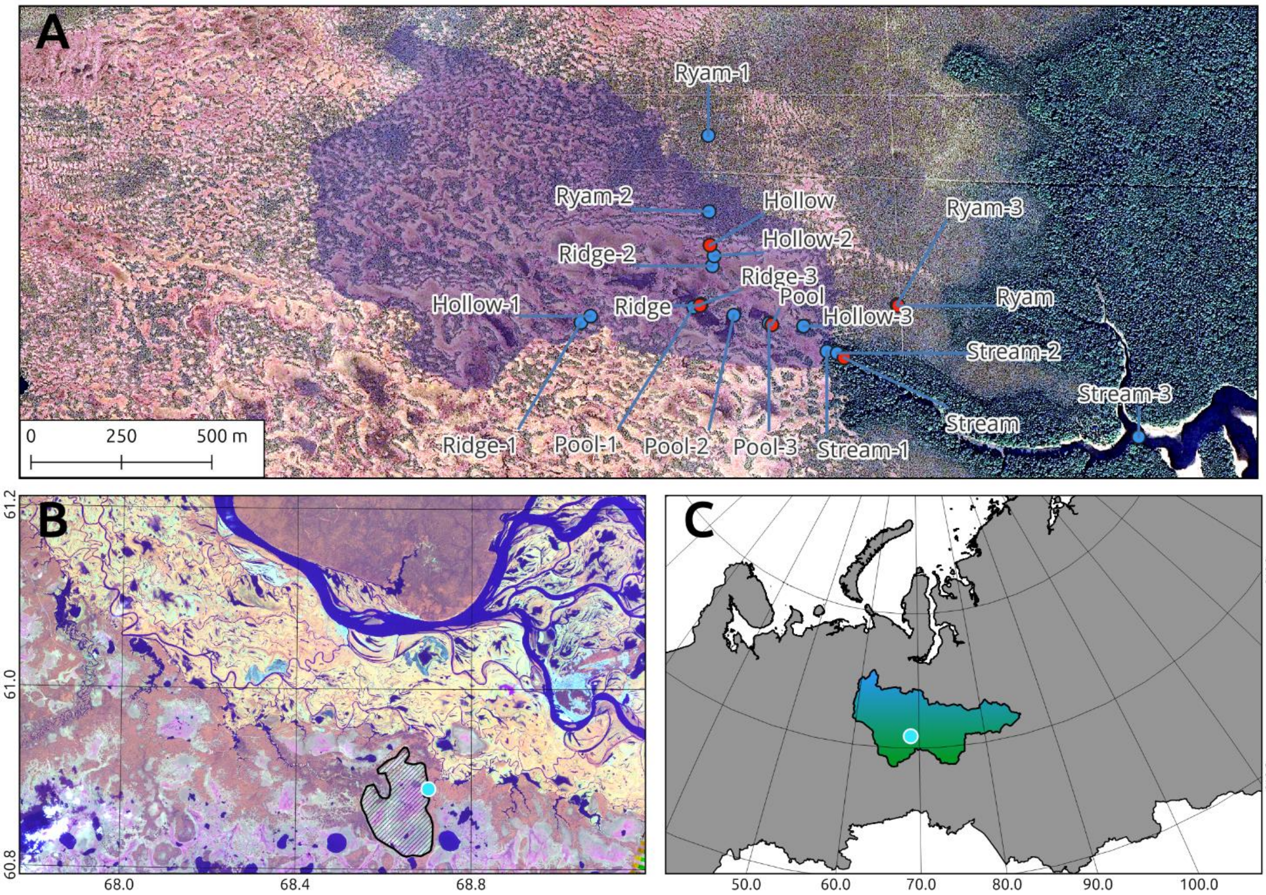

Figure 2. (A) Vertical aerial image of the Mukhrino peatland showing the stream catchment (shaded dark blue), and the locations of monitoring wells (red dots) and sampling points (blue dots). (B) Landsat-5 bands 4-5-3 composite image showing the locations of the Mukhrino peatland (outlined in black) and the Mukhrino field station (light blue dot) at regional scale. (C) Map showing the location of the Mukhrino peatland (light blue dot) within the Khanty-Mansiysk autonomous region (shaded blue-green) and Russia.

+4 °C until analysis, which was performed within 12–18 hours of arrival at the laboratory. Field measurements of pH, electrical conductivity (EC) and temperature were made using a HANNA Combo multiparameter meter (HANNA Instruments, USA). Water table depth was measured in each well using a water table tape.

Sample preparation and analysis

In the UNESCO chair "Environmental dynamic and global climate changes" laboratory, water samples were filtered through 0.45 µm pore-size cellulose acetate membrane filters (Whatman, Cytiva, USA) (Leenheer & Croué 2003). Dissolved organic carbon (DOC) concentration was determined using a Flash-2000 elemental analyser (Thermo Scientific, Germany) equipped with an AI1310 autosampler. Calibration was performed using a urea standard (C = 22.56 %, N = 7.84 %, H = 15.01 %, O = 18.59 %).

Optical properties of organic matter (OM) were measured with a UV/Visible spectrophotometer (PERESEE, T8DCS, China). Absorbance was recorded in a 1 cm quartz cuvette at wavelengths of 250, 254, 365, 400 and 600 nm. $SUVA_{254}$, calculated as absorbance at 254 nm normalised to DOC concentration, served as a proxy for DOM aromaticity (Weishaar *et al.* 2003). The E2:E3 ratio (250 nm / 365 nm) was used to assess the molecular size of DOM, with lower values indicating higher molecular size due to stronger light absorption (Peuravuori & Pihlaja 1997, Lou & Xie 2006, Helms *et al.* 2008). The E4:E6 ratio (400 nm / 600 nm) reflected the relative contributions of humic and fulvic acids, where higher values indicated greater humification (Thurman 1985, Grayson & Holden 2012). Iron concentration can affect spectral measurements, particularly in the 250 nm range (Poulin *et al.* 2014). Based on unpublished Inductively Coupled Plasma Mass Spectrometry (ICP-MS) results, the iron concentration in the studied peatland waters did not exceed 0.863 mg L^{-1}. Therefore, the potential influence of iron on the spectral features was considered negligible.

Water table fluctuations were monitored using a network of wells (Figure 2). Each consisted of a perforated plastic pipe (50 mm diameter, ~4.5 m length), installed vertically in major bog ecosystems. The base was sealed and anchored into the mineral layer to prevent displacement from "peatland breathing" (peat volume changes due to water saturation/desaturation). Each well was equipped with a HOBO U20L-04 water table logger (150–200 cm depth), recording hourly measurements year-round.

Precipitation was measured with a HOBO RG3-M raingauge, operational from late April to late October. Air temperature was recorded using a Rotronic HC2A-S3 logger housed in a meteorological box at 2 m height.

Statistical analyses

All data processing and visualisation were conducted using R programming language (version 4.0.2; R Core Team 2020). Graphical representations were generated using the 'ggplot2' package (Wickham 2016), while statistical computations were performed with the 'dplyr' package (Wickham *et al.* 2023).

For datasets with multiple measurements, the mean value is reported in the text, followed by the standard deviation after the '±' sign.

RESULTS

Our monitoring data revealed distinct seasonal patterns in both water table fluctuations and hydrochemical properties. These findings enabled us to identify long-term trends in peatland hydrological behaviour and establish significant relationships between key environmental variables.

Water table

All studied ecosystems exhibited synchronised water table fluctuations, though with varying magnitudes of response to precipitation events and dry periods. The ryam ecosystem showed the greatest amplitude, with water tables dropping to 180 cm below the peat surface in 2020 and rising 10 cm above the surface during April–May 2023. In contrast, pool ecosystems maintained the most stable water tables, remaining perpetually inundated except during the extreme drought of August 2020 when water tables fell 5 cm below the pool bottoms (Figure 3).

The ridge-hollow complex displayed synchronous water tables during summer months (June–August), with divergence occurring in spring and autumn. Notably, 2023 was the only observation year when ridge and hollow water tables remained desynchronised throughout the entire warm season.

Seasonal patterns revealed peak water tables occurring from mid-May to early June due to snowmelt recharge, followed by progressive declines through late July and early August driven by discharge and evapotranspiration. Autumn typically brought recovery from late-season precipitation and cooling, while short-term precipitation-driven fluctuations occurred throughout the observation period (Figure 3).

The annual range of precipitation for the hydrological season (from November till the end of October; Figure 3) during the monitoring period was 338–491 mm, with average winter precipitation 120 mm and average summer precipitation 280 mm. The evenly distributed precipitation throughout the summer season may keep water tables high (Figure 3, May–August 2021); the dry periods with no rain (Figure 3, middle of July to beginning of August 2022 and August 2023) or no intense precipitation (Figure 3, August 2020 and June–July 2021) cause the water table to drop.

Dissolved organic carbon concentration and hydrochemical properties

The mean DOC concentration across the peatland study area was 48.8 mg L^{-1}, with interannual variation showing maximum values (~ 52.0 mg L^{-1}) in 2021 and 2023 and minimum values (43.6 mg L^{-1}) in 2022. All monitored ecosystems exhibited consistent seasonal changes, characterised by minimum DOC concentrations during the early (April–May) and late (September–October) seasonal periods, and maximum concentrations mid-season (late July to early August) as shown in Figure 4.

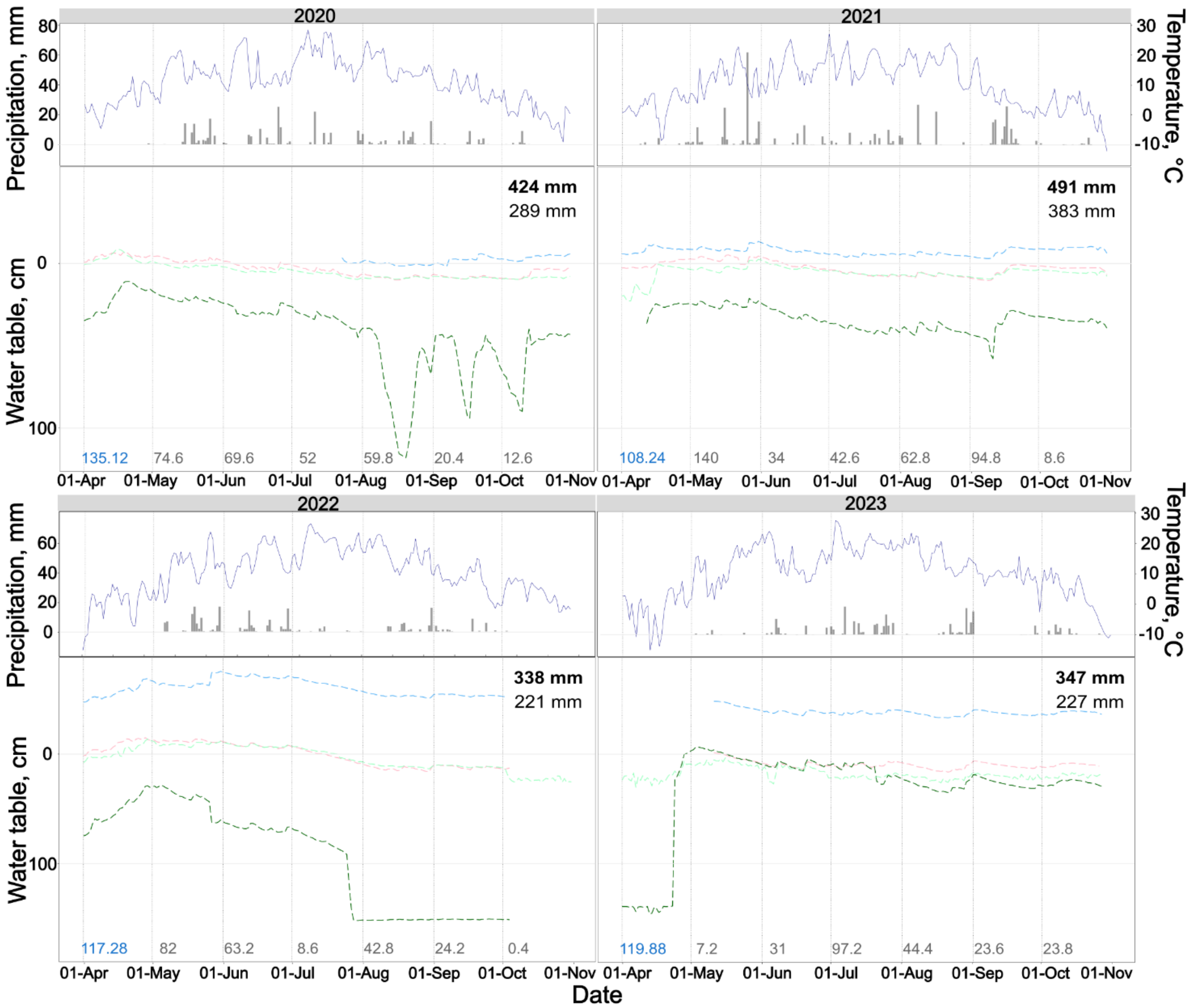

Figure 3. Seasonal fluctuation of air temperature and precipitation (upper part of each panel) and the water table (lower part of each panel), for the period 2020–2023. The dark blue curves show air temperature (°C), and grey bars represent daily precipitation totals (mm). Dashed curves show the water table in hollow (pink), ridge (light green), pool (light blue) and ryam (dark green) locations; zero on the vertical axis represents the ground surface level. Vertical grey dashed lines separate the monitoring months. Numbers between these lines at the bottom show monthly precipitation totals in grey for rainfall (mm) and blue for snowfall (mm). Numbers at top right of the water table plots are totals for the whole hydrological year (November to October) of all precipitation (upper bold number) and rainfall (lower number).

Distinct ecosystem-specific DOC concentration patterns emerged, with streams and pools maintaining the lowest concentrations (30.5 ± 8.2 and 31.1 ± 7.0 mg L^{-1}, respectively), ryam ecosystems exhibiting the highest concentrations (70.6 ± 19.7 mg L^{-1}), and ridge-hollow complexes showing intermediate values (54.0 ± 20.4 and 49.4 ± 14.2 mg L^{-1} for ridges and hollows, respectively).

The magnitude of seasonal DOC variation differed among ecosystems, being most pronounced in ridges (84.0 mg L^{-1} difference between maximum and minimum values), moderate in hollows and ryam (51.3 and 69.5 mg L^{-1}, respectively), and least variable in pools and streams (25.1 and 30.1 mg L^{-1}). Enhanced temporal resolution sampling (biweekly) revealed a transient DOC concentration increase during the late snowmelt discharge period (late May to early June, Figure 4). A notable DOC concentration anomaly occurred in the ryam ecosystem during early October 2022 following an extended period of exceptionally low water tables (Figure 3).

The highest seasonally averaged EC values (for the monitoring period from May to the end of October) were recorded in the ryam ecosystem (91.4 ± 23.6 µS cm^{-1}), while the lowest values were observed in the pool (35.8 ± 8.1 µS cm^{-1}) and stream (42.6 ± 11.2 µS cm^{-1}) ecosystems. Intermediate EC levels were found in the hollow (53.9 ± 19.9 µS cm^{-1}) and ridge (58.4 ± 28.6 µS cm^{-1}) ecosystems. Across all ecosystems, peak EC values typically occurred in mid-summer, whereas the lowest readings were recorded at the beginning and end of the season.

Seasonally averaged pH values (for the monitoring period from May to the end of October) ranged narrowly from 3.33 to 3.50, with the most acidic conditions in the ryam and ridge ecosystems and slightly higher pH levels in the stream and pool. The seasonal pH variation was most pronounced in the stream (amplitude ~ 1.0), compared to ~ 0.8 in other ecosystems. Notably, pH reached its lowest point in mid-summer and peaked toward the end of the season.

Spectral features of the dissolved organic carbon

The spectral features of DOC revealed distinct seasonal variations in composition. $SUVA_{254}$ values exhibited an initial increase across all ecosystems at season onset, although peak timing varied asynchronously (Figure 5). A sequential progression of $SUVA_{254}$ peaks occurred from May through June, appearing first in hollows, followed by streams, ridges, and finally pools. The $SUVA_{254}$ peak in pools appeared less distinct and potentially occurred prior to initial sampling. A secondary $SUVA_{254}$ peak emerged uniformly across ecosystems during September–October, while the overall seasonal trend showed decreasing values reaching minima by late October. Seasonally averaged $SUVA_{254}$ values were highest in streams and ryams (3.83 ± 1.1 L mg^{-1} m^{-1} and 3.70 ± 0.52 L mg^{-1} m^{-1}, respectively), and lowest in ridge-hollow complexes (2.70 ± 0.84 L mg^{-1} m^{-1}

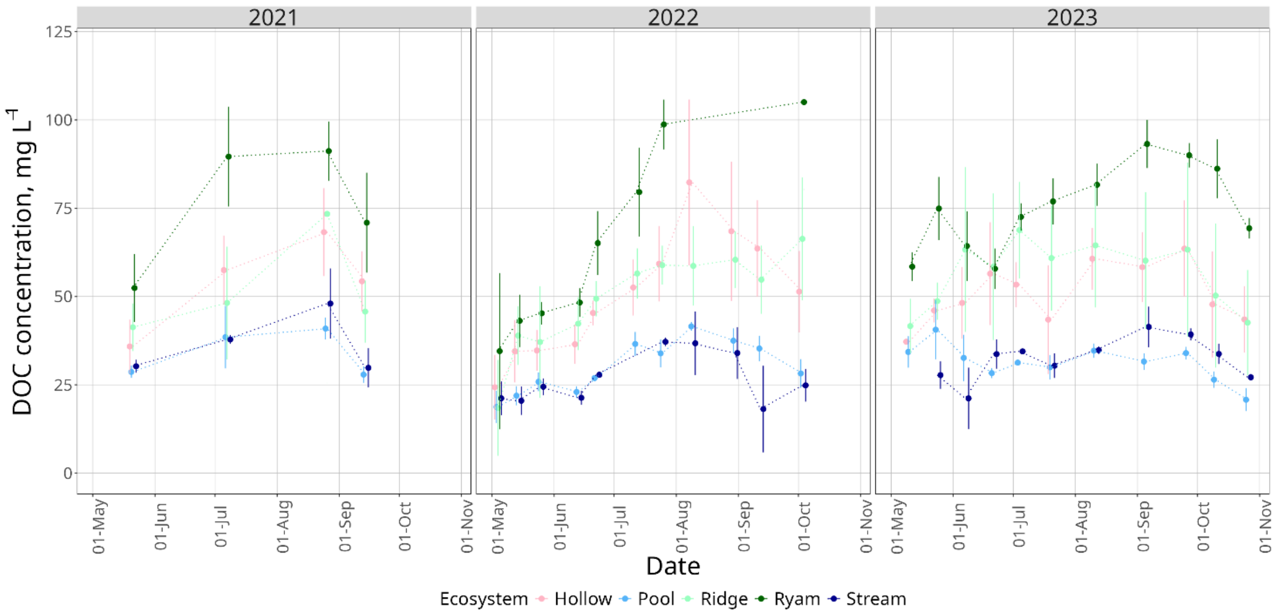

Figure 4. Seasonal DOC concentration changes for the period 2021–2023. Dashed lines connect the median values for each ecosystem over a season; dots represent the mean DOC concentration; error bars represent the standard deviation.

and 2.68 ± 0.65 L mg^{-1} m^{-1} for hollows and ridges) and pools (2.58 ± 0.55 L mg^{-1} m^{-1}).

E2:E3, inversely related to molecular size, demonstrated ecosystem-specific patterns (Figure 5). Seasonal averages were lowest in ryams (4.56 ± 0.17), intermediate in streams, ridges and hollows (5.23 ± 0.38, 5.27 ± 0.36 and 5.34 ± 0.57, respectively), and highest in pools (5.92 ± 0.79). While ryam maintained stable values throughout the season, other sites showed increasing trends toward season end. All ecosystems exhibited fluctuations with three to four distinct peaks during the monitoring period.

The E4:E6 ratio displayed wavelike patterns with diminishing amplitude over the season. Maximum values occurred uniformly in June across ecosystems, with minima observed in July, superimposed on an overall decreasing trend. Ryam ecosystems showed the highest E4:E6 averaged ratios (16.55 ± 5.50), pools and ridges the lowest (10.51 ± 6.10 and 12.40 ± 7.50, respectively), with intermediate values in streams and hollows (13.91 ± 10.01 and 14.05 ± 11.11).

DISCUSSION

Winter precipitation, accounting for approximately one-third of annual totals, generated substantial snowmelt inputs. However, peatland hydrological self-regulation prevented extreme water table fluctuations (Couwenberg *et al.* 2022). Initial frozen surface conditions promoted surface runoff, limiting infiltration, while subsequent thawing enabled rapid vertical percolation through highly conductive upper peat layers (Bay 1969, Ivanov 1981, Bishop *et al.* 2011, Bleuten *et al.* 2020). This mechanism produced the most pronounced water table rise in April 2023, following an exceptionally dry (only 221 mm summer rainfall total) preceding year 2022 with depressed end-of-season water tables (Figure 3).

The reduced spring DOC concentrations corresponded with periods of increased discharge and elevated water tables resulting from snowmelt dilution effects. This pattern was subsequently reversed during mid-July dry periods, when DOC concentrations increased, consistent with previous studies (Fraser *et al.* 2001, Jager *et al.* 2009, Broder

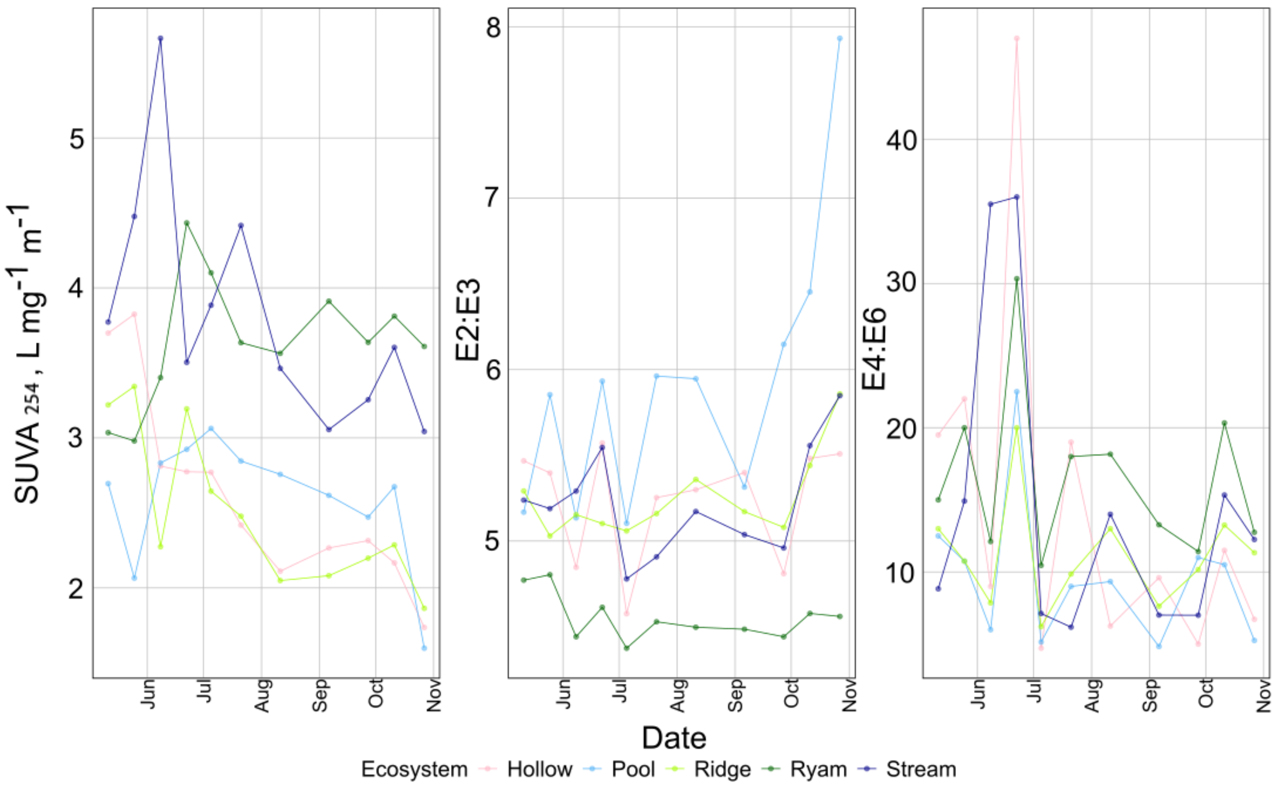

Figure 5. Seasonal changes during 2023 of the spectral features of DOC that were evaluated as proxies for DOC quality, in different ecosystems. The spectral features are: $SUVA_{254}$ (specific ultraviolet absorbance at 254 nm) for aromaticity, E2:E3 ($SUVA_{250}$ / $SUVA_{365}$) for molecular size, and E4:E6 ($SUVA_{400}$ / $SUVA_{600}$) for humification degree. Points represent the mean values and lines are connecting curves fitted to the mean values.

et al. 2017), and for Siberian rivers in particular (Avagyan *et al.* 2016, Gandois *et al.* 2021).

DOC concentrations exhibited strong ecosystem dependence, with highest values occurring in drier ecosystems (ryam and ridge) and lowest concentrations in wetter systems (stream and pool). It is likely that this pattern reflects both the vascular plant dominance in ryam and ridge communities, which are rich in lignin compounds (Spencer *et al.* 2008), and the expanded oxic zones resulting from lower water tables that promote organic matter oxidation (Munir *et al.* 2017). The slope position of ryam creates a drainage gradient between open bog complexes and adjacent forests, while ridges are elevated 40–50 cm above hollows due to characteristic hydrological functioning (Ivanov 1981, Couwenberg *et al.* 2022). These topographic features enhance oxidation of organic litter and peat, accelerating humification processes. Subsequent rainfall events mobilise decomposed OM through vertical water movement and rising water tables, generating OM export fluxes (Broder *et al.* 2017). Although such mechanisms should theoretically produce short-term DOC concentration spikes at stream outlets following precipitation, our biweekly sampling interval (not synchronised with rainfall events) apparently missed these transient signals, highlighting the need for higher-frequency automated monitoring to capture event-driven export changes.

Spectral characteristics provided insights into ecosystem contributions to DOC export. $SUVA_{254}$ values, reflecting aromatic compound abundance (Weishaar *et al.* 2003), showed distinct spatial patterns. Notably, the stream displayed consistently high $SUVA_{254}$, indicating continuous aromatic DOC inputs peaking during June snowmelt (Ågren *et al.* 2008; Figure 5), when winter-accumulated OM undergoes flushing. The apparent disconnection between ryam-derived high-$SUVA_{254}$ DOC and intermediate ecosystems suggests subsurface transport mechanisms (>1.5 m depth) requiring future tracer studies.

DOC characteristics showed strong environmental coupling with pH, EC and water table changes (Dobrovolskaya *et al.* 2014). The inverse pH-EC relationship (Figure 6) reflects *Sphagnum*-mediated acidification in nutrient-poor conditions (Clymo & Hayward 1982, Børsheim *et al.* 2001), which enhances ion dissociation and EC. The EC-DOC correlation (Figure 6) indicates that organic compounds dominate peatland EC, contrasting with low EC rainwater inputs (8–11 µS cm^{-1} versus peatland ranges of 20–135 µS cm^{-1}) and poor ion content in peatland water (Litvinov *et al.* 2025).

Peat formation processes typically involve FA loss and concomitant HA accumulation in bulk organic matter (Savicheva & Inisheva 2003), making HA abundance an indicator of OM maturity. Molecular parameters revealed systematic variations:

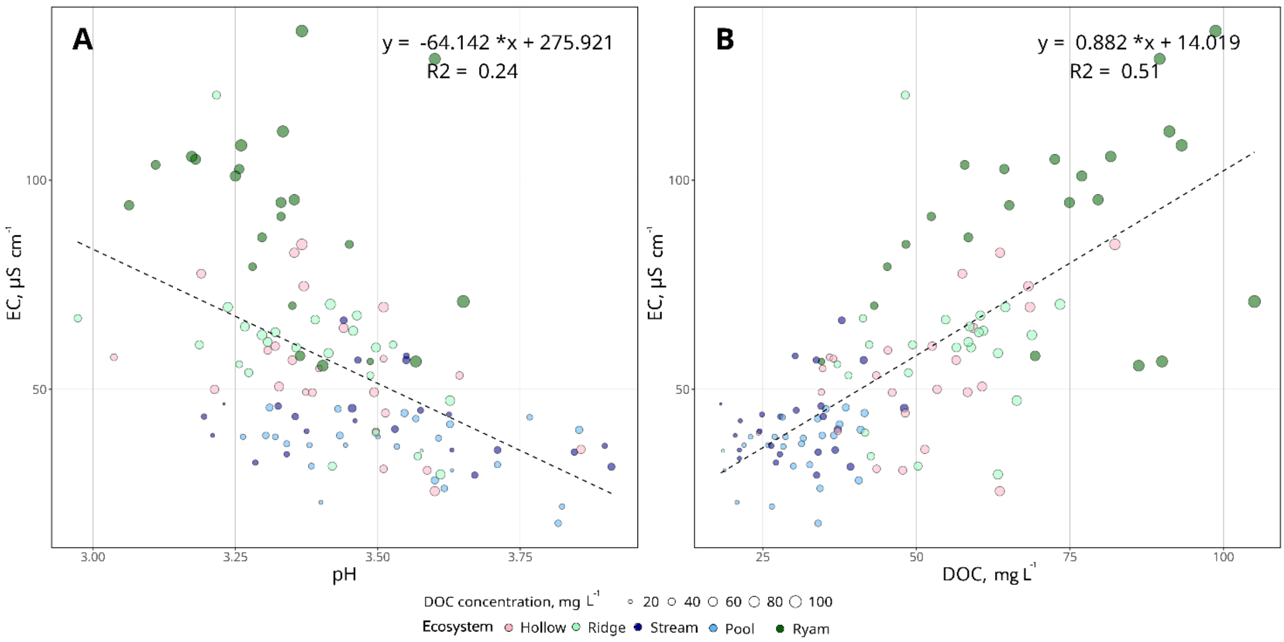

Figure 6. The relationships between (A) pH and EC, and (B) DOC and EC. The dashed lines show the linear regressions.

aromatic, high-E2:E3 DOC dominated ryam systems, while pools contained low-E2:E3 and less aromatic compounds (Figure 7A). Ridge-hollow complexes exhibited intermediate but variable characteristics, suggesting dynamic source OM contributions. The stream's anomalous high-$SUVA_{254}$, low-concentration signature may reflect preferential degradation of labile compounds (Mastný *et al.* 2018, Foereid *et al.* 2018) and/or inputs from deeper peat layers with longer residence times, higher molecular size and aromaticity (Stutter *et al.* 2007). Simple linear regression clearly differentiated ecosystems (Figures 7B and 8), with ryams (high-DOC, aromatic, humified) and pools (low-DOC, labile) representing oligotrophic extremes, while streams occupied a unique position with unexpectedly high aromaticity.

Our study focused on a pristine ombrotrophic bog in the middle taiga of Western Siberia, which is representative of *Sphagnum*-dominated peatlands with minimal anthropogenic influence. We demonstrated that DOC changes (concentration, $SUVA_{254}$, molecular size) are tightly coupled to hydrological conditions and vegetation type (e.g., ryam vs. pools). This aligns with regional studies showing similar DOC range in 20–50 mg L^{-1} and $SUVA_{254}$ trend 2.8–5.5 in southern taiga (Raudina *et al.* 2022). However, northern permafrost-affected peatlands exhibit lower DOC (13–17 mg L^{-1}; Manasypov *et al.* 2015), highlighting a latitudinal gradient tied to climate and permafrost. Our values (30–90 mg L^{-1}) exceed those in Swedish peatlands (Laudon *et al.* 2011). This suggests stronger peat decomposition in Western Siberia, possibly due to warmer temperatures or longer hydrological residence times. $SUVA_{254}$ in our study (2.6–3.8 L mg^{-1} m^{-1}) overlaps with values from Payandi-Rolland *et al.* (2020) in northern Siberia (3.5–4.5), but ryam ecosystems showed higher aromaticity, resembling DOC from vascular-plant-dominated systems (Spencer *et al.* 2008).

While our site typifies middle taiga bogs, extrapolation to the entire West Siberian taiga requires caution due to northern peatlands with permafrost having distinct DOC export mechanisms, e.g., surface flow vs. deep groundwater flow (Ivanov 1981). Forested bogs, fens and thaw lakes may differ in DOC quality (Pokrovsky *et al.* 2015). Future work should include transects across taiga subzones.

The high spatiotemporal variability in DOC that we observed (e.g., ryam vs. pools, seasonal peaks) poses challenges but also opportunities for model parameterisation. The ryam ecosystem exhibited the greatest amplitude in DOC concentration (70.6 mg L^{-1}), corresponding to the largest fluctuations in water table (Figures 3 and 4). This supports the "transmissivity feedback" hypothesis (Bishop *et al.* 2011). The mechanism is that a high water table enhances discharge due to the high hydraulic conductivity of the surface peat layer (Ivanov 1981, Bleuten *et al.* 2020), causing DOC flushing and a subsequent concentration drop. Conversely, a low water table reduces discharge,

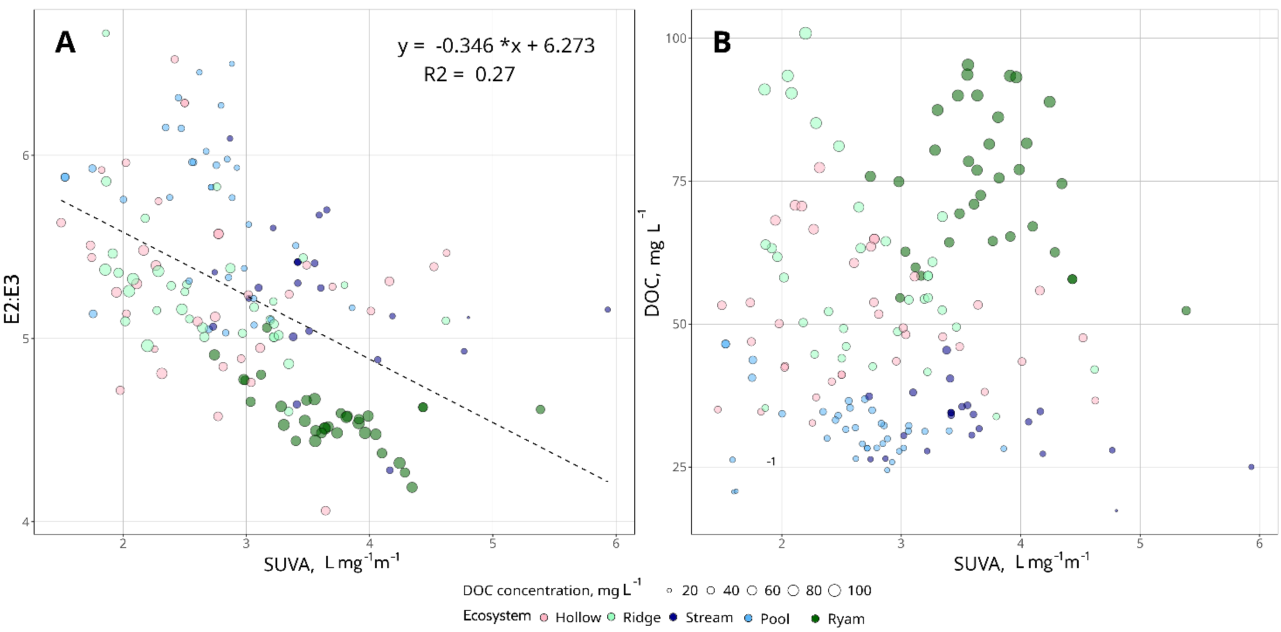

Figure 7. The relationships between (A) $SUVA_{254}$ and E2:E3, and (B) DOC and $SUVA_{254}$. The dashed line in (A) shows the linear regression.

diminishes flushing, and leads to elevated DOC concentrations. This could be modelled using water table-DOC relationships specific to ecosystem types. High $SUVA_{254}$ (aromaticity) in ryam suggests DOC stability, while low $SUVA_{254}$ in pools implies labile carbon. These traits could inform degradability parameters in models (Kellerman *et al.* 2018).

Global models often treat peatlands homogenously (Bechtold *et al.* 2020, Zou *et al.* 2022). We advocate for ecosystem-specific modules (ryam, hollows, etc.) based on our observed differences in DOC flux and quality. Drought-induced DOC spikes (e.g., the post-2022 ryam peak) may amplify CO_2 emissions under warming. Models should integrate hydrological extremes to capture nonlinear responses. Thus, continuous high-frequency monitoring (beyond our biweekly sampling) is needed to resolve event-driven DOC pulses (Gandois *et al.* 2021). $SUVA_{254}$ and E4:E6 ratios could serve as proxies for DOC lability in models, but require validation across more sites.

CONCLUSION

In this study we conducted multi-year, high-frequency monitoring of water table dynamics along with concentrations and optical properties ($SUVA_{254}$, E2:E3, E4:E6) of DOC across distinct ecosystems (ryam, ridge, hollow, pool and stream) in a pristine middle-taiga ombrotrophic bog in Western Siberia. Our findings demonstrate that each ecosystem functions as a unique biogeochemical unit with distinct hydrological and hydrochemical properties. Consequently, the individual contributions of these ecosystems to DOC export differ substantially and must be explicitly represented in carbon cycle and climate models. Specifically, the driest ecosystem, ryam, with the lowest water table, exhibited the highest DOC concentrations, aromaticity ($SUVA_{254}$) and E2:E3, indicating its role as a source of stable, recalcitrant DOC to runoff. In contrast, permanently inundated pools, which integrate water from the wider catchment, showed the lowest DOC concentrations, $SUVA_{254}$ and E2:E3, likely due to photochemical and biological processing. The stream presented a unique signature, combining the concentration levels of wet ecosystems with the aromaticity of dry ones, highlighting the complexity of integrated catchment processes.

The observed ecosystem-specific patterns in DOC quantity and quality were consistent across seasons, underscoring the primary control of local ecohydrological conditions—rather than uniform peatland-scale drivers—on carbon dynamics. To fully capture the short-term pulses and complex interactions governing DOC export, future research should employ higher-frequency, automated monitoring. Such advancements are crucial for developing precise, mechanistic ecohydrological models capable of predicting peatland carbon responses to climatic change.

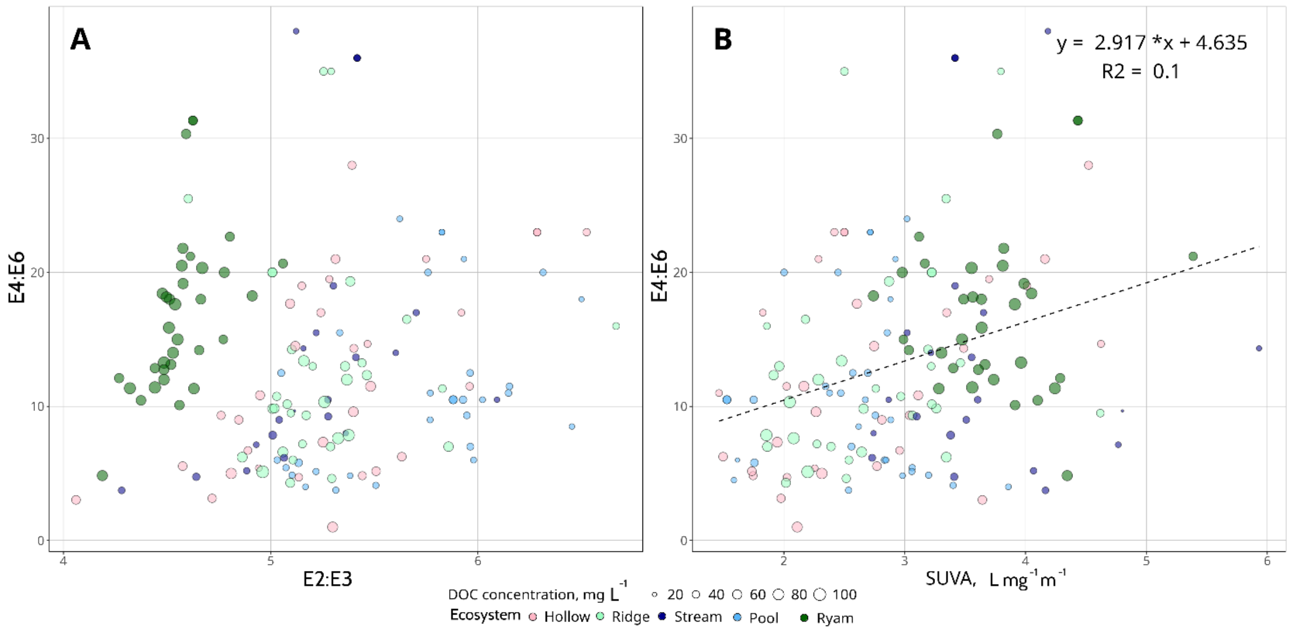

Figure 8. The relationships between E4:E6 and (A) E2:E3, (B) $SUVA_{254}$. The dashed line in (B) shows the linear regression.

ACKNOWLEDGEMENTS

The research was funded by the Russian Science Foundation (Project No. 25-27-00272 "Dissolved organic matter and associated trace elements losses from the ombrothrophic peatlands, its transformation through the hydrological continuum").

AUTHOR CONTRIBUTIONS

Conceptualisation: ISI, EAZ; methodology: VSS, SER, LVL; software: EAZ, VSS; investigation: VSS, SER, LVL, ISI, EAZ; writing (original draft preparation): EAZ, ISI; writing (review and editing): LVL, ISI; visualisation: EAZ; supervision: ISI; all authors read and agreed to the published version of the manuscript.

REFERENCES

Ågren, A., Buffam, I., Jansson, M., Laudon, H. (2007) Importance of seasonality and small streams for the landscape regulation of dissolved organic carbon export. *Journal of Geophysical Research: Biogeosciences*, 112(G3), G03003. https://doi.org/10.1029/2006JG000381

Ågren, A., Buffam, I., Berggren, M., Bishop, K., Jansson, M., Laudon, H. (2008) Dissolved organic carbon characteristics in boreal streams in a forest-wetland gradient during the transition between winter and summer. *Journal of Geophysical Research: Biogeosciences*, 113(G3), G03031. https://doi.org/10.1029/2007JG000674

Amon, L., Tsyganov, A.N., Zarov, E.A., Burkanova, E., Vassiljev, J., Kulkov, M.G., Krivokorin, I., Chernyshov, V.A., Mazei, N.G., Salakhidinova, G.T., Gulina, A., Kuzmin, Ya., Mazei, Yu., Lapshina, E.D. (2025) Regional and local drivers of vegetation and humidity dynamics in Western Siberia during the Holocene: A case study of Mukhrino mire. *The Holocene*, 09596836251387252. https://doi.org/10.1177/09596836251387252

Avagyan, A., Runkle, B.R., Hennings, N., Haupt, H., Virtanen, T., Kutzbach, L. (2016) Dissolved organic matter dynamics during the spring snowmelt at a boreal river valley mire complex in Northwest Russia. *Hydrological Processes*, 30(11), 1727–1741. https://doi.org/10.1002/hyp.10710

Bai, H., Jiang, Z., He, M., Ye, B., Wei, S. (2018) Relating Cd^{2+} binding by humic acids to molecular weight: A modeling and spectroscopic study. *Journal of Environmental Sciences*, 70, 154–165. https://doi.org/10.1016/j.jes.2017.11.028

Baulin, V.V., Danilova, N.S. (1984) Dynamics of Late Quaternary permafrost in Siberia. In: Velichko, A.A. (ed.) *Late Quaternary Environments of the Soviet Union*, University of Minnesota Press, 69–77. https://www.jstor.org/stable/10.5749/j.ctttshdh

Bay, R.R. (1969) Runoff from small peatland watersheds. *Journal of Hydrology*, 9(1), 90–102. https://doi.org/10.1016/0022-1694(69)90016-X

Bechtold, M., De Lannoy, G.J.M., Reichle, R.H., Roose, D., Balliston, N., Burdun, I., Devito, K., Kurbatova, J., Strack, M., Zarov, E.A. (2020) Improved groundwater table and L-band brightness temperature estimates for Northern Hemisphere peatlands using new model physics and SMOS observations in a global data assimilation framework. *Remote Sensing of Environment*, 246, 111805. https://doi.org/10.1016/j.rse.2020.111805

Bengtsson, G., Törneman, N. (2004). Dissolved organic carbon dynamics in the peat-streamwater interface. *Biogeochemistry*, 70(1), 93–116. https://doi.org/10.1023/B:BIOG.0000049338.81809.7c

Bianchi, T.S., (2007) *Biogeochemistry of Estuaries*. Oxford University Press Inc, New York, 721 pp. https://doi.org/10.1093/oso/9780195160826.001.0001

Bishop, K., Seibert, J., Nyberg, L., Rodhe, A. (2011) Water storage in a till catchment. II: Implications of transmissivity feedback for flow paths and turnover times. *Hydrological Processes*, 25(25), 3950–3959. https://doi.org/10.1002/hyp.8355

Blanchet, M., Pringault, O., Panagiotopoulos, C., Lefèvre, D., Charrière, B., Ghiglione, J-F., Fernandez, C., Aparicio, F.L., Marrasé, C., Catala, P., Oriol, L., Caparros, J., Joux, F. (2017) When riverine dissolved organic matter (DOM) meets labile DOM in coastal waters: changes in bacterial community activity and composition. *Aquatic Sciences*, 79, 27–43. https://doi.org/10.1007/s00027-016-0477-0

Bleuten, W., Zarov, E., Schmitz, O. (2020) A high-resolution transient 3-dimensional hydrological model of an extensive undisturbed bog complex in West Siberia. *Mires and Peat*, 26, 06. https://doi.org/10.19189/MaP.2019.OMB.StA.1769

Bolin, B., Degens, E.T., Kempe, S., Ketner, P. (1979) The global carbon cycle. *Quarterly Journal of the Royal Meteorological Society*, 1(13), 35–38. https://doi.org/10.1016/B978-0-08-023252-2.50011-7

Børsheim, K.Y., Christensen, B.E., Painter, T.J. (2001) Preservation of fish by embedment in *Sphagnum* moss, peat or holocellulose: experimental proof of the oxopolysaccharidic nature of the preservative substance and of its antimicrobial and tanning action. *Innovative Food Science & Emerging Technologies*, 2(1), 63–74. https://doi.org/10.1016/S1466-8564(00)00029-1

Broder, T., Knorr, K.H., Biester, H. (2016) DOM quality in a peatland and forest headwater stream: seasonal and event characteristics. *Hydrology and Earth Systems Science Discussions*, 25 pp. https://doi.org/10.5194/hess-2016-377

Broder, T., Knorr, K.H., Biester, H. (2017) Changes in dissolved organic matter quality in a peatland and forest headwater stream as a function of seasonality and hydrologic conditions. *Hydrology and Earth System Sciences*, 21(4), 2035–2051. https://doi.org/10.5194/hess-21-2035-2017

Burd, K., Estop-Aragonés, C., Tank, S.E., Olefeldt, D. (2020) Lability of dissolved organic carbon from boreal peatlands: interactions between permafrost thaw, wildfire, and season. *Canadian Journal of Soil Science*, 100(4), 503–515. https://doi.org/10.1139/cjss-2019-0154

Clark, J.M., Lane, S.N., Chapman, P.J., Adamson, J.K. (2008) Link between DOC in near surface peat and stream water in an upland catchment. *Science of the Total Environment*, 404(2–3), 308–315. https://doi.org/10.1016/j.scitotenv.2007.11.002

Clymo, R.S., Hayward, P.M. (1982) The ecology of *Sphagnum*. In: Smith, A.J.E. (ed.) *Bryophyte Ecology*, Springer, Dordrecht NL, 229–289. https://doi.org/10.1007/978-94-009-5891-3_8

Clymo, R.S., Turunen, J., Tolonen, K. (1998) Carbon accumulation in peatland. *Oikos*, 81, 368–388. https://doi.org/10.2307/3547057

Coble, A.A., Koenig, L.E., Potter, J.D., Parham, L.M., McDowell, W.H. (2019) Homogenization of dissolved organic matter within a river network occurs in the smallest headwaters. *Biogeochemistry*, 143, 85–104. https://doi.org/10.1007/s10533-019-00551-y

Couwenberg, J., Baumann, M., Lamkowski, P., Joosten, H. (2022) From genes to landscapes: Pattern formation and self-regulation in raised bogs with an example from Tierra del Fuego. *Ecosphere*, 13(4), e4031. https://doi.org/10.1002/ecs2.4031

Dawson, J.J.C., Bakewell, C., Billett, M.F. (2001) Is in-stream processing an important control on spatial changes in carbon fluxes in headwater catchments? *Science of the Total Environment*, 265(1–3), 153–167. https://doi.org/10.1016/S0048-9697(00)00656-2

Del Vecchio, R., Blough, N.V. (2002) Photobleaching of chromophoric dissolved organic matter in natural waters: kinetics and modeling. *Marine Chemistry*, 78(4), 231–253. https://doi.org/10.1016/S0304-4203(02)00036-1

Dinsmore, K.J., Billett, M.F., Skiba, U.M., Rees, R.M., Drewer, J., Helfter, C. (2010) Role of the aquatic pathway in the carbon and greenhouse gas budgets of a peatland catchment. *Global Change Biology*, 16, 2750–2762. https://doi.org/10.1111/j.1365-2486.2009.02119.x

Dobrovolskaya, T.G., Golovchenko, A.V., Zvyagintsev, D.G. (2014) Analysis of ecological factors limiting the destruction of high-moor peat. *Eurasian Soil Science*, 47, 182–193. https://doi.org/10.1134/S106422931403003X

Dyukarev, E.A., Godovnikov, E.A., Karpov, D.V., Kurakov, S.A., Lapshina, E.D., Filippov, I.V., Zarov, E.A. (2019) Net ecosystem exchange, gross primary production and ecosystem respiration in ridge-hollow complex at Mukhrino Bog. *Geography, Environment, Sustainability*, 12(2), 227–244. https://doi.org/10.24057/2071-9388-2018-77

Dyukarev, E., Zarov, E., Alekseychik, P., Nijp, J., Filippova, N., Mammarella, I., Filippov, I., Bleuten, W., Khoroshavin, V., Ganasevich, G., Meshcheryakova, A., Vesala, T., Lapshina, E. (2021a) The multiscale monitoring of peatland ecosystem carbon cycling in the middle taiga zone of Western Siberia: The Mukhrino Bog case study. *Land*, 10(8), 824. https://doi.org/10.3390/land10080824

Dyukarev, E., Filippova, N., Karpov, D., Shnyrev, N., Zarov, E., Filippov, Voropay, N., Avilov, V., Artamonov, A., Lapshina, E. (2021b) Hydrometeorological dataset of West Siberian boreal peatland: a 10-year record from the Mukhrino field station. *Earth System Science Data*, 13(6), 2595–2605. https://doi.org/10.5194/essd-13-2595-2021

Evans, C.D., Jones, T.G., Burden, A., Ostle, N., Zieliński, P., Cooper, M.D., Freeman, C. (2012) Acidity controls on dissolved organic carbon mobility in organic soils. *Global Change Biology*, 18(11), 3317–3331. https://doi.org/10.1111/j.1365-2486.2012.02794.x

Filippov, I.V., Lapshina, E.D. (2008) Peatland unit types of lake-bog systems in the Middle Priobie (Western Siberia). *Environmental Dynamics and Global Climate Change*, 1(1S), 115–124 (in Russian with English summary). https://doi.org/10.17816/edgcc11S115-124

Foereid, B., Zarov, E.A., Latysh, I.M., Filippov, I.V., Lapshina, E.D. (2018) Photo-exposure affects subsequent peat litter decomposition. *Geoderma*, 315, 104–110. https://doi.org/10.1016/j.geoderma.2017.10.059

Fraser, C.J.D., Roulet, N.T., Moore, T.R. (2001)

Hydrology and dissolved organic carbon biogeochemistry in an ombrotrophic bog. *Hydrological Processes*, 15(16), 3151–3166. https://doi.org/10.1002/hyp.322

Freeman, C., Evans, C.D., Monteith, D.T., Reynolds, B., Fenner, N. (2001) Export of organic carbon from peat soils. *Nature*, 412, 785. https://doi.org/10.1038/35090628

Freeman, C., Fenner, N., Ostle, N.J., Kang, H., Dowrick, D.J., Reynolds, B., Hudson, J. (2004) Export of dissolved organic carbon from peatlands under elevated carbon dioxide levels. *Nature*, 430(6996), 195–198. https://doi.org/10.1038/nature02707

Gandois, L., Tananaev, N.I., Prokushkin, A., Solnyshkin, I., Teisserenc, R. (2021) Seasonality of DOC export from a Russian subarctic catchment underlain by discontinuous permafrost, highlighted by high-frequency monitoring. *Journal of Geophysical Research: Biogeosciences*, 126(10), e2020JG006152. https://doi.org/10.1029/2020JG006152

Grayson, R., Holden, J. (2012) Continuous measurement of spectrophotometric absorbance in peatland stream water in northern England: implications for understanding fluvial carbon fluxes. *Hydrological Processes*, 26(1), 27–39. https://doi.org/10.1002/hyp.8106

Hájek, T., Ballance, S., Limpens, J., Zijlstra, M., Verhoeven, J.T. (2011) Cell-wall polysaccharides play an important role in decay resistance of *Sphagnum* and actively depressed decomposition in vitro. *Biogeochemistry*, 103, 45–57. https://doi.org/10.1007/s10533-010-9444-3

Hansen, A.M., Kraus, T.E.C., Pellerin, B.A., Fleck, J.A., Downing, B.D., Bergamaschi, B.A. (2016) Optical properties of dissolved organic matter (DOM): Effects of biological and photolytic degradation. *Limnology and Oceanography*, 61(3), 1015–1032. https://doi.org/10.1002/lno.10270

Helms, J.R., Stubbins, A., Ritchie, J.D., Minor, E.C., Kieber, D.J., Mopper, K. (2008) Absorption spectral slopes and slope ratios as indicators of molecular weight, source, and photobleaching of chromophoric dissolved organic matter. *Limnology and Oceanography*, 53(3), 955–969. https://doi.org/10.4319/lo.2008.53.3.0955

Ivanov, K.E. (1981) *Water Movement in Mirelands*. Translation by Arthur Thomson and H.A.P. Ingram of "*Vodoobmen v bolotnykh landshaftakh*", Academic Press, London, New York, 276 pp. Online at: https://www.cabidigitallibrary.org/doi/full/10.5555/19811959095, accessed 13 Dec 2024.

Jager, D.F., Wilmking, M., Kukkonen, J.V. (2009) The influence of summer seasonal extremes on dissolved organic carbon export from a boreal peatland catchment: Evidence from one dry and one wet growing season. *Science of the Total Environment*, 407(4), 1373–1382. https://doi.org/10.1016/j.scitotenv.2008.10.005

Karlsson, J., Byström, P., Ask, J., Ask, P., Persson, L., Jansson, M. (2009) Light limitation of nutrient-poor lake ecosystems. *Nature*, 460(7254), 506–509. https://doi.org/10.1038/nature08179

Kellerman, A.M., Guillemette, F., Podgorski, D.C., Aiken, G.R., Butler, K.D., Spencer, R.G. (2018) Unifying concepts linking dissolved organic matter composition to persistence in aquatic ecosystems. *Environmental Science & Technology*, 52(5), 2538–2548. https://doi.org/10.1021/acs.est.7b05513

Kremenetski, K.V., Velichko, A.A., Borisova, O.K., MacDonald, G.M., Smith, L.C., Frey, K.E., Orlova, L.A. (2003) Peatlands of the Western Siberian lowlands: current knowledge on zonation, carbon content and Late Quaternary history. *Quaternary Science Reviews*, 22(5–7), 703–723. https://doi.org/10.1016/S0277-3791(02)00196-8

Kulik, A.A., Zarov, E.A. (2023) The influence of the hydrometeorological factors on the CO_2 fluxes from the oligotrophic bog surface. *Environmental Dynamics and Global Climate Change*, 14(4), 249–263 (in Russian with English summary). https://doi.org/10.18822/edgcc624160

Kupriianova, I.V., Kaverin, A.A., Filippov, I.V., Ilyasov, D.V., Lapshina, E.D., Logunova, E.V., Kulyabin, M.F. (2022) The main physical and geographical characteristics of the Mukhrino field station area and its surroundings. *Environmental Dynamics and Global Climate Change*, 13(4), 215–252 (in Russian with English summary). https://doi.org/10.18822/edgcc240049

Lapshina, E.D., Zarov, E.A. (2023) Stratigraphy of peat deposits and mire development in the south and middle taiga zones of Westerns Siberia in Holocene. *Environmental Dynamics and Global Climate Change*, 14(2), 70–101. https://doi.org/10.18822/edgcc568688

Laudon, H., Berggren, M., Ågren, A., Buffam, I., Bishop, K., Grabs, T., Kohler, S. (2011) Patterns and dynamics of dissolved organic carbon (DOC) in boreal streams: The role of processes, connectivity, and scaling. *Ecosystems*, 14(6), 880–893. https://doi.org/10.1007/s10021-011-9452-8

Leenheer, J.A., Croué, J.P. (2003) Characterizing aquatic dissolved organic matter. *Environmental*

Science & Technology, 37(1), 18A–26A. https://doi.org/10.1021/es032333c

Litvinov, L.V., Zarov, E.A., Ivanova, I.S. (2025) Hydrochemical differentiation in bog ecosystems. *Environmental Dynamics and Global Climate Change*, 16(2), 69–80. (in Russian with English summary). https://doi.org/10.18822/edgcc677932

Liu, H., Gu, Y., Ge, J., Yu, Z., Xu, X., Zhang, Z., Xie, S. (2022) The response of the Dajiuhu Peatland ecosystem to hydrological variations: Implications for carbon sequestration and peatlands conservation. *Journal of Hydrology*, 612, 128307. https://doi.org/10.1016/j.jhydrol.2022.128307

Lou, T., Xie, H. (2006) Photochemical alteration of the molecular weight of dissolved organic matter. *Chemosphere*, 65(11), 2333–2342. https://doi.org/10.1016/j.chemosphere.2006.05.001

Malik, A.A., Martiny, J.B., Brodie, E.L., Martiny, A.C., Treseder, K.K., Allison, S.D. (2020) Defining trait-based microbial strategies with consequences for soil carbon cycling under climate change. *The ISME Journal*, 14(1), 1–9. https://doi.org/10.1038/s41396-019-0510-0

Manasypov, R.M., Vorobyev, S.N., Loiko, S.V., Kritzkov, I.V., Shirokova, L.S., Shevchenko, V.P., Pokrovsky, O.S. (2015) Seasonal dynamics of organic carbon and metals in thermokarst lakes from the discontinuous permafrost zone of western Siberia. *Biogeosciences*, 12(10), 3009–3028. https://doi.org/10.5194/bg-12-3009-2015

Mastný, J., Kaštovská, E., Bárta, J., Chroňáková, A., Borovec, J., Šantrůčková, H., Urbanová, Z., Edwards K.R., Picek, T. (2018) Quality of DOC produced during litter decomposition of peatland plant dominants. *Soil Biology and Biochemistry*, 121, 221–230. https://doi.org/10.1016/j.soilbio.2018.03.018

Mellegård, H., Stalheim, T., Hormazabal, V., Granum, P.E., Hardy, S.P. (2009) Antibacterial activity of sphagnum acid and other phenolic compounds found in *Sphagnum papillosum* against food-borne bacteria. *Letters in Applied Microbiology*, 49(1), 85–90. https://doi.org/10.1111/j.1472-765X.2009.02622.x

Minor, E.C., Swenson, M.M., Mattson, B.M., Oyler, A.R. (2014) Structural characterization of dissolved organic matter: a review of current techniques for isolation and analysis. *Environmental Science: Processes & Impacts*, 16(9), 2064–2079. https://doi.org/10.1039/C4EM00062E

Munir, T.M., Khadka, B., Xu, B., Strack, M. (2017) Partitioning forest-floor respiration into source based emissions in a boreal forested bog: Responses to experimental drought. *Forests*, 8(3), 75. https://doi.org/10.3390/f8030075

Mutch, R.W. (1964) Ignition delay of ponderosa pine needles and sphagnum moss. *Journal of Applied Chemistry*, 14(7), 271–275. https://doi.org/10.1002/jctb.5010140702

Olefeldt, D., Roulet, N.T. (2012) Effects of permafrost and hydrology on the composition and transport of dissolved organic carbon in a subarctic peatland complex. *Journal of Geophysical Research: Biogeosciences*, 117, G01005. https://doi.org/10.1029/2011JG001819

Olk, D.C., Bloom, P.R., Perdue, E.M., McKnight, D.M., Chen, Y., Farenhorst, A., Senesi, N., Chin, Y.-P., Schmitt-Kopplin, P., Hertkorn, N., Harir, M. (2019) Environmental and agricultural relevance of humic fractions extracted by alkali from soils and natural waters. *Journal of Environmental Quality*, 48(2), 217–232. https://doi.org/10.2134/jeq2019.02.0041

Payandi-Rolland, D., Shirokova, L.S., Tesfa, M., Bénézeth, P., Lim, A.G., Kuzmina, D., Karlsson, J., Giesler, R., Pokrovsky, O.S. (2020) Dissolved organic matter biodegradation along a hydrological continuum in permafrost peatlands. *Science of The Total Environment*, 749, 141463. https://doi.org/10.1016/j.scitotenv.2020.141463

Peuravuori, J., Pihlaja, K. (1997) Molecular size distribution and spectroscopic properties of aquatic humic substances. *Analytica Chimica Acta*, 337(2), 133–149. https://doi.org/10.1016/S0003-2670(96)00412-6

Pinsonneault, A.J., Moore, T.R., Roulet, N.T., Lapierre, J.F. (2016) Biodegradability of vegetation-derived dissolved organic carbon in a cool temperate ombrotrophic bog. *Ecosystems*, 19, 1023–1036. https://doi.org/10.1007/s10021-016-9984-z

Pokrovsky, O.S., Manasypov, R.M., Loiko, S., Shirokova, L.S., Krickov, I.A., Pokrovsky, B.G., Kolesnichenko, L.G., Kopysov, S.G., Zemtzov, V.A., Kulizhsky, S.P., Vorobyev, S.N., Kirpotin, S.N. (2015) Permafrost coverage, watershed area and season control of dissolved carbon and major elements in western Siberian rivers. Biogeosciences, 12(21), 6301–6320. https://doi.org/10.5194/bg-12-6301-2015

Poulin, B.A., Ryan, J.N., Aiken, G.R. (2014) Effects of iron on optical properties of dissolved organic matter. *Environmental Science & Technology*, 48(17), 10098–10106. https://doi.org/10.1021/es502670r

Prijac, A., Gandois, L., Taillardat, P., Bourgault, M.A., Riahi, K., Ponçot, A., Tremblay, A., Garneau, M. (2023) Hydrological connectivity controls dissolved organic carbon exports in a peatland-dominated boreal catchment stream. *Hydrology and Earth System Sciences*, 27(21), 3935–3955. https://doi.org/10.5194/hess-27-3935-2023

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna AT. Online at: https://www.R-project.org, accessed 20 Jun 2024.

Raudina, T.V., Loiko, S.V., Lim, A.G., Krickov, I.V., Shirokova, L.S., Istigechev, G.I., Kuzmina, D.M., Kulizhsky, S.P., Vorobyev, S.N., Pokrovsky, O.S. (2017) Dissolved organic carbon and major and trace elements in peat porewater of sporadic, discontinuous, and continuous permafrost zones of western Siberia. *Biogeosciences*, 14(14), 3561–3584. https://doi.org/10.5194/bg-14-3561-2017

Raudina, T.V., Smirnov, S.V., Lushchaeva, I.V., Istigechev, G.I., Kulizhskiy, S.P., Golovatskaya, E.A., Shirokova, L.S., Pokrovsky, O.S. (2022) Seasonal and spatial variations of dissolved organic matter biodegradation along the aquatic continuum in the southern taiga bog complex, Western Siberia. *Water*, 14(23), 3969. https://doi.org/10.3390/w14233969

Robroek, B.J., Albrecht, R.J., Hamard, S., Pulgarin, A., Bragazza, L., Buttler, A., Jassey, V.E. (2016) Peatland vascular plant functional types affect dissolved organic matter chemistry. *Plant and Soil*, 407, 135–143. https://doi.org/10.1007/s11104-015-2710-3

Rosset, T., Binet, S., Rigal, F., Gandois, L. (2022) Peatland dissolved organic carbon export to surface waters: Global significance and effects of anthropogenic disturbance. *Geophysical Research Letters*, 49(5), e2021GL096616. https://doi.org/10.1029/2021GL096616

Roulet, N.T., Lafleur, P.M., Richard, P.J., Moore, T.R., Humphreys, E.R., Bubier, J.I.L.L. (2007) Contemporary carbon balance and late Holocene carbon accumulation in a northern peatland. *Global Change Biology*, 13(2), 397–411. https://doi.org/10.1111/j.1365-2486.2006.01292.x

Savichev, O.G. (2015) Geokhimicheskiye pokazateli bolotnykh vod v tayezhnoy zone Zapadnoy Sibiri (Geochemical parameters of bog waters in the taiga zone of Western Siberia). *Izvestiya Rossiiskoi Akademii Nauk: Seriya Geograficheskaya*, 4, 47–57 (in Russian with English abstract). https://doi.org/10.15356/0373-2444-2015-4-47-57

Savicheva, O.G., Inisheva, L.I. (2003) Biohimicheskaja aktivnost' torfov raznogo botanicheskogo sostava (Biochemical activity of peats of different botanical composition). *Himija rastitel'nogo syr'ja* (*Chemistry of Plant Raw Materials*), 3, 41–50 (in Russian).

Sirin, A.A. (2022) Bolota i antropogenno-izmenennye torfyaniki: uglerod, parnikovye gazy, izmenenie klimata (Peatbogs and anthopogenically modified peatlands: carbon, greenhouse gases and climate change). *Uspekhi Sovremennoi Biologii* (*Advances in Modern Biology*), 142(6), 560–577 (in Russian). https://doi.org/10.31857/S0042132422060096

Spencer, R.G., Aiken, G.R., Wickland, K.P., Striegl, R.G., Hernes, P.J. (2008) Seasonal and spatial variability in dissolved organic matter quantity and composition from the Yukon River basin, Alaska. *Global Biogeochemical Cycles*, 22(4), GB4002. https://doi.org/10.1029/2008GB003231

Strack, M., Zuback, Y., McCarter, C., Price, J. (2015) Changes in dissolved organic carbon quality in soils and discharge 10 years after peatland restoration. *Journal of Hydrology*, 527, 345–354. https://doi.org/10.1016/j.jhydrol.2015.04.061

Strack, M., Munir, T.M., Khadka, B. (2019) Shrub abundance contributes to shifts in dissolved organic carbon concentration and chemistry in a continental bog exposed to drainage and warming. *Ecohydrology*, 12(5), e2100. https://doi.org/10.1002/eco.2100

Stutter, M.I., Lumsdon, D.G., Thoss, V. (2007) Physico-chemical and biological controls on dissolved organic matter in peat aggregate columns. *European Journal of Soil Science*, 58(3), 646–657. https://doi.org/10.1111/j.1365-2389.2006.00851.x

Thurman, E.M. (1985) Amount of organic carbon in natural waters. In: *Organic Geochemistry of Natural Waters*, Developments in Biogeochemistry Volume 2, Springer, Dordrecht NL, 7–65. https://doi.org/10.1007/978-94-009-5095-5_2

Tsyganov, A.N., Zarov, E.A., Mazei, Y.A., Kulkov, M.G., Babeshko, K.V., Yushkovets, S.Y., Payne, R.J., Ratcliffe, J.L., Fatyunina, Y.A., Zazovskaya, E.P., Lapshina, E.D. (2021) Key periods of peatland development and environmental changes in the middle taiga zone of Western Siberia during the Holocene. *Ambio*, 50, 1896–1909. https://doi.org/10.1007/s13280-021-01545-7

Urban, N.R., Bayley, S.E., Eisenreich, S.J. (1989) Export of dissolved organic carbon and acidity from peatlands. *Water Resources Research*, 25(7), 1619–1628. https://doi.org/10.1029/WR025i007p01619

Verhoeven, J.T.A., Liefveld, W.M. (1997) The ecological significance of organochemical compounds in *Sphagnum*. *Acta Botanica Neerlandica*, 46(2), 117–130. https://doi.org/10.1111/plb.1997.46.2.117

Vorobyev, S.N., Kolesnichenko, Y., Krickov, I.V., Berezin, A.E., Kirpotin, S.N., Pokrovsky, O.S. (2025) The Great Vasyugan Mire of western

Siberia: Hydrochemistry and greenhouse gas dynamics of peatland pools of the world's largest mire. *Ecological Indicators*, 170, 113054. https://doi.org/10.1016/j.ecolind.2024.113054
Waldo, N.B., Tfaily, M.M., Anderton, C., Neumann, R.B. (2021) The importance of nutrients for microbial priming in a bog rhizosphere. *Biogeochemistry*, 152(2), 271–290. https://doi.org/10.1007/s10533-021-00754-2
Wallage, Z.E., Holden, J., McDonald, A.T. (2006) Drain blocking: An effective treatment for reducing dissolved organic carbon loss and water discolouration in a drained peatland. *Science of the Total Environment*, 367(2–3), 811–821. https://doi.org/10.1016/j.scitotenv.2006.02.010
Webster, K.L., McLaughlin, J.W. (2010) Importance of the water table in controlling dissolved carbon along a fen nutrient gradient. *Soil Science Society of America Journal*, 74(6), 2254–2266. https://doi.org/10.2136/sssaj2009.0111
Weishaar, J.L., Aiken, G.R., Bergamaschi, B.A., Fram, M.S., Fujii, R., Mopper, K. (2003) Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic carbon. *Environmental Science & Technology*, 37(20), 4702–4708. https://doi.org/10.1021/es030360x
Wickham, H. (2016) Data analysis. In: *ggplot2: Elegant Graphics for Data Analysis*, Use R! book series, Springer, Cham CH, 189–201. https://doi.org/10.1007/978-3-319-24277-4_9
Wickham, H., Francois, R., Henry, L., Muller, K., Vaughan, D. (2023) *Dplyr: A Grammar of Data Manipulation*. R package version 1.1.2 (computer software). Online at: https://github.com/tidyverse/dplyr, https://dplyr.tidyverse.org, accessed 13 Dec 2024.
Worrall, F., Gibson, H.S., Burt, T.P. (2008) Production vs. solubility in controlling runoff of DOC from peat soils - The use of an event analysis. *Journal of Hydrology*, 358(1–2), 84–95. https://doi.org/10.1016/j.jhydrol.2008.05.037
Xu, J., Morris, P.J., Liu, J., Holden, J. (2018) PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. *Catena*, 160, 134–140. https://doi.org/10.1016/j.catena.2017.09.010
Yu, Z., Charman, D., Beilman, D.W., Brovkin, V., Large, D.J. (2014) Carbon in Peat on EArth through Time (C-PEAT). *PAGES (Past Global Changes)*, 22(2), 92. https://doi.org/10.22498/pages.22.2.92
Zarov, E.A., Meshcheryakova, A.V., Shanyova, V.S., Khoroshavin, V.Y. (2022) Water table and dissolved organic carbon seasonal dynamic at the different ecosystems of the ombrotrophic bog (Mukhrino, West Siberia). In: Korneykova, M., Vasenev, V., Dovletyarova, E., Valentini, R., Gorbov, S., Vinnikov, D., Dushkova, D. (eds.) *Smart and Sustainable Urban Ecosystems: Challenges and Solutions*, SSC 2022 Proceedings, Springer Geography, Springer, Cham CH, 169–180. https://doi.org/10.1007/978-3-031-37216-2_14
Zarov, E.A., Lapshina, E.D., Kuhlmann, I., Schulze, E.D. (2023) Carbon accumulation and the possibility of carbon losses by vertical movement of dissolved organic carbon in Western Siberian peatlands. *Forests*, 14(12), 2393. https://doi.org/10.3390/f14122393
Zou, J., Ziegler, A.D., Chen, D., McNicol, G., Ciais, P., Jiang, X., Zheng, C., Wu, J., Wu, J., Lin, Z., He, X., Brown, L.E., Holden, J., Zhang, Z., Ramchunder, S.J., Chen, A., Zeng, Z. (2022) Rewetting global wetlands effectively reduces major greenhouse gas emissions, *Nature Geoscience*, 15, 627–632. https://doi.org/10.1038/s41561-022-00989-0

Submitted 20 Jan 2025, final revision 15 Dec 2025
Editor: Gerald Jurasinski

Author for correspondence:
Dr Evgeny A. Zarov (senior researcher), Yugra State University, Chekhova str. 16, Khanty-Mansiysk, Khanty-Mansiysk autonomous okrug, Russia, zip-code: 628007.
Tel: +7 3467 377000 (315); E-mail: zarov.evgen@yandex.ru

Supplementary material:
The data from this study are provided in a .zip file that may be downloaded separately. The .zip file contains one .xlsx file, namely “MaP_Vol_32_Art_36_Supplement.xlsx”, containing data values for pH, EC, water table, DOC, $SUVA_{254}$, E2:E3, E4:E6 and DOC (repeated for 2023 only); plus one .docx file, namely “MaP_Vol_32_Art_36_Read_Me.docx”, containing explanatory notes including descriptions of the data values.