Peat core research in the Western Siberian Lowland: applications of palaeoecological proxies~~methods applied~~, regions studied, and future prospects

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Abstract.

Peatlands are natural archives that preserve information not only about their own development but also about past environmental conditions in surrounding landscapes. This study presents a comprehensive review of palaeoecological research based on peat cores from the Western Siberian Lowland (WSL). We compiled and georeferenced 654 peat cores and documented the application of 26 palaeoecological proxies, including chronological, physical, chemical, and biological indicators, resulting in the creation of the Western Siberian Peat Core Database (WSPC). The database synthesizes information from 156 publications spanning 1953-2025 and captures both the temporal and methodological evolution of peatland studies in the region, highlighting a clear shift from early single-proxy, low resolution investigations to modern multi-proxy high-resolution studies. Spatial analysis reveals high density of peat-core studies~~high peat core density~~ along major rivers and in the Great Vasyugan Mire, while remote northern continuous permafrost regions remain underrepresented. Temporal coverage indicates that most cores capture Holocene peatland dynamics, with the longest records in non-permafrost and isolated permafrost zones, extending into the Late Glacial (~15,600 cal. yr BP). The database underscores the dominant role of fundamental physical and chemical proxies, while highlighting the selective application of biological proxies and the limited use of specialized chemical analyses. In addition, the study identifies key research challenges in ~~Western Siberia~~WSL, including narrow seasonal windows for fieldwork, permafrost, limited transport infrastructure, permit requirements, and geopolitical barriers, which collectively constrain peatland sampling. The WSPC database represents the most extensive compilation of metadata on peat cores in the region, integrating georeferenced core locations, original core identifiers, applied palaeoecological proxies, and associated literature, offering critical guidance for targeted sampling and future research to address spatial, temporal, and proxy-specific gaps in the study of WSL peatlands.~~The WSPC database represents the most extensive compilation of peat-core-based palaeoecological data for this region, offering critical guidance for targeted sampling and future research to address spatial, temporal, and proxy-specific gaps in the study of Western Siberian peatlands.~~

1 Introduction

Peatlands are one of the most important terrestrial ecosystems in the world, acting as significant carbon sinks, regulating hydrology, and providing unique habitats for diverse species. Covering only about 3% of the land surface, they store roughly one-third of the world's soil carbon, highlighting their critical role in the global carbon cycle (Greifswald Mire Centre, 2022; Scharlemann et al., 2014; Xu et al., 2018). In addition to their ecological importance, peat deposits constitute valuable natural archives due to the preservation of biological remains and physicochemical characteristics formed during peat accumulation under specific environmental conditions (Barber, 1993). Due to their stratified structure and often continuous accumulation, peat sequences provide long-term records of environmental and climatic changes.

The palaeoecological reconstructions from peat deposits are based on the analysis of palaeoecological proxies, which are indirect indicators of past environmental conditions preserved within peat sequences. Depending on their origin and the type of information they provide, these proxies can be broadly classified into biological, chemical, physical, and chronological proxies. The application of these proxies enables the reconstruction of past hydrological conditions, vegetation dynamics, fire activity, carbon accumulation patterns, and other aspects of ecosystem functioning, thereby providing detailed insights into Holocene environmental history (Chambers and Charman, 2004).

One of the largest peatland complexes in the world is found in Western Siberian Lowland (WSL), with almost 600 000 km^2 of peatlands and 70.2 Pg of carbon stored (Sheng et al., 2004). Peatlands across the WSL began accumulating almost simultaneously around 11,000-10,000 years BP, as postglacial environmental conditions became favourable for peat formation, with only a few sites showing evidence of earlier initiation (Alexandrov et al., 2016; Kremenetski et al., 2003). Spanning the entire Holocene and extending over an exceptionally large geographical area, these peatlands preserve detailed records of environmental and climatic changes, documenting not only their own developmental history but also broader landscape-scale ecosystem dynamics. The scale and ecological significance of the WSL make it a key region for understanding ~~past and future~~long-term peatland dynamics~~,~~ and predicting peatland responses to ongoing climate change. ~~particularly under ongoing climate change.~~

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Comprehensive syntheses by Kremenetski et al. (2003) and Solomeshch (2005), who consolidated the extensive Russian-language literature and documented the legacy of scientific work in the WSL, provide the historical context for early exploration and peatland research. As summarized by them, the scientific study of ~~Western Siberian~~WSL peatlands began in the early 20th century, initially through government botanical and pedological surveys in the southern WSL (Dranitsyn, 1914; Gordiagin, 1901; Zhilinsky, 1907), with more detailed investigations followed in the 1920s (Baryshnikov, 1929; Bronzov, 1930). During the 1930s, botanical expeditions to the Yamal and Gydan peninsulas generated the first scientific descriptions of arctic peatlands in the northern WSL (Gorodkov, 1932; Govorukhin, 1933). These early investigations, largely carried out along river valleys and exposed natural outcrops, formed the foundation for later palaeoecological research and represent a major legacy of early Soviet and Russian studies~~major legacy of early Russian scientists~~.

The discovery of significant oil reserves in the WSL in the 1950s triggered a wave of intensive peatland exploration aimed at assessing peat thickness, distribution, and suitability for infrastructure development. Exploration of the WSL have historically been difficult due to harsh climatic conditions, vast distances, and complex topography. Despite these challenges, the West Siberian Peat Exploratory Expedition (Glavtorffond RSFSR, 1956) produced the first large-scale estimates of peat stocks for the region, with similar work carried out in the Middle Taiga zone of the WSL in a following decade (Lapshina and Zarov, 2023). During the 1960s and 1970s, systematic surveys mapped the spatial distribution of peatlands and documented peat thickness, hydrology and vegetation cover (Ivanov and Novikov, 1976; Liss and Berezina, 1981; Neustadt, 1971). Important cartographic products, including Geoltorfrazvedka's peatland maps (Map of West Siberian wetlands, 1970, 1996) and Romanova's latitudinal zonation of Eurasian peatlands (Ivanov and Novikov, 1976), remain central references. This period also marked the beginning of modern paleoecology in the WSL, with the first radiocarbon dates (Liss and Kulikova, 1967; Neustadt, 1967) and the earliest pollen-dated peat stratigraphies (Glebov et al., 1974; Levkovskaya et al., 1970; Volkov et al., 1973). Evolution of paleoreconstruction methods started in the 1970s when more precise approach, including the method of retrospective ecological peat analysis with higher sampling resolution started to be implemented (Lapshina and Zarov, 2023; L'vov, 1974).

From the 1980s onward, research expanded into peatland ecology, carbon storage, and long-term accumulation dynamics (Botch et al., 1995; Botch and Masing, 1983; Neustadt, M.I., 1984). The first integrative, internationally accessible synthesis appeared in Kremenetski et al. (2003), who reviewed WSL peatland zonation, carbon stocks, and late-Quaternary development, highlighting major gaps in knowledge and the need to integrate the extensive Russian-language legacy. Solomeshch (2005) further refined understanding of WSL peatland ecology and provided an updated overview of their structure, distribution, and environmental significance. Together, these works emphasize the long-standing contributions of Russian scientists and underscore the global importance of the WSL for paleoclimate reconstruction and carbon-cycle research.

Despite the wealth of studies, much of the palaeoecological research in the WSL remains dispersed across numerous publications, often in older Russian-language journals or books. The variety of proxies, peatland types, and sampling locations complicates efforts to form a complete picture of the region's long-term ecological changes. Additionally, access to detailed site-level information, including peat core locations, stratigraphic data, and the specific proxies analysed, is limited, hindering cross-site comparisons and meta-analyses. These challenges underscore the need for a structured and accessible resource that consolidates existing information, providing a clear overview of what has been studied and where gaps in knowledge remain.

The goal of this review is to synthesize and organize existing palaeoecological research across the WSL by developing the Western Siberian Peat Core Database (WSPC). This database compiles information on peat core locations, the palaeoecological proxies analysed, and the original source references, providing a harmonized inventory of research in this globally significant peatland region. Beyond cataloguing peat cores and proxies, this synthesis addresses key questions about the development of peatland research in the WSL. How has the ~~suite~~ application of palaeoecological proxies evolved over time, from early single-proxy studies to modern multi-proxy approaches? Where are the main spatial gaps in the coverage of peat-core studies ~~gaps in peat-core coverage~~ across vegetation and permafrost zones, and how have logistical constraints shaped sampling locations? Which proxies remain rarely used, where are these methods under-represented, and what are the implications for reconstructing peatland hydrology, fire regimes, and geochemical conditions at a regional scale? By framing the database around these questions, our review not only documents past research but also highlights priorities and strategies for future studies. Rather than serving as a tool for quantitative analysis, the WSPC database provides a comprehensive overview of what has been studied to date. By consolidating dispersed and often difficult-to-access data, the database facilitates identification of sites with comparable proxy records, helps researchers locate relevant datasets, and supports strategic planning of future fieldwork. Ultimately, the WSPC database aims to enhance accessibility, transparency, and coordination in ~~Western Siberian~~WSL peatland research.

2 Study region

The geographical extent of the study region considered in this review follows the boundary of the Western Siberian Lowland (WSL) defined by Sheng et al. (2004). The natural boundaries of the region are marked by the Ural Mountains in the west, the Yenisey River in the east, the Altai Mountains and Kazakh steppes in the south, and the Kara Sea in the north (Fig. 1). The study region stretches from 60-93°E to 52-73°N and covers the area of approximately ~~3 0~~2 600 000 km^2. The WSL is the flattest and lowest major physiographic region of Russia, characterized by an extensive plain that gently slopes northward and lies between 0 and 300 m a.s.l (Solomeshch, 2005). Geologically, the lowland is underlain by a young tectonic plate covered by thick sedimentary sequence that increases from around 3 km in the south to 11 km in the north (Kurakova, 2024). This succession consists of alternating continental and marine deposits and is capped by 200–250 m of Quaternary sediments, primarily clays, sands, and loams (Kremenetski et al., 2003; Kurakova, 2024). The topography of the WSL contributes to the occurrence of a clear latitudinal distribution of climatic zones and vegetation. According to the Köppen-Geiger climate classification, most of the WSL has a subarctic climate (Dfc), with mean annual air temperatures ranging from -11.5°C in the Gyda Peninsula to 1 to -1°C in the south, and annual precipitation between 390 and 600 mm (Beck et al., 2018; Solomeshch, 2005; Trofimova and Balybina, 2014). Vegetation mirrors this latitudinal pattern, transitioning from arctic tundra in the north through the extensive zone of boreal forest (taiga), to a narrow belt of temperate broadleaf and mixed forests, and ultimately temperate grasslands and shrublands in the far south (Olson et al., 2001). The characteristic feature of this region is presence of permafrost, which developed mostly in Late Pleistocene (Duchkov, 2006). Currently, permafrost extends southward to about 60°N, with continuous permafrost on the Yamal and Gyda Peninsulas reaching up to ~ 67°N and ranging in thickness from 100 to over 500 m, whereas further south the permafrost becomes discontinuous, sporadic, isolated, and finally absent in the southernmost WSL (Solomeshch, 2005). The combination of flat terrain and fine-grained, poorly drained sediments promotes extensive waterlogging and widespread peatland development (Kirpotin et al., 2009). As a consequence, nearly 50% of the WSL is covered by wetland ecosystems. Peatlands occupy 592 ~~,~~440 km^2 (20%) of this area, with the largest peatland complex in the world, the Great Vasyugan Mire, covering 67 800~~.78~~ km^2 ~~million hectares~~ (Sheng et al., 2004; Vaganov et al., 2005). Most of the region lies within the Ob’ River watershed, with smaller northern sectors draining to the Nadym, Pur, and Taz rivers, and limited areas contributing to the left-bank tributaries of the Yenisey. The region is also rich in thermokarst lakes, mostly shallow systems less than 1 km^2 in area and 2–5 m deep, mainly formed due to the thawing of permafrost (Kirpotin et al., 2009; Polishchuk et al., 2017). In the forest-swamp zone, basins can contain up to 40–50% lake coverage, whereas lake density declines toward the southeast, though extensive marsh systems continue to regulate water tables and surface hydrology (Kurakova, 2024). Despite its vast area, population density in the WSL is low, especially in the northern sector where extensive peatland landscapes remain sparsely populated. However, since the mid-1960s, the region has undergone intensive oil and gas development, particularly in the mid- and lower Ob River basin. Consequently, although large areas i~~o~~n~~f~~ the north~~ern~~ ~~Lowland~~ remain relatively undisturbed, industrial activity and land-use change across ~~West Siberia~~WSL have imposed substantial pressures on peatlands, altering their structure, hydrology, and ecological dynamics (Solomeshch, 2005).

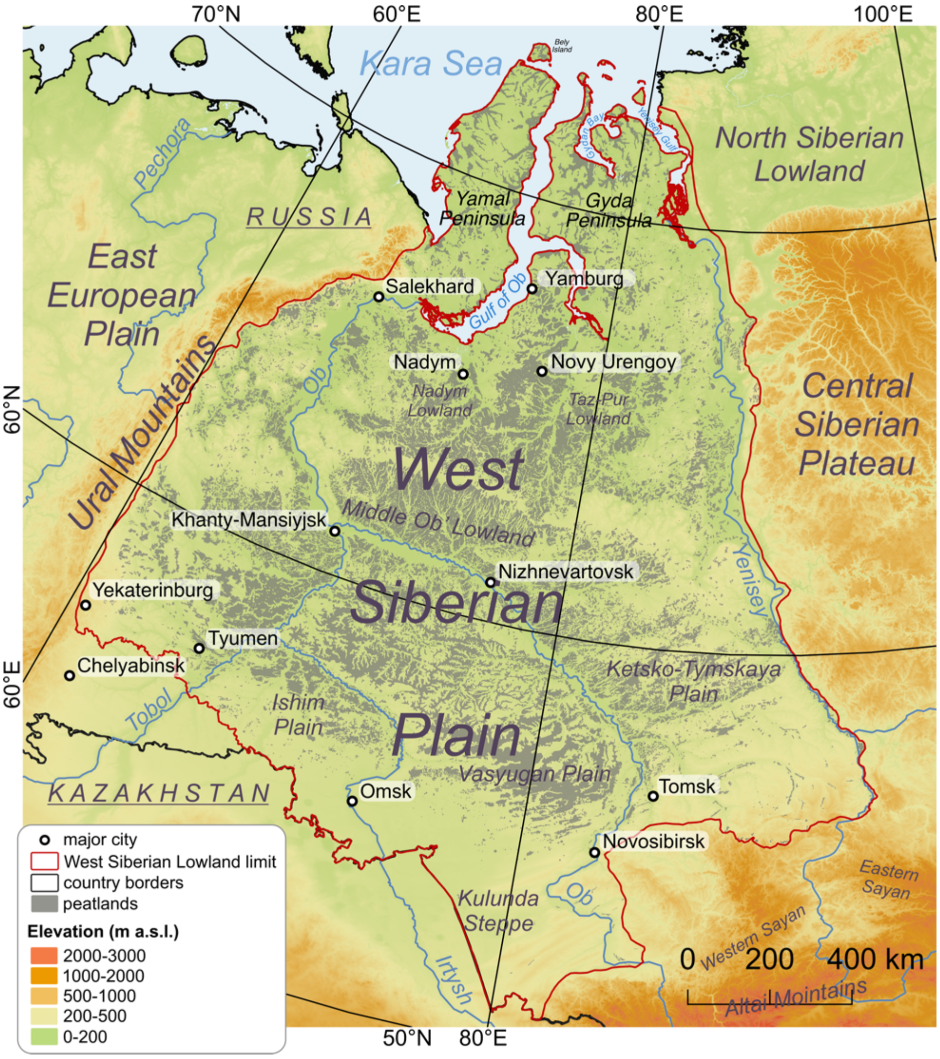

Figure 1. Topographic map of Western Siberian Lowland ~~(WSL)~~ with the extent of peatlands based on Sheng et al (2004), main rivers, selected cities, and main geographic units and geographical extent of study area considered in this literature review. Elevation source: © DLR e.V. 2010-2014 and © Airbus Defence and Space GmbH 2014-2018 provided under COPERNICUS by the European Union and ESA; all rights reserved.

2.1 Peatland extent mapping

Estimates of peatland extent in ~~Western Siberia~~WSL have varied considerably over time due to differences in mapping methods, definitions, and data availability. Early studies reported smaller areas; for example, Neustadt (1971) as a first estimated peatland extent to 325 ~~,~~380 km², later Tiuremnov (1976) 34~~1~~1 ~~,~~000 km², and Efremov and Efremova (2001) 464 ~~,~~000 km², illustrating the progressive refinement of peatland inventories. Sheng et al. (2004) provided a more detailed assessment, estimating 592 ~~,~~440 km² of peatlands with a total carbon pool of 70.2 Pg C, based on a comprehensive GIS-based inventory combining decades of Geoltorfrazvedka field surveys, Russian wetland maps, satellite imagery, and extensive digitized peat depth and carbon data (Fig. 2a). However, the authors noted that this estimate should still be considered a minimum value because the Russian survey data used in the compilation did not include thin peat deposits (<50 cm). Modern global products, such as the Global Peatland Map 2.0 (GPM2.0), classify regions as peat-dominated or peat-in-soil-mosaic at a 1×1 km resolution by integrating multiple regional and national datasets using proxy mapping, satellite classification, and expert judgement (Greifswald Mire Centre, 2022). The available version of GPM uses a peat depth threshold of ≥10 cm to account for climate-relevant peat carbon, rather than the conventional agricultural threshold of ≥30 cm, which increases Russia's estimated peatland area 2.6 times (UNEP, 2022). While GPM provides consistent and updated coverage, its ≥10 cm threshold overestimates the area of peatlands that are relevant for palaeoecological reconstruction. This overestimation is particularly visible in the continuous permafrost zone, where it shows nearly continuous peatland coverage; as well as along the western border and in the eastern parts of the region, including the Yenisey valley and the Ketsko-Tymskaya Plain (Fig.

2b). Therefore, for this review, the regional map created by Sheng et al. (2004) remains the most reliable source for WSL peatlands. Although this inventory likely underestimates the total peatland extent because peat deposits thinner than 50 cm were excluded, its methodological framework and closer correspondence to the ≥30 cm threshold commonly applied in palaeoecology make it more suitable for this review than GPM. Nevertheless, the selection of peatland datasets and peat depth thresholds should be considered in relation to the specific research objective. Inventories based on lower thresholds (e.g. ≥10 cm) may be more appropriate for large-scale carbon balance and climate-related studies, whereas thresholds closer to ≥30 cm are generally more applicable in palaeoecological investigations focused on sufficiently developed peat sequences suitable for long-term environmental reconstruction. Therefore, future field campaigns and research expeditions in WSL should evaluate peatland products and thresholds according to the aims of the study.~~Although many peat cores in the database are located outside the extent defined by Sheng et al. (2004), and GPM likely has higher overall accuracy, its methodological approach makes it unsuitable for studies requiring peatlands above the ≥30 cm threshold typically used in palaeoecology.~~

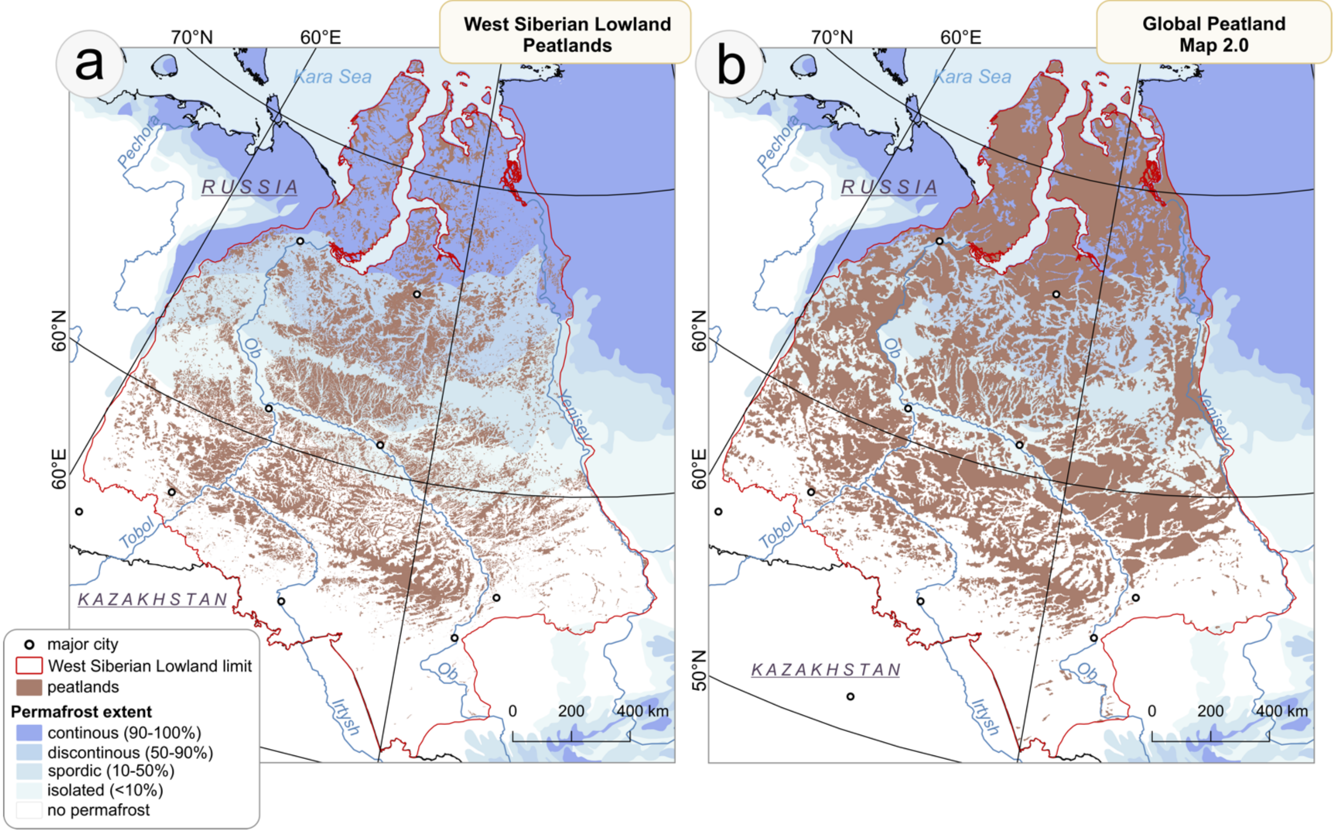

Figure 2. Spatial distribution of peatlands in the Western Siberian Lowlands: (a) regional map by Sheng et al. (2004) with peat depth threshold >50 cm; (b) Global Peatland Map 2.0 (Greifswald Mire Centre, 2022) with peat depth threshold ≥10 cm.

3 Methods and materials

3.1 Literature selection

This literature selection was based on two online databases of scientific papers: Google Scholar and Scopus, using the keywords "*Western Siberia*" AND "*reconstruction*" AND "*peatland*". The initial results were screened manually to identify relevant studies. We applied specific inclusion and exclusion criteria to select studies further used in this review:

- Publication type: only published articles and books were considered.
- Time span: studies published up to May 2025 were included.
- Language: only publications in English or Russian were considered.
- Temporal coverage: only stratigraphic peat cores or peat cross-sections were included, with a focus on Holocene records.

- Geographical extent: only studies in which at least one peat core was located within the borders of the Western Siberian Lowland (Fig. 1), as defined by Sheng et al. (2004) were included (Sheng, 2016).
- Core location: studies were included if they reported precise or approximate coring coordinates, or if approximate locations could be estimated from maps provided in the original publication. Studies lacking sufficient locational information were excluded.
- Coring material: only peat sediments (peat cores or peat cross-sections) were included. If the type of sediment could not be clearly determined, the core was excluded.
- Study type: eligible studies presented original palaeoecological data derived from peat cores, or meta-analyses synthesizing data from a defined set of peat core studies. Review articles and books that only summarized previously published data without referencing specific peat cores were excluded. We also excluded studies based solely on modelling or simulations not directly grounded in empirical peat core data.
- Minimum information required: to be eligible, peat cores had to provide at least one source of palaeoecological information (proxy), regardless of whether chronology was available (e.g., palynology, charcoal analysis, loss-on-ignition or bulk density). In addition, cores were also considered if they contained only chronological information or only basal depth data.

3.2 Data extraction and database creation

After compiling a database of relevant studies, we developed the Western Siberian Peat Core Database (WSPC) by extracting information on individual cores from each publication. For every peat core, we recorded the following required information: location and core name. Whenever available, we also collected supplementary details, including coring date, dating method, number of dated levels, temporal span of the record, sampling resolution, and applied proxies~~, and basal depth~~. In total, 26 different proxies were identified (~~Supplementary Table S1~~Table A1). To avoid duplication, we cross-checked all entries to identify peat cores reported in multiple publications. We first compared core names and reported coordinates (or approximate locations when exact coordinates were unavailable). When cores shared identical or nearly identical locations and had the same ages, lab numbers, basal depths, reference or any unique metadata that could be compared, we treated them as the same record. In cases where the same core was described across multiple publications, we merged the information into a single record. The ages of the records were obtained from the original publications, expressed in calibrated radiocarbon years (cal. yr BP) where available. For 27 sites with only uncalibrated ages, calibration was conducted in R Statistical Software (R Core Team, 2022) using the *bchron* package (Haslett and Parnell, 2008) and the IntCal20 calibration curve (Reimer et al., 2020) (~~Supplementary~~ Table A2~~S2~~). Peat cores were identified as basal (representing the complete peat sequence down to the mineral substrate) when such information was provided in the source publication, or when it could be inferred from the stratigraphic diagrams. In the WSPC database, each peat core was assigned a unique Core ID in the format WS_X (e.g., WS_001, WS_002, WS_003). Cores were numbered sequentially according to their geographic position, starting from the southernmost site and progressing northwards. In addition to the assigned Core IDs, we retained the original core names as reported in the source publications and databases to facilitate easier identification and cross-referencing. Each core includes also references to the original source from which the authors of this database obtained it, as well as information about the publication of the initial core source, if such details were provided in the reviewed publication.

3.3 Spatial analysis and data visualization

3.3.1 GIS data preparation and spatial datasets

To visualize and analyse the spatial distribution of peat cores, a shapefile (SHP) layer was created for WSPC database. All sites were georeferenced and compiled into a unified GIS layer using QGIS 3.16.2 software (QGIS Development Team, 2025), and the database attribute structure is described in Table 1. The extent of the study region, as well as all subsequent spatial analyses, followed the ~~Western Siberian Lowland~~WSL boundary as described by Sheng et al. (2004). Given the vast extent of the study region and clustering of coring sites, peat core density was assessed by dividing the area into 50 × 50 km grid cells. The number of cores within each cell was calculated using the *join attributes by location (summary)* tool (geometric predicate: *contains*) in QGIS. Besides the attributes obtained from the original publications, each peat core record was supplemented with information on its location within specific vegetation, permafrost, and peatland zones using the same tool in QGIS. Spatial data about vegetation zones were obtained from the map of terrestrial ecoregions by Olson et al. (2001), while permafrost extent was derived from the circum-Arctic map of permafrost and ground-ice conditions by Brown et al. (2002). The spatial extent of peatland zones was based on the map of major peatland zones originally published by Ivanov and Novikov (1976) and reproduced in Kremenetski et al. (2003). This map was georeferenced and digitized for use in this study.

Table 1. The column headers within Western Siberian Peat Core database and their meaning.

Column name	**Description**
Core_ID	Unique identifier for each or peat core
Core_name	Original names or identifiers used in the original publication with references
Coord_true	Information if exact geographical coordinates of the location of peat core were provided in the original publication
Lat	Latitude of the core location (in decimal degrees)
Lon	Longitude of the core location (in decimal degrees)
Core_date	Year or period when the core was collected
S_interval	Sampling interval (cm)
N_proxy	Number of proxy types analyzed in the core
P_type	Peatland type based on peatland zone by Kremenetski et al. (2003) after Ivanov and Novikov (1976)
Perm	Permafrost zone based on Brown et al. (2002)
Veg	Vegetation zone in WSL based on Olson et al. (2001)
Ref_n	Source publication reference (n = 1–12)
URL_n	DOI, repository link, or other online source corresponding to Ref_n (n = 1–12)
Chronology	
N_dates	Number of radiocarbon or other chronological dates available for the core
Age_calBP	Calibrated age in years before present (BP)
Error_calBP	Uncertainty or error range associated with the calibrated age
Age	Availability of data about core age
Biological proxies	
Pol	Availability of pollen data
NPP	Availability of non-pollen palynomorph data
Macro	Availability of plant macrofossil data
TA	Availability of testate amoebae data
MIC_char	Availability of microscopic charcoal data
MAC_char	Availability of macroscopic charcoal data
Orib	Availability of oribatid data
Moll	Availability of mollusc data
Diatom	Availability of diatom data
Arth	Availability of arthropod data
Zoo_rem	Availability of zoological remains data
Physical proxies	
BD	Availability of bulk density data
Moist	Availability of moisture content data
P_accum	Availability of peat accumulation data

Decomp	Availability of degree of decomposition data
Humif	Availability of peat humification data
B_depth	Availability of basal depth data
Chemical proxies	
Ash	Availability of ash content data
pH	Availability of pH data
OM	Availability of organic matter (loss on ignition) data
C_accum	Availability of carbon accumulation data
S_isotop	Availability of stable isotope data ($\delta^{13}C$, $\delta^{15}N$, δD, $\delta^{18}O$)
XRF_XRD	Availability of XRF (X-ray fluorescence) or XRD (X-ray diffraction) data
FTIR	Availability of FTIR (Fourier-transform infrared spectroscopy) data
Geochem	Availability of geochemical data (e.g., elemental analysis, trace element concentrations, radioisotopes, geochemical ratios)

3.3.2 Temporal coverage analysis and permafrost-related grouping

To analyse the percentage of peat cores covering each time interval, we assumed that the age of the record represents the period from the time of sampling back to the oldest dated level, although in some cases (particularly in the northern part of the study area) this may not have been the case. The same assumption was used to analyse the temporal coverage of individual proxies across ~~Western Siberia~~WSL. Given the substantial influence of permafrost on sampling and data availability, peat cores were classified into three groups corresponding to different permafrost zones: (1) non-permafrost and isolated permafrost, (2) sporadic and discontinuous permafrost, and (3) continuous permafrost.

3.3.3 Scoring system and spatial visualization of proxy representation

To~~For~~ evaluate~~ing~~ peat core datasets, we developed a quantitative scoring system to assess the quality and informational value of each peat core record. Proxies were grouped into three categories (biological, physical, and chemical) and each proxy was assigned an individual weight reflecting its relative contribution to environmental reconstructions (~~Supplementary~~ Table A~~S~~3). In addition to proxy-specific weights, we also applied an additional weighting step when integrating proxy information into the final scores. For each proxy group (biological, physical, and chemical), the total sum of all proxy weights from a given group was multiplied by a factor of 4 to emphasize the contribution of group-level proxy richness. When calculating the overall proxy score, the total sum of all proxies across groups was instead multiplied by 5, giving greater influence to records that include a broad suite of proxy types. Each record was also evaluated based on (1) the presence of a chronology, (2) total record length, and (3) the number of proxy types available. These components were scaled to 0–1 and combined with the weighted proxy information to generate four aggregated scores (*combined_bio*, *combined_phys*, *combined_chem*, and *combined_all*) (Table A~~S~~4). Higher scores indicate records with greater chronological control, longer temporal coverage, and richer multiproxy data. All calculations were performed in R Statistical Software (R Core Team, 2022) using the *dplyr* package (Wickham et al., 2023) for data manipulation. Spatial patterns of combined scores were visualized using QGIS. We applied the Heatmap (Kernel Density Estimation, KDE) tool to each dataset, using a 30 km radius and a pixel size of 100 × 100 m. The KDE was weighted by the combined scores of all proxies as well as separately for the biological, chemical, and physical proxy groups. The resulting density maps provide a spatially smoothed representation of proxy distribution and highlight both well-sampled regions and areas with insufficient proxy coverage.

3.3.4 Literature-based data extraction and figure assembly

For the literature analysis, if the full text of publication was unavailable, information on the language and proxies used was inferred from the available title, abstract, or bibliographic data accessible to the authors. All plots and diagrams were prepared in R Statistical Software (R Core Team, 2022) using *ggplot2* (Wickham, 2016) ~~and *ggbreak* (Xu et al., 2021)~~ package~~s~~, and final figures were assembled in CorelDRAW Graphic Suite 2021.

4 Results and Discussion

4.1 Peat core studies in the Western Siberian Lowland – literature analysis

4.1.1 Source publications overview

The database was compiled from a total of 156 publications published between 1953 and 2025, which were classified into two categories. The first group *primary sources* included 99 publications identified through an extensive literature review, from which data were directly obtained and used to build the database. The second group *secondary sources* included 57 original publications that were not directly accessible, but were cited within the primary publications used for data extraction. For each core, references are provided both to the publication from which the data were obtained (primary source) and, where available, to the original source publication cited therein (secondary source). The WSPC database is based on 82 English-language, 73 Russian-language, and one German-language publications. The authors had direct access to 79 of the English-language and 20 of the Russian-language sources.

The publications used in the compilation of the database contained information on varying numbers of peat cores. The majority of studies (82%) presented data from one to five cores, typically providing reconstructions at the local or regional scale. Another 13% of the publications included results from six to fifty cores. These studies analysed various regions within the Western Siberian Lowland (WSL), often along transects across peatlands, or incorporated WSL data as part of larger datasets. Only eight publications contained datasets with more than fifty peat cores. These studies generally focused on large-scale syntheses addressing specific research questions at the global scale (such as carbon accumulation) or provided a more detailed analysis of the ~~Western Siberia~~WSL, and include Kremenetski et al. (2003), Sheng et al. (2004), Smith et al. (2004, 2012), MacDonald et al. (2006), Loisel et al. (2014), Hugelius et al. (2020), and Lapshina and Zarov (2023).

Based on conducted literature review, it was observed that between 1950 and 1990, the number of peat core studies in ~~Western Siberia~~WSL increased notably, with most results published in Russian-language journals or books and only a limited number appearing in English (Fig. 3~~2~~a). This pattern reflects the early growth of peat research during the Soviet period and the dominance of domestic Soviet research activity, as the region remained largely inaccessible to the international scientific community. After 1990, this trend shifted, as the number of English-language publications increased rapidly, reflecting the onset of international collaboration after the collapse of the USSR.~~reflecting the collapse of the USSR and the onset of international collaboration.~~ The decade 2010–2020 saw the highest number of publications, reflecting not only regional research dynamics but also the broader global growth in scientific output. Although the decade 2020–2030 is only halfway through, 28 papers on this topic have already been published. While this trend may suggest that the current decade will produce the highest number of publications, ongoing geopolitical tensions, limited accessibility of some areas, and difficulties in collaborating with Russian scientists may slow down further research activity.

4.1.2 Trends in palaeoecological proxy use in the Western Siberian Lowland~~Evolution of proxy use in Western Siberian studies~~

Based on the use of proxies, two distinct periods can be identified in ~~Western Siberian~~WSL studies: an early stage (1950–2000), characterized by single-proxy studies, and the modern period (after 2000), marked by increasing integration of biological, physical, and chemical indicators (Fig. 3~~2~~b). A major step forward in peatland research was the implementation of radiocarbon dating, developed in the 1940s (Olsson, 2009). Since the 1960s, it has become increasingly important in paleoenvironmental studies and remains the most widely applied chronological tool in peatland research i~~o~~n ~~Western Siberia~~WSL (Kremenetski et al., 2003). Whereas earlier studies often reported results solely based on depth, radiocarbon dating is now used almost universally. Basal depth was an important physical parameter not only from a scientific perspective but also from an economic one. The discovery of oil in the 1950s initiated intensive studies of ~~Western Siberian~~WSL peatlands, as information on peat thickness was essential for constructing roads and infrastructure required for oil exploration (Kremenetski et al., 2003). Early decades were dominated by classic palynological studies. Pollen was the first biological proxy applied in this region and has maintained its importance to the present day. However, although pollen analysis is widely used, it primarily provides information about the vegetation and environment surrounding the peatland rather than the peatland itself. Growing interest in peatland development led to the increasing use of plant macrofossil analysis, which began to be applied from the 1980s onward. After 2000, more proxies started to be implemented in research on ~~Western Siberia~~WSL. New biological proxies, such as testate amoebae and micro- and macrocharcoal, were introduced, providing valuable tools for reconstructing changes in peatland hydrology and fire activity at different spatial scales. More laboratory analyses aimed at obtaining more precise data on the physical and chemical properties of peat began to be applied (e.g., bulk density, pH, ash content), along with newly developed technologies introduced over the past decade (e.g., XRF (X-ray fluorescence), FTIR (Fourier-transform infrared spectroscopy)). Peat and carbon accumulation were already studied in research conducted before 2000; however, their frequency had increased noticeably since then. The increased variety of applied proxies over the past 25 years, on one hand reflects the development of new research methods, and on the other, a growing awareness of the importance of ~~these~~ peatland ecosystems and the desire to better understand their history.

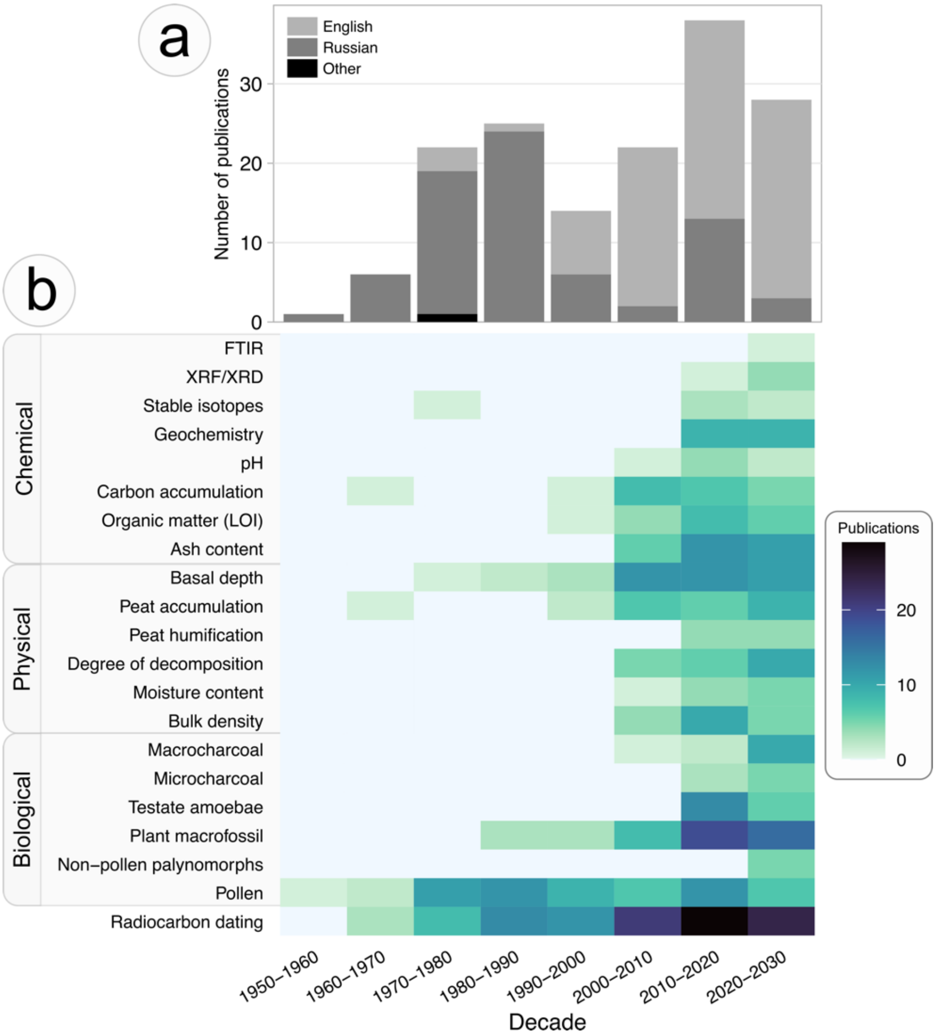

Figure 3. Temporal patterns in research output and methodological approaches: (a) trends in the number of publications in Russian and English per decade; (b) frequency of selected proxies used in studies across decades. Abbreviations: XRF – X-ray fluorescence; XRD – X-ray diffraction; FTIR – Fourier-transform infrared spectroscopy.

4.2 Western Siberian Peat Core Database

4.2.1 General information and spatial distribution

The Western Siberian Peat Core Database (WSPC) includes information on the locations and applied palaeoecological proxies of 654 peat cores or peat cross-sections collected from the~~ Western Siberian Lowland (WSL~~ WSL~~)~~ (Fig. 4~~3~~a). The spatial distribution of cores highlights the considerable challenges associated with conducting research in the WSL peatlands~~ of Western Siberia~~. Their vast extent, the widespread presence of permafrost, and limited transport accessibility largely determine the areas where sediment sampling is logistically feasible. Notably, 47% of all peat cores (306 out of 654) included in the WSPC database were collected within a 100 km buffer zone of the major rivers: Ob, Yenisey, Irtysh, and Tobol, with high~~t~~ density of cores in the Middle Ob' Lowland (Fig. 4~~3~~b). A distinct concentration of collected cores is observed in the Great Vasyugan Mire (west of Tomsk), which represents the largest contiguous peatland in the world (Fig. 4~~3~~c) (Kirpotin et al., 2009). Various parts of this extensive complex have been the focus of numerous previous studies (e.g.: Blyakharchuk et al., 2019; Lapshina and Zarov, 2023; Rudmin et al., 2018; Syso and Peregon, 2009) due to the absence of permafrost and the proximity to major cities facilitating field work organisation. Another distinct concentration of peat cores is observed in the central part of the study region, between the Ob and Yenisey rivers, where numerous cores were collected during extensive Russian-American field campaigns conducted between 1999 and 2001 (Sheng et al., 2004; Smith et al., 2000). Although the railway network in ~~Western Siberia~~WSL is relatively sparse, a major line crosses this area, connecting Tyumen with Novy Urengoy, Nadym, and Yamburg, thereby facilitating logistical access to this part of the region. Peatlands in the northern part of the WSL have been studied mostly on the Yamal Peninsula, with a few coring sites on the Gyda Peninsula, mainly along the shore of the Gydan Bay. The northernmost core in the database was located on Bely Island (73.~~,~~34190°N, 70.~~,~~12760°E) and southernmost on Dolgon'koye swamp (53.~~,~~21250°N, 84.~~,~~40720°E).

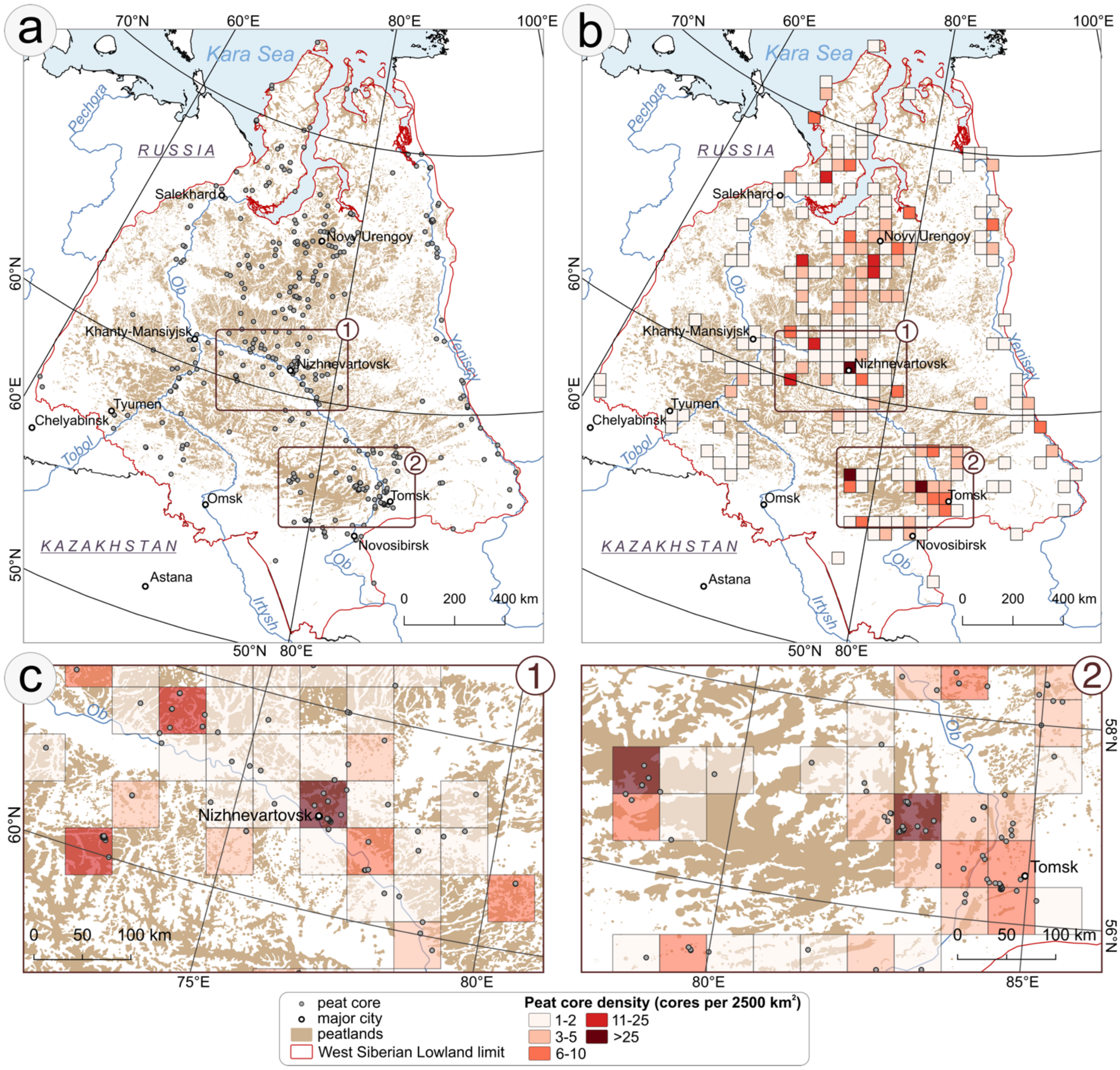

Figure 4. Distribution of peat cores in Western Siberian Peat Core Database: (a) spatial distribution of peat cores in Western Siberia Lowland (WSL), (b) peat core density (number of cores per 2500 km^2), (c) the zoomed maps of two regions within the ~~Western Siberian Lowland~~WSL: (1) peatland complexes in the Middle Ob' Lowland near Nizhnevartovsk, and (2) the eastern part of the Great Vasyugan Mire. Maps include peatlands extent based on Sheng et al. (2004).

The WSPC database includes peat cores, representing a broad range of environmental settings across the region. Peatlands in ~~Western Siberia~~WSL occupy all major permafrost zones and vegetation types, although their spatial extent and sampling intensity vary~~ in some cases.~~ (Fig. 54a, 54c). Peatlands are most extensive in the non-permafrost zone, which covers 41.5% of the total peatland area, followed by the discontinuous (18.6%), sporadic (14.1%), isolated (13.9%), and continuous (11.9%) permafrost zones. In general, the number of peat cores reflects the relative area of peatlands in each zone. The two permafrost zones with the largest peatland areas also have the highest numbers of peat cores: the non-permafrost zone (278 cores, 42.5% of the total) and the discontinuous permafrost zone (132 cores, 20.2%). The number of peat cores in the isolated (94 cores, 14.4%) and continuous (101 cores, 15.4%) permafrost zones also corresponds closely to the proportion of peatland area in these zones. The main exception is the sporadic permafrost zone, which contains the third-largest share of peatland area (14.1%) but is relatively underrepresented, accounting for only 7.5% of all peat cores in the database.

Across vegetation types, the majority of ~~Western Siberian~~WSL peatlands are associated with boreal forests/taiga (78.9%), followed by tundra (13.7%), temperate broadleaf and mixed forests (6.1%), and temperate grasslands and shrublands (1.3%).

The distribution of peat cores reflects this pattern: cores from peatlands in boreal forests dominate the dataset (405 cores, 61.9%), followed by tundra sites (118 cores, 18.0%), while mixed forests (92 cores, 14.1%) and shrubland peatlands (39 cores, 6.0%) are considerably less represented by peat cores in the database.

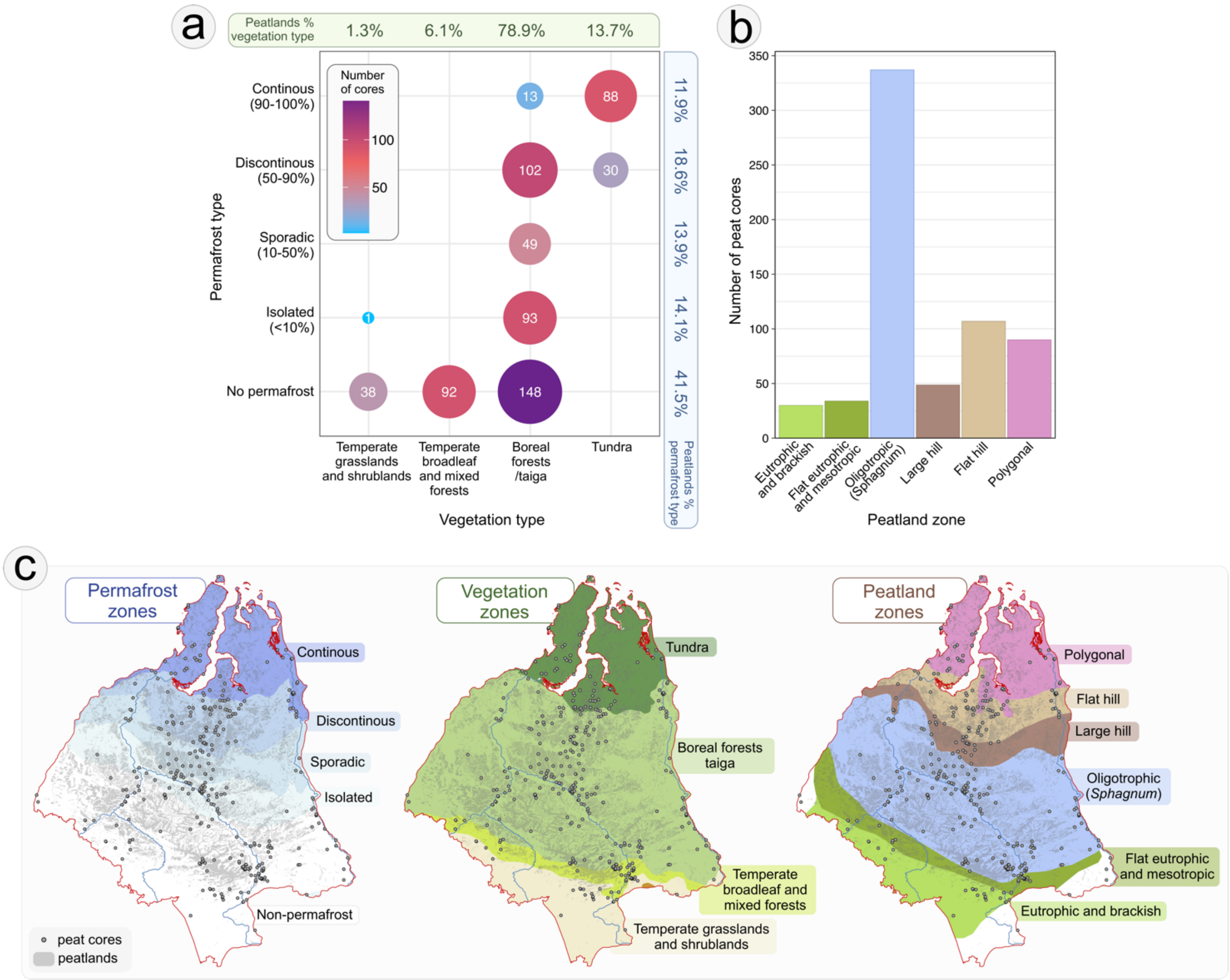

Figure 5. Distribution of peat cores in the Western Siberian Peat Cores Database by permafrost, vegetation, and peatland type; (a) number of peat cores within each permafrost zone and vegetation type, with percentages of peatlands occurring in each category; (b) number of peat cores by major peatland zones; (c) spatial distribution of peat cores in relation to permafrost zone, vegetation type and peatland type. Vegetation zones are based on Olson et al. (2001), permafrost extent on Brown et al. (2002), major peatland zones on Kremenetski et al. (2003) (after Ivanov and Novikov, 1976), and peatland extent on Sheng et al. (2004).

Based on major peatland zones, polygonal peatlands, which dominate north of 67°N and are associated with continuous permafrost and tundra vegetation, are represented by 90 cores (13.8%) in the database (Fig. 54b, 54c). Flat hill and large hill peatlands, which occur predominantly within the discontinuous permafrost zone and are associated with taiga vegetation between 61–67°N, account for 107 (16.4%) and 49 (7.5%) cores, respectively. Oligotrophic (*Sphagnum*-dominated) peatlands, concentrated between 56–61°N and typically associated with boreal forest/taiga areas exhibiting either non-permafrost, isolated or sporadic permafrost, represent the most frequent peatland type in WSL and are represented by the largest group of 337 cores (51.5%). The two southernmost peatland zones, where permafrost is absent and temperate vegetation types predominate, are the least represented in the dataset. Flat eutrophic and mesotrophic peatlands, occurring in a narrow belt from 55–58°N in the east and up to 60°N in the west, include 34 cores (5.2%), while eutrophic and brackish peatlands, located south of 55°N, form the smallest group, with 30 cores (4.6%). Additionally, 7 cores (1.0%) are outside the extent of the defined peatland zones.

4.2.2 Variation in the number of proxies per core

The WSPC database documents the application of 26 palaeoecological proxies in ~~Western Siberian~~ peat cores in the WSL, grouped into four categories: biological, physical, chemical and chronological (Fig. 6~~5~~b, ~~Table S1~~Table A1). Peat cores in the database differ substantially in the number of applied proxies, ranging from only one to a maximum of 12 per core (Fig. 6~~5~~a, Fig. 8~~6~~a). The most common in the database were cores containing one or two palaeoecological proxies, representing 26.3% and 28.4% of all records, respectively. Peat cores that include only a single proxy ~~Fewer than 5% of all cores include only a single proxy,~~ most commonly contain information on basal depth or sediment age; and in some cases, ~~they include only~~ pollen or plant macrofossil data. For cores containing only biological proxies, this may be explained by the extraction of data from more recent, method-focused publications (e.g. palynology), whereas broader and potentially more comprehensive information may have been reported in earlier sources that were inaccessible for the authors of this database. In cores containing two proxies, t~~Cores analysed using two proxies constitute the largest group in the database, representing 50.1% of all records. T~~he most frequent combinations include basal depth or age paired with either pollen or carbon accumulation data. Peat cores containing data from three to six proxies typically include several biological proxies combined with age or basal depth information, and in some cases supplemented with peat property measurements (e.g. peat or carbon accumulation, or organic matter content). The second most common proxy count is seven (13.0~~5~~%). Within this group, two distinct core types can be distinguished: (1) cores that resemble the “3–6 proxy” category but incorporate more biological proxies, and (2) cores that lack biological proxies but provide more extensive data on the physical and chemical properties of peat. Cores containing eight or more proxies represent multi-proxy analyses, integrating biological, physical, and chemical data along with sediment dating, and thus provide the most comprehensive information on the history of the studied peatlands. Only 9.8% of all cores include this number of proxies, while just 1.2% contain ten or more. The spatial distribution of peat cores with a given number of proxies is also evident (Fig. 8~~6~~a). High concentrations of well-studied peatlands occur along major rivers, particularly the Ob (Mukhrino, Sredne Vasyuganskoe, Samara, and Bakchar) and the Yenisey (Igarka). Given its large size and ecological significance, the Great Vasyugan Mire also contains numerous peat cores with a high number of proxies, reflecting its long-term use as a key site for multi-proxy palaeoecological research. Another cluster of cores analysed with multiple proxies is observed in the central part of the study region, between the Ob and Yenisey rivers. These cores were mostly collected during Russian-American field campaigns and include detailed physical and chemical analyses of peat, as well as cores described in single-core studies, such as the Khanymei peatland (Halaś et al., 2025).

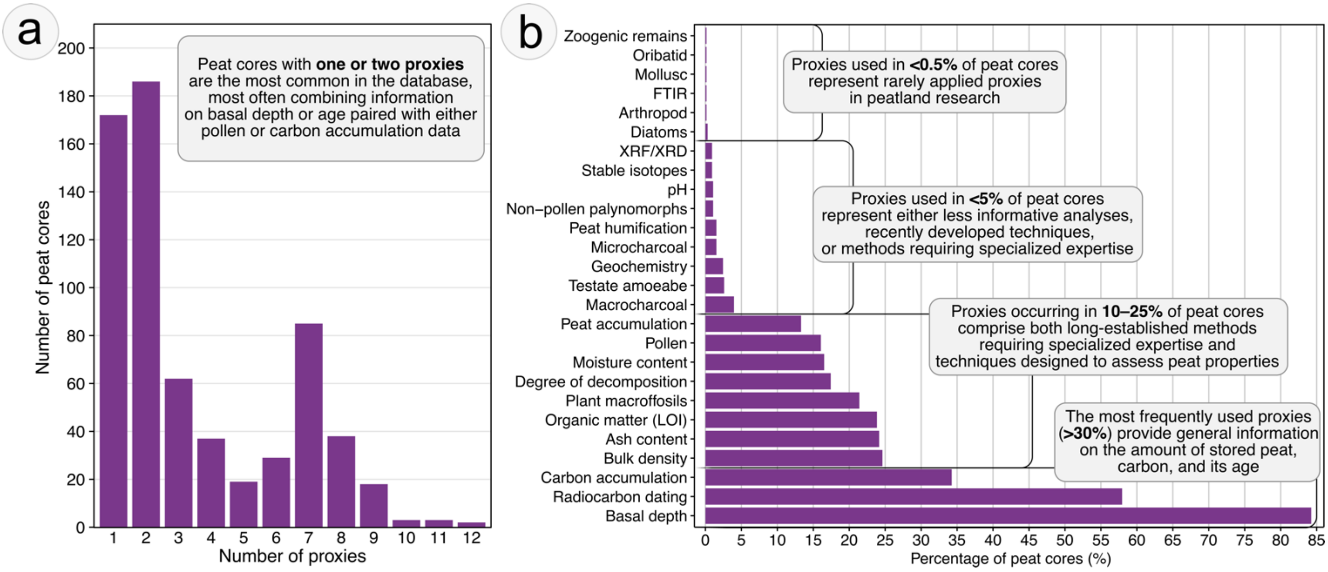

Figure 6. Summary of palaeoecological proxies applied in peat cores in the Western Siberian Peat Core Database; (a) number of proxies used and corresponding number of peat cores, (b) frequency (%) of use of individual proxies across the peat cores. Abbreviations: XRF – X-ray fluorescence; XRD – X-ray diffraction; FTIR – Fourier-transform infrared spectroscopy.

4.2.3 Relative use of different proxy and their regional patterns

In the WSPC database, a total of 26 palaeoecological proxies has been applied to peat cores from ~~Western Siberia~~WSL; however, their use varies significantly, both in quantitative frequency and in spatial distribution across the study area (Fig. 6b, 7, ~~S1~~B1).

Chronological proxies

Chronological proxies are essential for reconstructing peatland development over time and were applied in 58.0% of all peat cores. Radiocarbon dating is by far the most frequently used method in the region, enabling age-depth modelling and temporal correlation of palaeoecological data (Chambers and Charman, 2004). The resolution of dating varies considerably between cores: some cores were dated only at the basal level, whereas others include several dated horizons. This variability often reflects financial constraints, as multipoint dating remains relatively expensive. Nevertheless, in recent decades researchers have increasingly adopted multi-level dating within individual cores to achieve more robust reconstructions and to facilitate comparison with paleoclimate data~~-change records~~ (e.g. Feurdean et al., 2019; Lamentowicz et al., 2015; Leonova et al., 2022; Novenko et al., 2023). Due to its widespread application, the spatial distribution of this proxy is relatively uniform, and it is represented in peat cores across most of ~~Western Siberia~~WSL (Fig. ~~S1~~B1a~~e~~).

Physical proxies

Physical proxies, which provide information on peat properties and stratigraphy, are frequently applied in the included in the ~~in the~~ database. Basal depth is by far the most common proxy, present in 84.3% of cores (Fig. 6~~5~~b). Such a large number of basal depth measurements is primarily due to the fact that this parameter is relatively easy to obtain in the field and usually does not require specialist expertise (Parry et al., 2014). Many basal depth data were collected during geological prospecting campaigns or as part of detailed investigations of the development of individual peatland complexes (Kremenetski et al., 2003; Lapshina and Zarov, 2023). This widespread use reflects both its fundamental importance for peatland development studies and its relevance as an economically significant parameter (Fig. ~~S1~~B1b~~a~~). Another important physical proxy useful e.g. for carbon content calculations is bulk density, reported in 24.6% of cores, mostly from the central part between the Ob and Yenisey rivers and from the Vasyugan Plain (Fig. ~~S1~~B1c~~d~~). Degree of decomposition and peat humification are both analyses that indicate the intensity of decay processes; however, the methods differ (Biester et al., 2014). Peat humification is an older technique and is rarely used (1.5% of cores), whereas the degree of decomposition, usually assessed via the von Post scale – a traditional Russian field method – is much more common in ~~Western Siberian~~WSL cores (17.4~~3~~%). Their occurrence within the study area is characterized by a clear concentration in the south, on the Vasyugan Plain, while in the remaining regions the proxy is represented only in a small number of sites (Fig. ~~S1~~B1d~~h~~, ~~S1~~B1g~~p~~). Moisture or water content, a proxy useful for interpreting decomposition processes or nutrient mobility (Rydin et al., 2006), was applied in 16.5% of all cores, and its spatial distribution is similar to that of bulk density (Fig. ~~S1~~B1e~~i~~). Peat accumulation is an important proxy that not only provides information about peatland development but can also indirectly inform about past climate variability (Swindles et al., 2025). It was used in 13.3% of the cores, which are distributed across the study region, with more sites located on the Vasyugan Plain (Fig. ~~S1~~B1f~~k~~). The form in which this information is reported varies depending on analytical resolution, sometimes it is a single value for the entire core, and its accuracy increases with increasing resolution. Nevertheless, accumulation rates in permafrost-affected peatlands should be interpreted with caution, as cryogenic structures and variable ice content may substantially influence peat accumulation and preservation processes (Treat et al., 2016). However, such information was not consistently reported in the analysed studies and therefore could not be systematically included in the database.

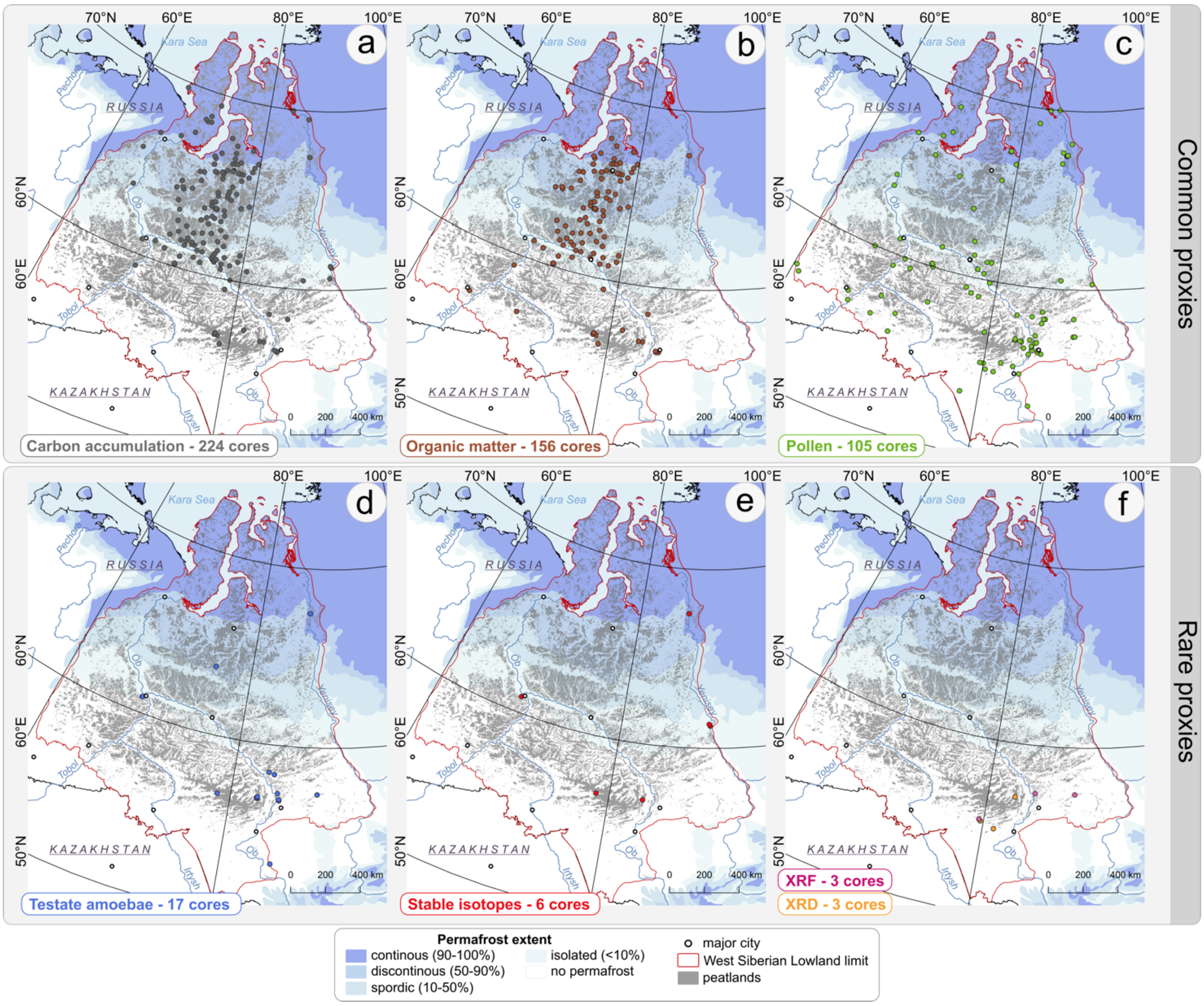

Figure 7. Spatial distribution of peat cores included in the Western Siberian Peat Core Database with records of selected proxies. Commonly used palaeoecological proxies are shown in panels a-c (a – carbon accumulation; b – organic matter; c – pollen), while rarely applied proxies are presented in panels d-f (d – testate amoebae; e – stable isotopes; f – XRF/XRD). Numbers indicate the total count of cores containing each proxy. Maps include peatlands extent based on Sheng et al. (2004) and permafrost extent based on Brown et al. (2002). Abbreviations: XRF – X-ray fluorescence; XRD – X-ray diffraction.

Chemical proxies

Chemical properties of accumulated peat in ~~Western Siberia~~WSL have also been frequently analysed in peat cores. The most commonly used chemical proxy is carbon accumulation, applied in 34.3~~60.4~~% of all studied cores (Fig. 6b~~5b~~). This proxy provides valuable information about the total amount of stored carbon in the peat and about long-term changes in peatland carbon sink strength (Charman et al., 2015). ~~Western Siberia~~WSL is recognized as a global carbon hotspot; therefore, many studies focus on carbon budgets and accumulation patterns, which explains the widespread use of this proxy. This proxy is predominantly reported in sites from the central part of the study region and the peatlands of the Vasyugan Plain; however, cores containing this information are also frequently found in river valleys and on the Yamal Peninsula~~This proxy has been applied to cores collected in river valleys and on the Yamal Peninsula; however, its use is still dominated by sites from both the central part of the study region and the peatlands of the Vasyugan Plain~~ (Fig. 7a). ~~Organic matter and a~~Ash content and organic matter, typically measured via loss-on-ignition (LOI) analysis, are also commonly analysed in ~~Western Siberian~~WSL peat cores, appearing in 24.2~~0~~% and 23.9% of peat cores, respectively. These simple and low-cost methods are widely used in paleoecology and provide information about peat composition and the input of inorganic material (Chambers and Charman, 2004; Tolonen, 1984). Their spatial distribution is very similar and resembles the distribution pattern of bulk density (Fig. 7b, ~~S1~~B1t~~e~~). Other chemical proxies included in this database: geochemistry, pH, stable isotopes, XRF or XRD and FTIR have been rarely applied in ~~Western Siberian~~WSL peat cores. Data on pH, which reflects peat acidity, are more characteristic of modern ecological surveys than of palaeoecological studies. Consequently, this proxy was used in only 1.1% of all cores, exclusively in non-permafrost peatlands in the southern part of the region (Fig. ~~S1~~B1w~~r~~). Traditional geochemical analyses (2.4%), stable isotopes (0.9%), XRF/XRD (0.9%), and FTIR (0.2%) all require specialised expertise and laboratory infrastructure, which until recently were not widely accessible. Geochemical analyses and XRF/XRD are different methods for determining the elemental composition of peat.~~;~~ G~~g~~eochemistry has become increasingly popular in recent years, whereas XRF and XRD, traditionally used in lake sediment studies, have only recently begun to be applied to peat (Longman et al., 2019; Shotyk, 1988). Geochemical analyses have been conducted in several peatlands south of 64°N, while XRF/XRD has been used primarily in peatlands near Tomsk in the south-eastern part of the study area (Fig. 7f, ~~S1~~B1v~~n~~). Stable isotopes in peat provide valuable insights into past environmental and climatic conditions; however, they are costly and require specialized isotope facilities (McClymont et al., 2010). Such data are scattered across ~~Western Siberia~~WSL and are typically collected from cores analysed in extensive studies that integrate multiple other proxies (Fig. 7e) (Feurdean et al., 2019; Startsev et al., 2022)~~ (Fig. 7e)~~.

Biological proxies

The group of palaeoecological proxies that has been the least frequently applied in ~~Western Siberian~~WSL peat cores are biological proxies (Fig. 6~~5~~b). They rely on the identification of remains of organisms preserved in peat and are therefore highly dependent on preservation conditions. Additionally, they are usually time-consuming and require specialist expertise. The most frequently used biological proxy, applied in 21.4~~3~~% of all cores, is plant macrofossils (referred to as "botanical composition" in older publications), which reflect local peatland vegetation and are essential for reconstructing peatland development and hydrology (Birks and Birks, 2000). However, the level of analytical detail varies between studies. In some cores, particularly in older works, the data are limited to reporting dominant *Sphagnum* species or other major plant groups, often at a low sampling resolution of 10 or 25 cm. In contrast, more recent studies tend to use higher-resolution sampling and more detailed identifications, frequently including subfossil vegetative fragments and carpological remains (e.g.: Halaś et al., 2025; Novenko et al., 2022). Peat cores with plant macrofossil data are spread across ~~Western Siberia~~WSL, with a higher concentration on Vasyugan Plain and in the area near Tomsk (Fig. ~~S1~~B1h~~g~~). Pollen is an excellent proxy for reconstructing past regional vegetation and landscape-scale ecological changes (Mander and Punyasena, 2018). Owing to its long-established use in palaeoecological studies, it was introduced very early in ~~Western Siberian~~WSL research. To date, 16.1% of all cores in the database contain pollen data. These cores cover the majority of ~~Western Siberia~~WSL, with their highest frequency occurring in areas where core density is greatest (Fig. 7c). Non-pollen palynomorphs (NPPs) are additional microfossils that can be identified during standard palynological analysis (Shumilovskikh et al., 2021). Because Quaternary palynologists historically did not focus on these other palynomorphs, their identification is challenging, and their systematic documentation only began in the late 1970s, their use in ~~Western Siberian~~WSL cores has remained limited. Although the scientific community has increasingly recognized the potential of this proxy to reflect local ecological conditions and it is now being applied at more sites (Feurdean et al., 2022; Halaś et al., 2025), only 1.1% of all cores currently include NPP data, and these come from only a few locations in the WSL (Fig. ~~S1~~B1m~~q~~). Peatlands are also valuable archives of past fire activity, with charcoal commonly used as a proxy for this purpose. Depending on the intended spatial scale of fire reconstruction, different charcoal size fractions are analysed: macrocharcoal for local fires and microcharcoal for regional fire activity (Conedera et al., 2009). Both types are present in the WSL, although at low frequency. Macrocharcoal has been used more often, occurring in 4.0% of all cores, whereas microcharcoal appears in only 1.5%. There is no clear spatial pattern in their use; instead, they are found sporadically in isolated cores across the study area (Fig. ~~S1~~B1j~~l~~, ~~S1~~B1l~~o~~). A lack of fire-history research in ~~Western Siberia~~WSL (and in Russia more broadly) was also noted by Pupysheva and Blyakharchuk (2023). They emphasized that fire proxies are relatively new to this region and highlighted the importance of expanding fire-history studies across this territory. Hydrology is one of the most important environmental variables controlling the condition of peatland (Rydin et al., 2013), and testate amoebae are a well-established proxy for reconstructing past hydrology of these ecosystems (Charman, 2001). Although their widespread use in palaeoecological research began roughly 40 years ago (Mitchell, 2025), their application in ~~Western Siberian~~WSL peat cores remains very limited, appearing in only about 2.6% of all studied cores. Testate amoebae have been used primarily in non-permafrost peatlands in the southern part of the WSL, while in other types of permafrost peatlands they have been applied only sporadically (Fig. 7d). Less frequently used biological proxies include arthropods, molluscs, oribatid mites, diatoms, and zoogenic remains, each recorded in less than 0.3% of cores. Although these proxies can offer valuable insights into local environmental conditions, their preservation in peat is generally poor, and they are more characteristic of lake sediment studies. As a result, they are rarely applied in peatland research. This pattern is also evident in ~~Western Siberia~~WSL, where their use in peat cores is limited to only a few isolated cases (Fig. ~~S1u, S1~~B1~~w~~n-~~S1~~B1r~~z~~).

Overall, the WSPC database demonstrates a strong focus on fundamental physical and chemical proxies, particularly basal depth, carbon accumulation, and organic matter content, reflecting the importance of these variables in peatland palaeoecology. Biological proxies are applied more selectively, often depending on the research question, while more specialized proxies such as geochemistry, stable isotopes, or FTIR are rarely used. This distribution highlights both the breadth of multi-proxy approaches in ~~Western Siberian~~WSL peatlands and the gaps in underrepresented proxy types, particularly in biological and specialized chemical analyses.

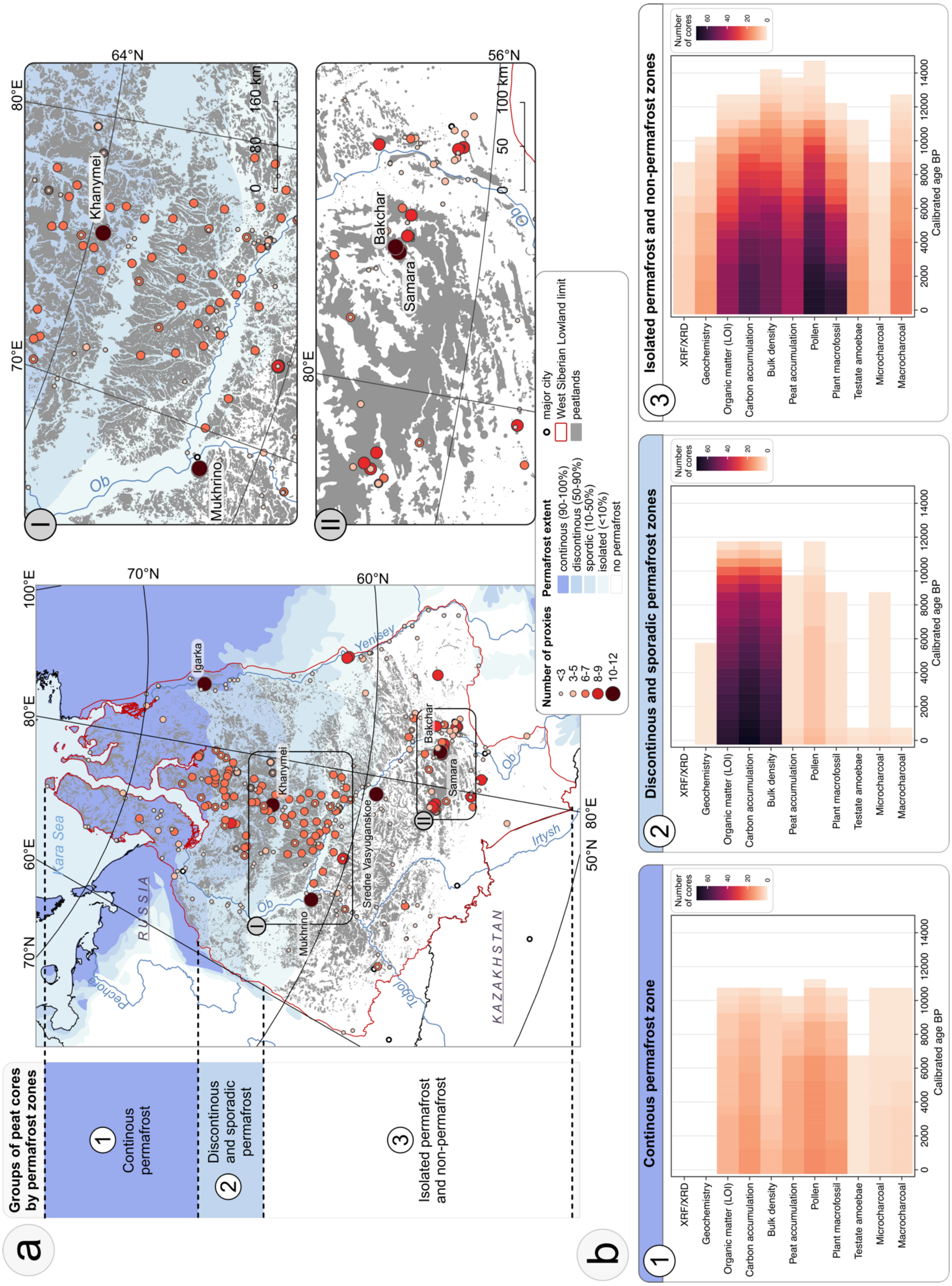

Figure 8. Palaeoecological proxies used in peat cores in the Western Siberian Peat Core Database: (a) spatial distribution of peat cores categorized by the number of proxies analysed, with names of peatlands (cores) with the greatest number of proxies, permafrost zones based on Brown et al. (2002), and peatland extent based on Sheng et al. (2004); (b) heatmaps of the temporal coverage of individual proxies within three groups of cores distinguished by permafrost zone: (1) the continuous permafrost zone, (2) the discontinuous and sporadic permafrost zones, and (3) the isolated permafrost and non-permafrost zones. Colour intensity reflects the number of cores contributing data within 500-year intervals. Abbreviations: XRF – X-ray fluorescence; XRD – X-ray diffraction.

**Heatmaps were prepared only based on cores with established chronologies.*

4.2.4 Age structure of peat cores and temporal coverage of proxies

The WSPC database includes three types of peat cores: (1) full-length sequences that extend from the basal mineral substrate to the sampling date and thus capture the complete peat accumulation history; (2) upper-only sequences that begin at the modern peat surface but do not reach the basal layer, typically resulting from targeted sampling strategies such as upper-core ecological reconstructions or from logistical constraints, particularly in permafrost regions; and (3) cores that may or may not reach the basal mineral substrate but are distinguished by the absence of the youngest peat layer due to climate-driven cessation of peat accumulation or degradation of previously accumulated peat, a pattern most commonly observed in polygonal peatlands in the northern part of the region. The temporal distribution of peat core ages, summarised in 300-year intervals, shows a highly uneven pattern, revealing several distinct phases across the time span up to ~16,000 cal. yr BP (Fig. 9b). Since the majority of cores in the WSCP database were published after 1950 and type-3 cores are relatively rare, we assumed for this analysis that each peat core represents continuous data from 1950 to the deepest dated layer.

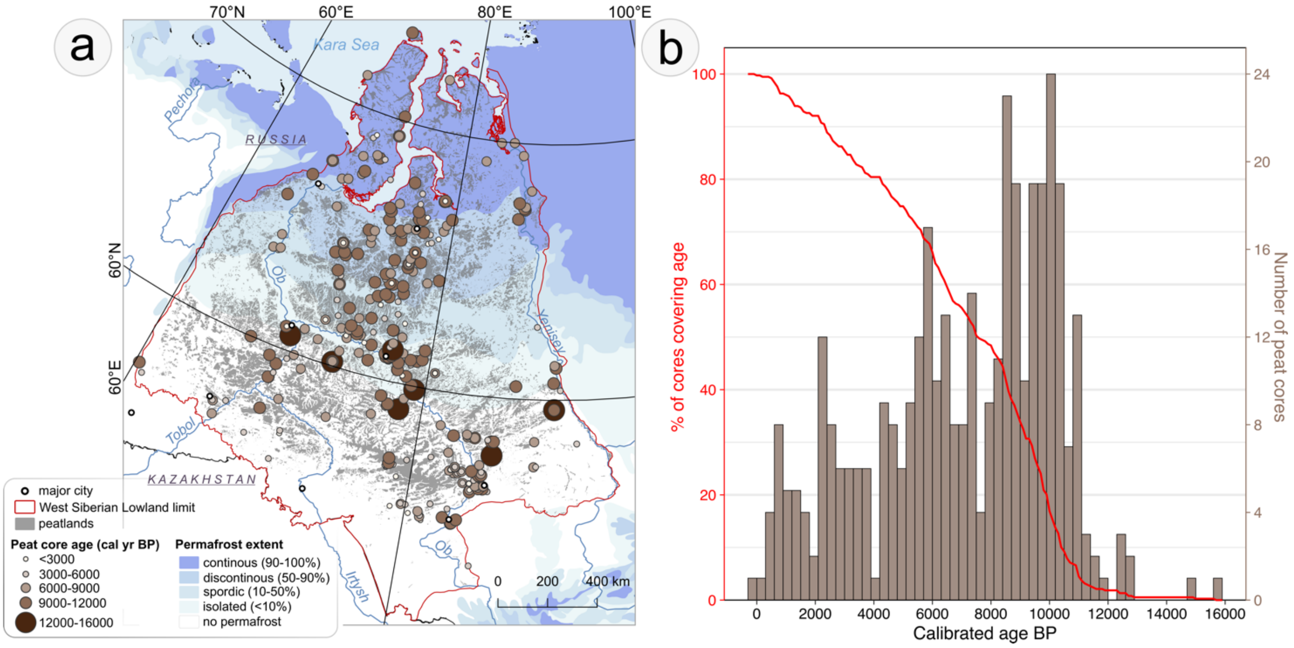

Figure 9. Age distribution of peat cores in the Western Siberian Peat Core Database (WSPC): (a) spatial distribution of peat cores with calibrated ages (cal. yr BP) of basal or dated bottom levels across ~~Western Siberia~~Western Siberian Lowland; (b) histogram of the number of peat cores within 300-year age intervals, representing the temporal coverage and length of palaeoecological records in the database, and percentage of peat cores in the WSPC database covering age.
**Map and plot created only based on cores with established chronologies.*

Peat cores covering only the near-modern period (0-2,000 cal. yr BP) are quite rare in the database, usually less than 5 cores per 300-year interval (Fig. 9b). There is an increase in the number of cores that cover longer periods of the Late Holocene up to 4,000 cal. yr BP, with 6-12 cores per interval. Cores covering the Middle Holocene (~4,000-8,000 cal. yr BP) form the second most frequent group, averaging 10 cores per interval. The highest representation is observed for cores spanning ~8,000–11,000 cal. yr BP, with nearly half of all chronologically established cores reaching this period. Beyond ~11,500 cal. yr BP, the number of cores declines sharply, with only individual cores reaching into the Late Glacial. The oldest peat core in the WSPC database dates to 15,623 cal. yr BP (core WSL_246) and is located near the Yenisey River within a present-day non-permafrost region (Fig. 9a). Peat cores older than 11,500 cal. yr BP are exclusively situated south of 62°N, where current ground conditions correspond to non-permafrost or isolated permafrost zones, and all of these oldest records are located within 100 km of major river channels ~~(Fig. 9a)~~. The lack of records from this period is consistent with limited peatland development in WSL during the Late Glacial, when conditions were generally unfavourable for peat accumulation (Alexandrov et al., 2016;

Velichko et al., 2011). In terms of coverage, ~80% of cores extend over the last 4,000 cal. yr BP, ~50% reach 8,000 cal. yr BP, and only ~5% cover 11,000 cal. yr BP.

Because the database includes both basal-depth and upper-only cores, these data cannot be interpreted as direct records of peatland initiation and serve as a basis for analysis spatial peatland development in WSL. Instead, it reflects the age extent of available peat profiles. Despite this limitation, the broad temporal pattern – many cores spanning the early Holocene and very few extending into the Late Glacial – broadly aligns with regional peatland development phases described for this region (Kremenetski et al., 2003).

Temporal coverage of selected proxies varies across permafrost zones, reflecting differences in peat core density, maximum peat age in each zone, and the overall frequency of proxy application (Fig. 8b). The longest peat records occur in isolated and non-permafrost zones, where the majority of studied proxies have been applied, and where most of them provide the greatest temporal coverage, with some extending to almost 15,000 cal. yr BP. In other permafrost zones less proxies have been used, in sporadic and discontinuous permafrost zones proxies' coverage span up to 11,500 cal. yr BP, whereas in continuous permafrost zone, maximum temporal coverage reaches ~11,000 cal. yr BP. Temporal coverage of proxies also depends on the number of cores available for each time interval, which directly affects the completeness and spatial representativeness of the data. When only a few cores provide information for a given variable, such as peat accumulation, the insights are limited and largely local, whereas larger numbers of cores allow for more comprehensive and regionally representative interpretations.

Isolated and non-permafrost zones

The peat cores from isolated and non-permafrost zone provide the earliest and most continuous proxy coverage of all three regions, with several proxies extend into the Late Glacial, providing broader and more detailed insights into the regional peatland history (Fig. 8b). Pollen data for this region are present from ~15,000 cal. yr BP, making it the oldest palaeoecological proxy across all regions and providing a continuous record of vegetation composition and broader regional ecological transitions from the Late Glacial through the Holocene. Although the earliest period is represented by only a few sites, the number of cores grows rapidly after 11,000 cal. yr BP, reaching more than 60 cores in the recent period. Thus, this region offers the ~~highest-resolution~~highest resolution, most spatially extensive vegetation reconstructions from peatlands in ~~Western Siberia~~WSL. Peat-property proxies, including organic matter and bulk density, as well as peat and carbon accumulation extend to ~14,000 and 12,000 cal. yr BP, earlier than in any other region. Their steady increase to dozens of cores through the Holocene offers robust reconstruction of substrate evolution, decomposition dynamics, carbon accumulation rates, and peat accumulation phases. Macrofossils data are available until ~12,000 cal. yr BP and reach over 60 cores in the Late Holocene, enabling high-resolution reconstructions of local plant assemblages, peatland microtopography, and fen-bog transitions. Hydrological reconstructions through testate amoebae extend to ~11,000 cal. yr BP and increase to 14 cores, supporting long-term and spatially extensive water-table reconstructions. Geochemical and XRF/XRD records are present from ~10,000-8,500 cal. yr BP, capturing changes in mineral influx, ash content, and geochemical environment. These datasets are largely only available in this part of ~~Western Siberia~~WSL; although representation increases through time, they still allow only spatially restricted interpretations. Fire proxies vary in temporal coverage. Macrocharcoal is recorded from ~12,500 cal. yr BP, with moderate representation after 8,500 cal. yr BP, providing the deepest temporal perspective on local fire history across ~~Western Siberia~~WSL. Microcharcoal, which can inform on regional fire dynamics, is traceable to ~8,500 cal. yr BP but remains very sparse.

Sporadic and discontinuous permafrost zones

The temporal coverage in the discontinuous and sporadic permafrost zones differs markedly from the previous region. Here, a few proxies dominate, providing long-term data across the Holocene, while others are absent or offer temporally and spatially restricted information (Fig. 8b). Organic matter, carbon accumulation, and bulk density data are available until ~11,500 cal. yr BP, and their representation increases sharply through the Early Holocene, remaining exceptionally high (>60 cores) throughout the Mid- and Late Holocene. This suggests that this zone provides the strongest quantitative foundation for Holocene carbon-accumulation reconstructions among all permafrost regions. In contrast, peat accumulation data extend only to ~9,500 cal. yr BP and are available from a very limited number of cores. While these data add a quantitative dimension to vegetation productivity, low representation restricts their use to localized reconstructions rather than regional-scale trends. Pollen data, similar to bulk density, are present from ~11,500 cal. yr BP but remain sparse until the Mid-Holocene. Only from ~7,000 cal. yr BP onward does pollen coverage expand to 7–9 cores per interval, allowing spatially broader vegetation reconstructions. Macrofossil and microcharcoal data extend to ~8,500 cal. yr BP but remain rare, providing long-term yet localized records of plant communities, peatland-surface conditions, and regional fire history. Geochemical information obtained from traditional geochemical analyses is limited to a single site but extends back to ~6,000 cal. yr BP, whereas XRF/XRD data are unavailable for peatlands located in ~~sporadic and discontinuous~~these permafrost zones. Hydrological records through testate amoebae are largely absent, appearing only within the last 500 years, which restricts water-table reconstructions to the very recent past. A similar pattern is observed in macrocharcoal data; information on local fire activity, in contrast to the southern region of WSL, is almost entirely absent for peatlands in this region.

Continuous permafrost zone

Proxy data in the continuous permafrost zone are available up to ~11,000 cal. yr BP, with pollen providing the longest and most continuous environmental record (Fig. 8b). Most other proxies are present until ~10,500–10,000 cal. yr BP, and in all cases, representation peaks around 6,500 cal. yr BP, though it remains relatively low compared to the other regions. These datasets allow reconstruction of peatland vegetation changes, substrate development, and peat and carbon accumulation dynamics across almost the entire Holocene; however, spatial coverage is limited due to the low number of cores. Hydrological information from testate-amoebae extends to ~7,000 cal. yr BP but is available from only a single site, making water table reconstructions largely site-specific. Fire proxies (micro- and macrocharcoal) are present through the Holocene but remain sparse, restricting fire history interpretations to localized events and preventing robust regional-scale reconstructions. Geochemical information, derived from traditional analyses or XRF/XRD, is absent for peatlands in the continuous permafrost zone.

In summary, there is a clear regional variation in the temporal coverage of selected proxies across different permafrost zones. The longest and most continuous records are found in isolated and non-permafrost zones, reflecting both the early initiation of peatlands in this region and the relatively easy accessibility for research due to the absence or spare presence of permafrost. In discontinuous and sporadic permafrost zones, only a few proxies provide long-term, spatially extensive coverage, primarily for basic peat and carbon properties, while other biological and geochemical proxies remain sparse. In continuous permafrost zones, many proxies extend into the early Holocene, but the low number of cores limits spatial representativeness, meaning that long-term reconstructions of ecological dynamics are largely site-specific.

5 Challenges and future directions in ~~Western Siberian~~ paleoenvironmental research in the Western Siberian Lowland

Fieldwork in ~~Western Siberian~~WSL peatlands is associated with persistent and interrelated logistical, environmental, and political constraints, which together contribute to the underrepresentation of some areas in paleoenvironmental research. First, environmental conditions complicate fieldwork. In northern areas, permafrost dictates when and how sampling can occur. Winter freeze improves travel across bog surfaces but makes coring extremely difficult due to frozen sediments. In summer, the thawed active layer allows proper coring, yet saturated, unstable ground often makes sites inaccessible. This narrow and seasonally contradictory operational window limits the number of reachable localities. This also contributes to limited accessibility, many parts of ~~Western Siberia~~WSL lacks roads or rail connections, and many sites can only be reached by navigable waterways, helicopter or specialized off-road vehicles. This greatly increases costs and restricts the spatial extent of sampling, leaving remote peatlands poorly studied. Additional logistical and political constraints, including permit requirements, transport coordination, and recent geopolitical restrictions further reduce access to certain regions (Schuur et al., 2024). As a result, some parts of ~~Western Siberia~~WSL, particularly remote and permafrost-affected zones, remain underrepresented in palaeoecological research simply because they are exceptionally difficult to reach and sample (Fig. 10a). Moreover, even regions that appear relatively well studied, such as the Great Vasyugan Mire, are often sampled unevenly, with research concentrated mainly along accessible margins and transport corridors, while large central areas remain poorly investigated. This issue is particularly important in the WSL, where peatlands form extensive and internally heterogeneous landscape-scale complexes rather than isolated systems. Consequently, individual peat cores cannot always be considered representative of entire peatland regions, especially for locally sensitive proxies such as testate amoebae, whereas broader-scale proxies such as pollen may reflect more regional environmental patterns.

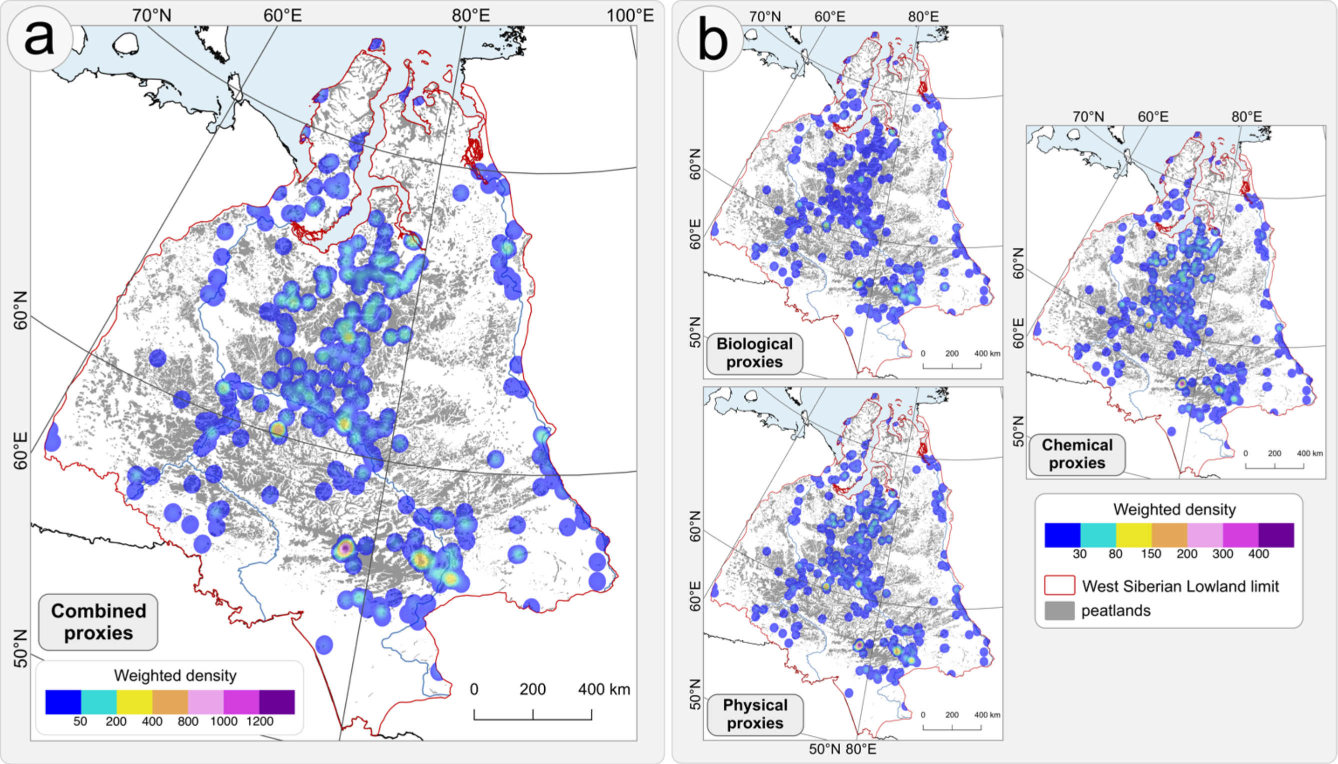

Figure 10. Spatial representation of peatland areas in Western Siberian Lowland sampled by peat cores and their relative contribution of information: (a) heatmap of combined scores of all proxy types, and (b) heatmaps of proxy group scores (biological, chemical, and physical). Heatmaps were generated using Kernel Density Estimation, with a 30 km radius, assuming each core represents the surrounding of 30 km, and weighted by the combined or group-specific scores to depict relative data density. Peat core scoring was based on both chronology and proxies.

These limitations are especially critical given the global climatic importance of ~~Western Siberian~~WSL peatlands. The WSL stores one of the largest peat carbon pools on Earth (Hugelius et al., 2020; Kremenetski et al., 2003; Sheng et al., 2004) and acts both as a long-term carbon sink and a major methane source (Kirpotin et al., 2009; MacDonald et al., 2006; Smith et al., 2004), while ongoing climate change drives complex, regionally variable shifts in ecosystem functioning (Halaś et al., 2025; Zhang et al., 2022). In the context of global soil carbon and peatland assessments (Scharlemann et al., 2014), reducing spatial and methodological gaps in this region is therefore essential for both local process understanding and improved global C–CH_4 budgets.

Looking ahead, the patterns revealed by the WSPC database suggest clear priorities. Continuous and sporadic permafrost zones, especially beyond major river corridors and well-studied complexes such as the Great Vasyugan Mire, should be key targets for new coring campaigns (Fig. 10a). ~~-~~In addition, some areas that appear well covered in terms of core numbers are represented mainly by low-resolution, single-proxy records based on older methods; where detailed reconstructions of hydrology, fire regimes or carbon dynamics are needed, such sites should be revisited or re-analysed using modern, high-resolution multi-proxy approaches. Future work would benefit from wider use of underrepresented biological proxies (e.g. testate amoebae, macro- and microcharcoal, non-pollen palynomorphs) and advanced geochemical and isotopic analyses, particularly in permafrost-affected peatlands (Fig. 10b).

At the same time, overcoming logistical and political barriers will require new collaboration and field strategies, including closer partnerships with regional institutions and local communities, greater use of remote sensing and existing infrastructure to pre-select coring sites, and flexible multi-site expeditions using lighter, easily deployable equipment. Aligning such practical solutions with the spatial and methodological gaps highlighted by the WSPC database will allow future research in ~~Western Siberia~~WSL to move beyond opportunistic sampling towards systematically planned, hypothesis-driven studies that better capture the diversity and dynamics of WSL peatlands.

6 Database limitations

- Incomplete coverage of literature sources – t~~T~~he database is based on a literature review of available repositories, which may be missing some publications. The authors acknowledge that not all studies presenting peat core data from the region were identified or accessible.
- Limited access to Russian-language literature published before 1990 – m~~M~~ost pre-1990 Russian-language publications were not available in open-access repositories. As a result, some original sources could not be obtained, limiting the ability to gather comprehensive information on peat cores and proxy usage. Consequently, certain proxies may have been applied earlier or more frequently than indicated by this database.
- Uncertainty related to incomplete reporting in key studies – s~~S~~ome works provided aggregated descriptions of coring efforts without reporting exact locations of individual cores. For example, Lapshina & Zarov (2023) described 355 sampling cores along hypsometric profiles, yet precise coordinates were not provided, allowing only 76 cores to be included in this database. It remains possible that many of these cores overlap with records included in other compilations (e.g., Hugelius et al., 2020), but this could not be verified.
- Ambiguity in reporting complete basal peat sequences ~~Ambiguity in classification of basal cores –~~ i~~I~~n most cases the oldest core from a study site represents a basal core; however, some publications did not clearly specify whether a core reached the mineral substrate. This ambiguity may introduce minor uncertainty into the interpretation of basal depths included in the database.
- Existence of unpublished data – s~~S~~ome peat cores are known to exist (e.g., from reports, institutional archives, or personal communications), but lack published stratigraphic or proxy data. These could not be incorporated into the database.
- Variable spatial precision of reported core locations – m~~M~~any older or regionally published studies provide only approximate locations (e.g., mire name or nearest settlement) rather than precise coordinates. As a result, included cores differ in coring location~~spatial~~ accuracy.
- Dependence on secondary sources for inaccessible studies – w~~W~~hen original publications, particularly older Russian-language works, were unavailable, information was obtained from secondary citations in later papers. This reliance on indirect sources may introduce errors. For example, Liss and Berezina (1981) published stratigraphic diagrams with

several dated levels within single core~~s~~, but in later studies these levels were misinterpreted as separate basal cores. Such discrepancies highlight the risk of propagating mistakes when direct access to original materials is not possible.

- Potential duplication or omission of cores – s~~S~~ome cores appear repeatedly across multiple publications, yet lack of precise metadata sometimes prevented determining whether two references referred to the same core. This introduces a small risk of either under- or over-counting cores.

Data availability

The data are available on the Zenodo platform at the following link: https://doi.org/10.5281/zenodo.20323517 (Halaś and Słowiński, 2026)~~10.5281/zenodo.17866098 (Halaś and Słowiński, 2025)~~. We plan to expand this database in the future by providing a submission form that will allow researchers to contribute additional peat cores, either from new studies or from existing collections not yet included in the database.

Conclusions

The Western Siberian Peat Core Database (WSPC) provides a harmonized and georeferenced dataset of peat cores that greatly advances the capacity for regional analyses of Holocene environmental change in the Western Siberian Lowland (WSL). The literature review demonstrates a clear progression in ~~Western Siberian~~WSL peatland research, from early single-proxy and low-resolution studies to modern multi-proxy approaches with higher chronological and analytical precision. Increasing attention to peatland hydrology, fire history, and carbon accumulation reflects both methodological developments and a growing recognition of the crucial ecological and climatic importance of WSL peatlands. The WSPC database integrates ~~information~~ metadata from 654 georeferenced peat cores or cross-sections reported in 156 publications (1953–2025), documenting 26 palaeoecological proxies across biological, physical, chemical, and chronological categories. Spatial analyses reveal a concentration of sampling along major rivers (Ob, Yenisey, Irtysh, Tobol) and in the Great Vasyugan Mire, reflecting both the extent of peatlands and relative accessibility. Most cores originate from non-permafrost and discontinuous permafrost zones, whereas continuous permafrost regions remain sparsely sampled. Temporal coverage varies substantially: ~80% of cores span the last 4,000 years, ~50% extend to 8,000 years, and only a limited number reach the Late Glacial (~15,600 cal. yr BP), with the longest and most continuous records found in non-permafrost and isolated permafrost zones. Overall, the dataset shows a strong dominance of fundamental physical and chemical proxies, particularly basal depth, carbon accumulation, and organic matter content, which underscores their central role in peatland palaeoecology. Biological proxies such as plant macrofossils, pollen, and testate amoebae are applied more selectively and largely depend on specific research goals, while specialized chemical proxies (e.g., traditional geochemical analysis~~stry~~, FTIR, XRF, stable isotopes) remain infrequently used. This distribution highlights both the breadth of existing multi-proxy approaches and the clear gaps in the application of biological and advanced geochemical methods. Collectively, this database provides an essential foundation for large-scale reconstructions of Holocene peatland development, hydrology, fire regimes, and carbon dynamics, while clearly identifying spatial and proxy-specific gaps. Several limitations must be acknowledged, including incomplete access to older or Russian-language literature, inconsistent reporting of complete basal peat sequences~~ambiguous reporting of basal cores~~, variable spatial precision of core locations, reliance on secondary sources, and the existence of unpublished or inaccessible core data. These factors introduce minor uncertainties and may lead to under- or overrepresentation of some cores or proxies. Despite these constraints, the WSPC database constitutes a valuable and robust resource for regional and pan-WSL palaeoenvironmental research. At the same time, i~~I~~t highlights key spatial, temporal, and methodological gaps and provides clear guidance for future research priorities, particularly regarding~~in~~ the limited coverage of northern regions, the uneven application of different proxies, and the logistical challenges associated with fieldwork in the WSL peatlands.~~under-sampled~~

~~northern regions, underrepresented proxy types, and logistical strategies needed to overcome the persistent challenges of fieldwork in Western Siberia.~~

Appendix A: Additional methodological information

Table A1 Proxies used in palaeoecological peatland studies in Western Siberia Lowland (WSL) included in the Western Siberian Peat Cores Database (WSPC)

Proxy type	**Proxy**	**Information provided / interpretation**	**Examples of studies in the WSPC database**
Biological[1]	Pollen	Pollen and spores provide information on past vegetation composition, allowing reconstruction of historical vegetation dynamics and the climatic conditions (Mander and Punyasena, 2018).	~~(~~Blyakharchuk, 2003; Novenko et al., 2023; Peteet et al., 1998~~)~~
	Non-pollen palynomorphs (NPPs)	NPP assemblages reflect local ecological conditions, including hydrology, fire, erosion, and grazing activities, providing complementary information to pollen for reconstructing past environments (Shumilovskikh et al., 2021; Van Geel, 2001).	~~(~~Feurdean et al., 2022; Halaś et al., 2025~~)~~
	Plant macrofossils	Provide information on local vegetation and flora with high taxonomic precision, allowing reconstruction of site-scale vegetation dynamics, paleoclimatic conditions (Birks and Birks, 2000).	~~(~~Preis, 2015; Tarasov et al., 1998; Tikhonravova et al., 2023~~)~~
	Testate amoebae (TA)	Mainly used for reconstruction of past changes in peatland hydrology and as a proxy for hydroclimate (Charman, 2001; Mitchell and Payne, 2018).	~~(~~Halaś et al., 2025; Kurina et al., 2020; Willis et al., 2015~~)~~
	Oribatid mites	Good bioindicators of microhabitat and moisture conditions in peatlands (Seniczak et al., 2022).	~~(~~Kurina et al., 2017, 2023~~)~~
	Molluscs	Useful for reconstruction of water chemistry, hydrology and paleoclimate, like precipitation and temperature (Horsák, 2011).	Kurina et al., 2017, 2023
	Arthropods	Arthropods serve as bioindicators, used to assess biodiversity, restoration success, habitat alteration, and potential impacts of climate change (Batzer et al., 2016).	~~(~~Panova et al., 2010~~)~~
	Diatoms	Diatoms are mostly used in minerotrophic peatlands, indicate past water level, chemical conditions or human disturbances (Carballeira and Pontevedra-Pombal, 2020).	~~(~~Paradossky et al., 2019~~)~~
	Microcharcoal	Provide information on past fire history, based on the size of charcoal particles the distance to the source can be determined. Microcharcoal is used to recontract regional fire history, while macrocharcoal is used for local-scale fire reconstructions(Conedera et al., 2009).	~~(~~Halaś et al., 2025; Lamentowicz et al., 2015; Shefer et al., 2024~~)~~
	Macrocharcoal		~~(~~Feurdean et al., 2019; Novenko et al., 2023; Ryabogina et al., 2024~~)~~
Physical	Bulk density	Provide information on peat compaction, peat accumulation, decomposition and carbon content (Chambers and Charman, 2004).	~~(~~Preis et al., 2024; Smith et al., 2012~~)~~
	Moisture content	Moisture controls decomposition, microbial activity and nutrient mobility (Rydin et al., 2006).	~~(~~Preis et al., 2024; Tikhonravova et al., 2023~~)~~
	Degree of decomposition / Peat humification	Is a measure of peat decomposition, useful as proxy to reconstruct past hydrological and climatic conditions (Biester et al., 2014).	~~(~~Syso and Peregon, 2009; Tsyganov et al., 2021; Turunen et al., 2001~~)~~
	Peat accumulation	Gives information about past climate variability, peatland development and productivity (Swindles et al., 2025).	~~(~~Borren et al., 2004; Malyasova et al., 1991~~)~~
	Basal depth	Basal depth provides information on peatland initiation, development and functioning, it is also essential for carbon accumulation calculation and in climate change models (Parry et al., 2014).	~~(~~Kremenetski et al., 2003; MacDonald et al., 2006; Smith et al., 2004~~)~~
Chemical	Ash content	Informs about mineral input, dust or pollution deposition, erosion, or fire signal (Tolonen, 1984).	~~(~~Kurina et al., 2023; Veretennikova et al., 2021~~)~~

	pH	Paleo pH provides information about trophic status, carbon/methane cycling and can be used as an indirect proxy for paleoclimate (Schaaff et al., 2024).	~~(~~Stepanova and Volkova, 2017; Syso and Peregon, 2009~~)~~
	Organic matter (LOI)	It helps to identify non-organic input and reconstruct land-use history (Chambers and Charman, 2004).	~~(~~Lapshina and Zarov, 2023; Minayeva et al., 2006; Peteet et al., 1998~~)~~
	Carbon accumulation	Provides information about carbon sequestration over time, indicates past changes in peatland productivity, decomposition and indirectly climate conditions (Charman et al., 2015).	~~(~~Sheng et al., 2004; Turunen et al., 2001; Yu et al., 2009~~)~~
	Stable isotopes ($\delta^{13}C$, $\delta^{15}N$, δD, $\delta^{18}O$)	Stable isotopes combined with other analysis are valuable tools to reconstruct past temperature, humidity, and water table conditions (McClymont et al., 2010).	~~(~~Feurdean et al., 2019; Novenko et al., 2024; Startsev et al., 2022~~)~~
	Geochemistry[2]	To determine chemical composition of peat, natural and anthropogenic fluxes of metals, secondary sources of mineral matter e.g. sea spray, fires or industrial emissions (Shotyk, 1988).	~~(~~Fiałkiewicz-Kozieł et al., 2016; Veretennikova et al., 2021~~)~~
	X-ray fluorescence (XRF) / X-ray diffraction (XRD)	XRF determines elemental composition of the sediment, interpretation depends on the elements/element ratios used, e.g. used to infer anthropogenic impact, hydrological shifts or dust input. Measurements can be of uncertain reliability (Longman et al., 2019). XRD identifies crystalline minerals in a sample, allowing direct, non-destructive mineral characterization, though amorphous or poorly crystalline materials may not be detected (Sjöström et al., 2019).	~~(~~Feurdean et al., 2022; Leonova et al., 2022; Shvartseva et al., 2024~~)~~
	FTIR (Fourier transform infrared spectroscopy)	FTIR spectra can indicate peat decomposition, organic matter quality, peat mineral matter and assessment of peatland restoration success (Artz et al., 2008; Martínez Cortizas et al., 2021).	~~(~~Kurina et al., 2023~~)~~
Chronological	Dating (e.g., ^{14}C, ^{210}Pb, ^{137}Cs)	Used to determine peat components age, for age–depth model calculations, accumulation rate and sedimentation chronology (Chambers and Charman, 2004).	~~(~~Borisova et al., 2011; Glebov et al., 2002; Kremenetski et al., 2003~~)~~

[1] *Among the biological proxies, a category termed "zoogenic remains" was also distinguished, which was used in the context of the study by Paradossky et al. (2019). In that study, the authors identified general groups of zoogenic remains rather than specific taxa.*

[2] *General group of analysis applied on peat core excluding stable isotopes, XRF and FTIR.*

Table A2 Results of calibration of uncalibrated radiocarbon ages (yr BP) for peat cores in Western Siberian Peat Cores Database (WSPC) with reference to the source of original (uncalibrated) ages.

No.	**Core ID**	**^{14}C age (yr BP)**	**± 1σ (yr)**	**Calibrated age range (cal. yr BP)**	**Median calibrated age (cal. yr BP)**	**Reference**
1	WS_6	8710	105	9539-10127	9676	~~(~~MacDonald et al., 2006~~)~~
2	WS_8	4578	72	4992-5465	5310	~~(~~Leonova et al., 2021; Preis et al., 2024~~)~~
3	WS_15	5611	54	6304-6519	6398	Leonova et al., 2021; Preis et al., 2024
4	WS_67	5260	60	5921-6207	5997	Lapshina and Zarov, 2023
5	WS_68	1780	70	1534-1846	1644	Lapshina and Zarov, 2023
6	WS_71	5260	160	5666-6355	5997	Blyakharchuk, 2003
7	WS_134	8450	60	9308-9532	9479	Blyakharchuk, 2003
8	WS_158	4310	90	4601-5253	4856	~~(~~Preis, 2024~~)~~
9	WS_171	9780	210	10588-11912	11207	~~(~~Khotinsky, 1984~~)~~
10	WS_221	9000	100	9753-10395	10196	MacDonald et al., 2006
11	WS_228	8400	80	9149-9525	9454	Liss and Berezina, 1981
12	WS_251	10600	80	12236-12723	12627	Khotinsky, 1984
13	WS_549	4840	110	5329-5860	5587	~~(~~Vasil'chuk et al., 2001~~)~~
14	WS_567	7420	110	8019-8406	8280	Vasil'chuk et al., 2001
16	WS_584	8670	100	9504-10100	9553	~~(~~Punning et al., 1974~~)~~
15	WS_585	7960	100	8559-9083	8930	Punning et al., 1974
17	WS_589	6550	170	7054-7729	7429	MacDonald et al., 2006

18	WS_590	7640	220	8028-9008	8414	MacDonald et al., 2006
19	WS_591	7730	220	8089-9151	8524	MacDonald et al., 2006
20	WS_592	7800	170	8269-9083	8591	MacDonald et al., 2006
21	WS_593	7820	200	8233-9224	8595	MacDonald et al., 2006
22	WS_594	8000	50	8656-9000	8820	MacDonald et al., 2006
23	WS_595	8000	200	8436-9399	8820	MacDonald et al., 2006
24	WS_596	8180	40	9022-9274	9106	MacDonald et al., 2006
25	WS_597	8180	230	8538-9584	9106	MacDonald et al., 2006
26	WS_598	8400	240	8706-10069	9454	MacDonald et al., 2006
27	WS_645	8790	170	9512-10235	9774	Vasil'chuk et al., 2001

Table A3 Proxy groups and individual proxy weights used in the scoring framework

Proxy group	Proxy	Weight
Biological	Pollen	2.0
	Non-pollen palynomorphs (NPPs)	1.2
	Plant macrofossils	1.5
	Testate amoebae	2.5
	Microcharcoal	1.5
	Macrocharcoal	1.5
	Oribatid mites	0.5
	Molluscs	0.5
	Diatoms	1.0
	Arthropods	0.2
	Zoogenic remains	0.2
Physical	Bulk density	2.0
	Moisture content	0.5
	Degree of decomposition	1.0
	Peat humification	1.0
	Peat accumulation	2.0
	Basal depth	1.0
Chemical	Ash content	1.5
	pH	1.0
	Organic matter (LOI)	2.0
	Carbon accumulation	2.5
	Stable isotopes	2.5
	Geochemistry	2.0
	XRF/XRD	2.0
	FTIR	2.0

Table A4 Components of scoring framework for peat cores in WSPC database

Component	Description	Scaling	Weight
Chronology (chron)	Presence of an independent age model	Binary: 1 = present, 0 = absent	1
Record length (record)	Total temporal coverage of the core	Scaled 0.05–1.0: <200 yr = 0.05 200-500 yr = 0.2 500-2,000 yr = 0.4 2,000-5,000 yr = 0.6 5,000-10,000 yr = 0.8 >10,000 yr = 1.0	1
Proxy count (count)	Number of proxy available	Linearly rescaled 0–1 (1–12 proxies)	1
Proxy group scores (proxies)	Weighted sum of proxies within each group	According to Table A3	4
All proxies combined (proxies)	Weighted sum of all proxies across groups	According to Table A3	5

$$\text{Combined Score} = S_{\text{chron}} \times W_{\text{chron}} + S_{\text{record}} \times W_{\text{record}} + S_{\text{count}} \times W_{\text{count}} + \sum_{\text{S proxies}} \times W_{\text{proxies}}$$

Where: S – score, W – weight

Appendix B: Spatial distribution of palaeoecological proxies in the WSPC database

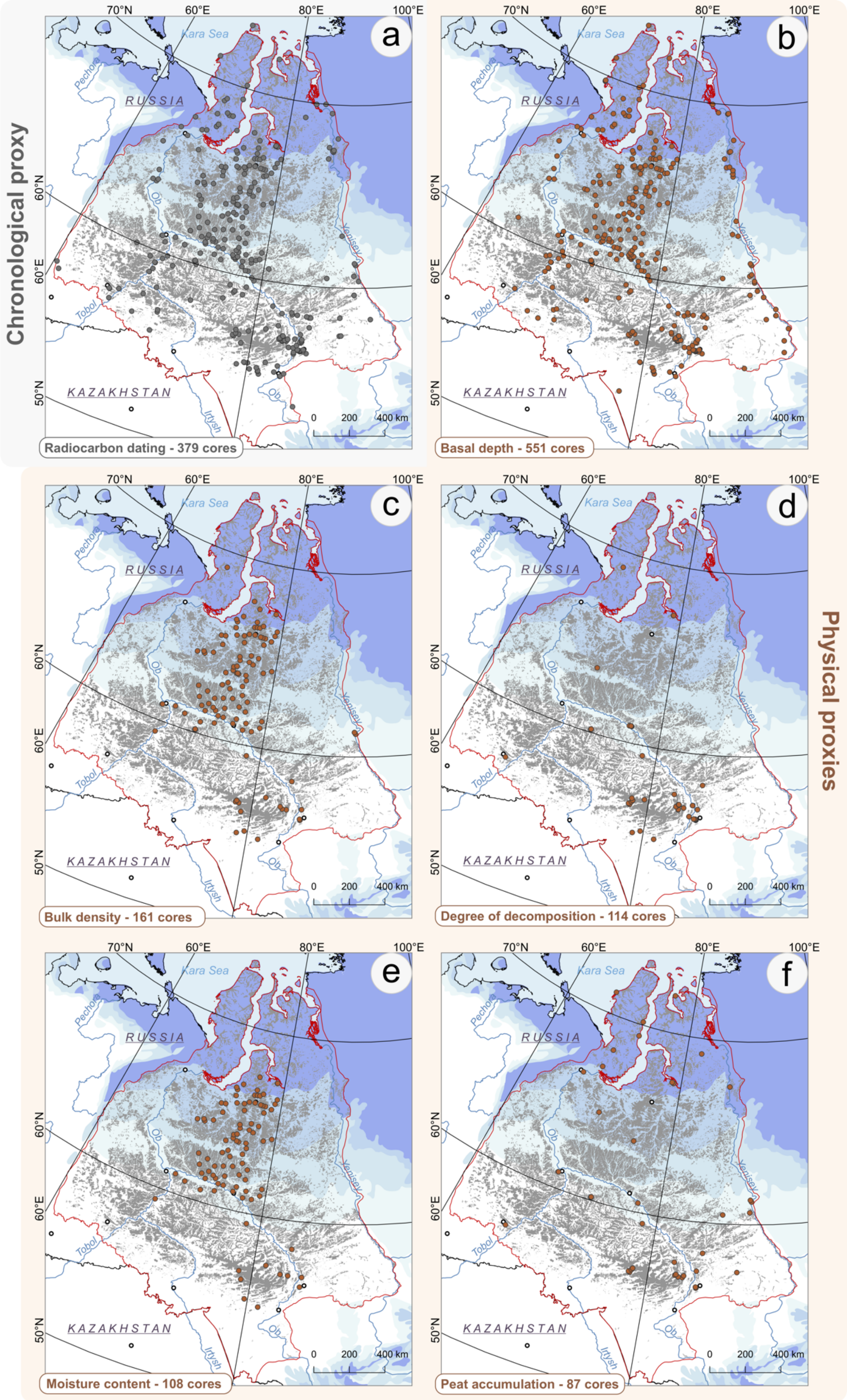

Figure B1. Spatial distribution of peat cores included in the Western Siberian Peat Core Database with records of proxies: (a) radiocarbon dating, (b) basal depth, (c) bulk density, (d) degree of decomposition, (e) moisture content, (f) peat accumulation, (g) peat humification, (h) plant macrofossils, (i) pollen, (j) macrocharcoal, (k) testate amoebae, (l) microcharcoal, (m) non-pollen palynomorphs, (n) diatoms, (o) oribatid, (p) arthropod peat humification, (q) mollusc, (r) zoogenic remains, (s) carbon accumulation, (t) ash content, (u) organic matter, (v) geochemistry, (w) pH, (x) stable isotopes, (y) XRF (X-ray fluorescence)/XRD (X-ray diffraction), (z) FTIR (Fourier transform infrared spectroscopy).

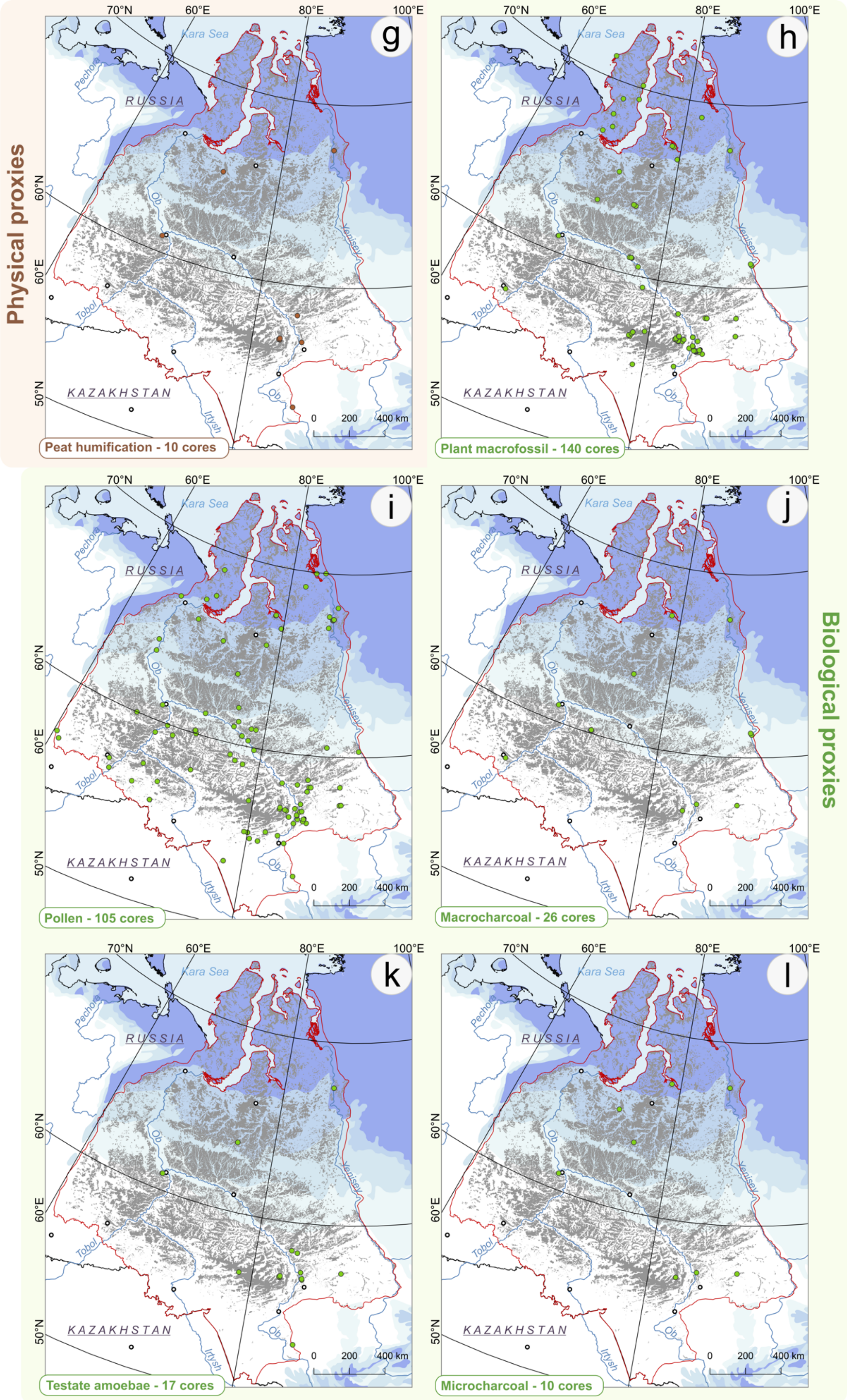

Figure B1. Continued

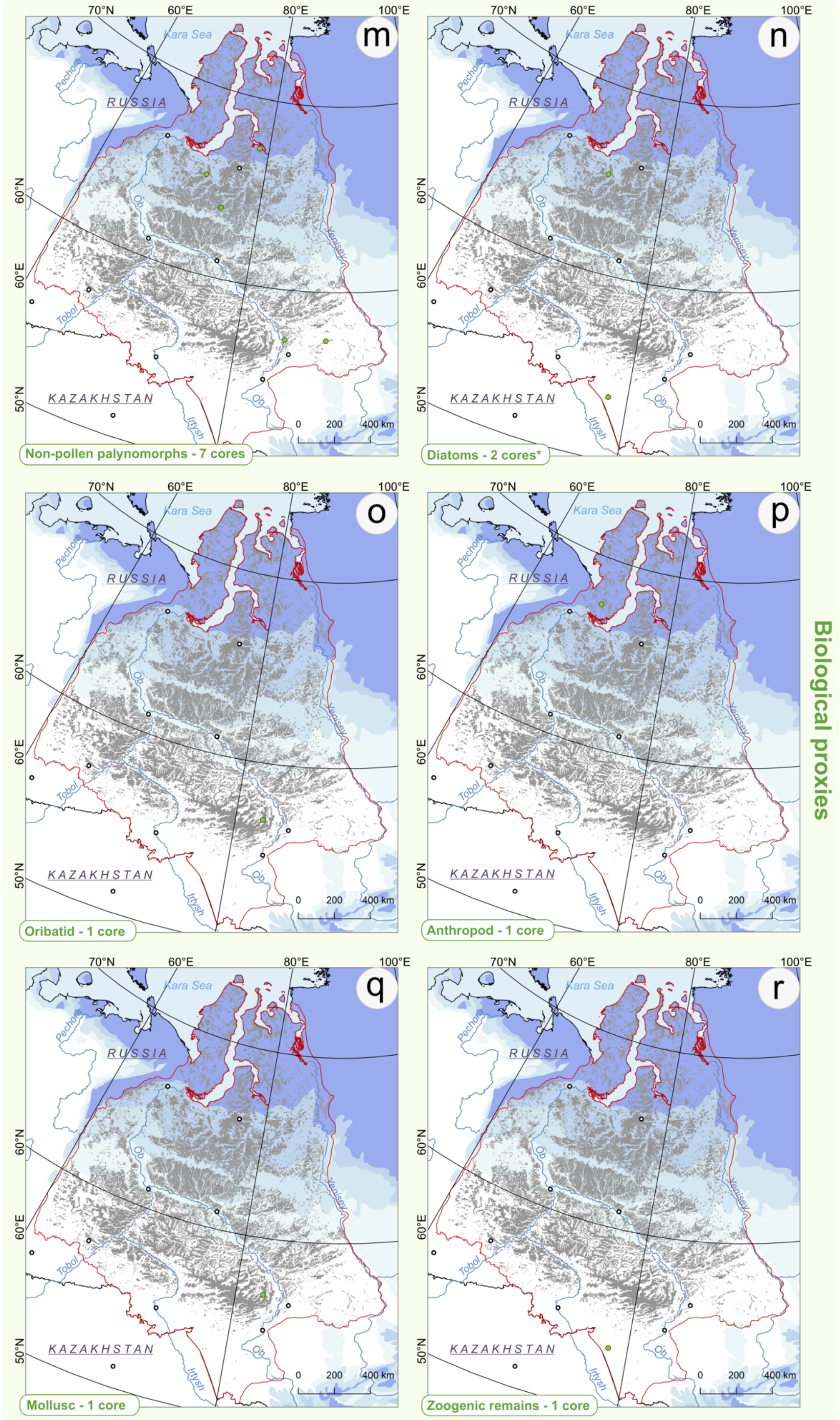

Figure B1. Continued
* In one core (located in the north), diatoms were applied only on the lake section of the core below the peat.

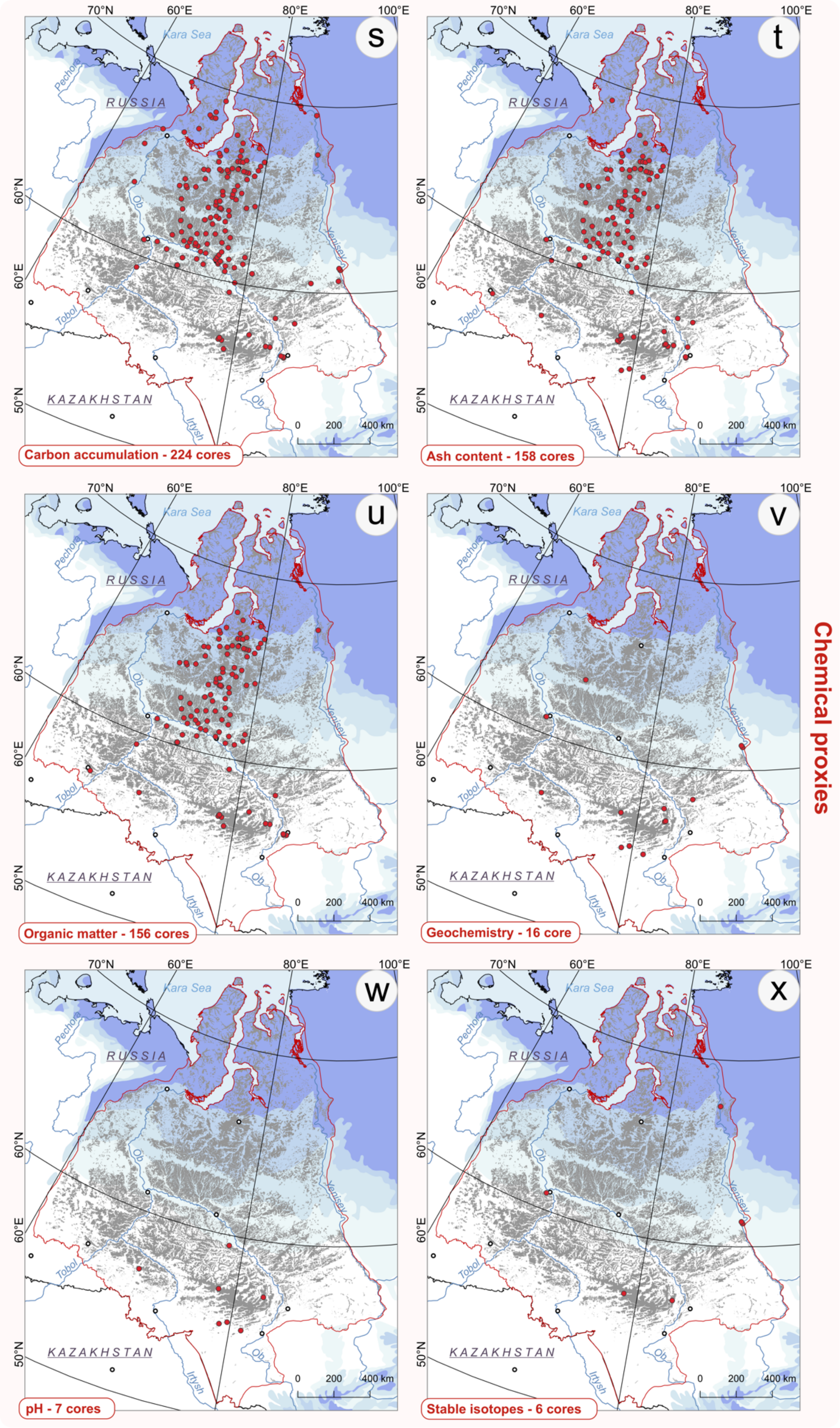

Figure B1. Continued

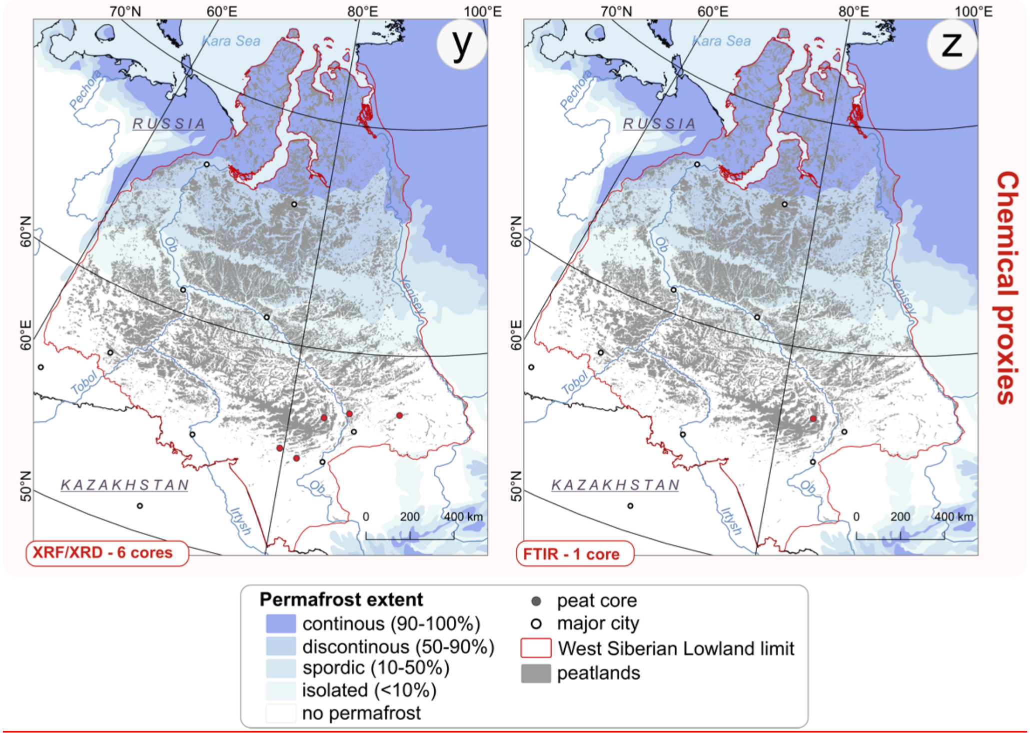

Figure B1. Continued

Author contribution

AH designed the research, conducted the literature review, compiled the database,~~and~~ wrote the original draft of the manuscript and led the revision process, including preparing the responses to the reviewers' comments and implementing the manuscript and database corrections. MS contributed to the research design, supervised the project, revised the manuscript,~~and~~ contributed to the writing, and participated in responding to the reviewers' comments and manuscript corrections.~~.~~

Competing interests

The contact author has declared that none of the authors has any competing interests.

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