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RESEARCH ARTICLE

Diversity and syntaxonomy of aquatic macrophyte communities in floodplain lakes of the Middle Ob River (Tomsk Carbon Polygon, Western Siberia)

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Abstract

The floodplain of the Ob River, one of the largest wetland systems in Eurasia, plays a significant role in the regional carbon cycle, yet its aquatic macrophyte communities remain poorly studied. This work presents the first comprehensive study of the diversity and syntaxonomy of aquatic macrophyte communities in three floodplain lakes of the Middle Ob River, located within the "Kaybasovo" Carbon Polygon. Field studies conducted in the summer and autumn of 2025 included geobotanical surveys and bathymetric mapping. We recorded 40 species of aquatic and semi-aquatic vascular plants from 19 families, with the core of the flora represented by hydrophytes and helophytes (77.5%). The most species-rich families were Cyperaceae, Potamogetonaceae, and Araceae. Syntaxonomic analysis revealed five associations of aquatic vegetation, belonging to the classes *Lemnetea* and *Potamogetonetea*. The dominant communities were Stratiotetum aloidis and Nymphaeo albae-Nupharetum luteae. The flora is characterized by a stable core of 12 species common to all lakes, formed by ecologically plastic taxa adapted to the dynamic hydrological regime of the floodplain. The high alpha-diversity (23–29 species per lake) significantly exceeds that of the main river channel, highlighting the importance of floodplain lakes as local biodiversity hotspots. The obtained data provide a baseline for future monitoring of these aquatic ecosystems in the context of climate change and the functioning of carbon polygons.

Keywords
Middle Ob River, aquatic macrophytes, floodplain lakes, Western Siberia, carbon polygon, syntaxonomy, biodiversity, *Lemnetea*, *Potamogetonetea*

Introduction

The floodplain of the Ob River, one of the largest wetland systems in Eurasia, plays a significant role in the regional carbon cycle (Krickov et al. 2021; Vorobyev et al. 2024). Lakes and wetland systems of floodplains accumulate substantial amounts of organic matter, acting both as sites of carbon sequestration and as sources of carbon emissions (Tranvik et al. 2009; Serikova et al. 2019). In this case, aquatic macrophytes, as a key component of ecosystems, play a significant role (Krause-Jensen 2016; Pedersen 2021). Macrophytes form three-dimensional biotope structures, regulate the cycling of matter and energy, influence the hydrochemical properties of water, and serve as effective bioindicators for assessing the state of both the aquatic environment and bottom sediments (Reitsema et al. 2018; Zervas et al. 2018). They generate primary production, control the sediment accumulation rate and the subsequent mineralization of organic carbon (Gripp et al. 2013; Manasypov et al. 2021), which is particularly relevant in the context of studying the carbon balance.

Despite its high ecological significance, the Ob River floodplain remains poorly studied from a hydrobotanical perspective. A substantial proportion of publications devoted to the vegetation cover of the Ob River floodplain focus on terrestrial plant and vegetation (Lapshina 1987; Lvov et al. 1987; Taran et al. 2004; Taran 2006, 2023; Shibanova 2009, 2010; Shepeleva 2019; Shepeleva et al. 2020, 2022, 2024; Morozova, Golovatin 2023). In contrast, there are quite a few publications devoted entirely to the aquatic plant and Ob floodplain vegetation (Taran 1996, 2001, 2008, 2009; Zarubina 2001; Sviridenko et al. 2013; Sviridenko 2018; Sokolova and Zarubina 2019; Philippov and Komarova 2021; Bobrov, Philippov 2024). Therefore, the aim of this study was to assess the floristic composition and syntaxonomic composition of aquatic and emergent macrophytes in floodplain lakes of the Middle Ob River within the Kaibasovo research station of the Tomsk Carbon Polygon.

Materials and methods

Study Area

The studies were conducted on three floodplain lakes (Domashnee, Krivoe and Inkino) located in the northern part of the Shegarsky area within the central floodplain zone of the Middle Ob River. The research was carried out within the Kaibasovo station of the Tomsk Carbon Polygon (Fig. 1).

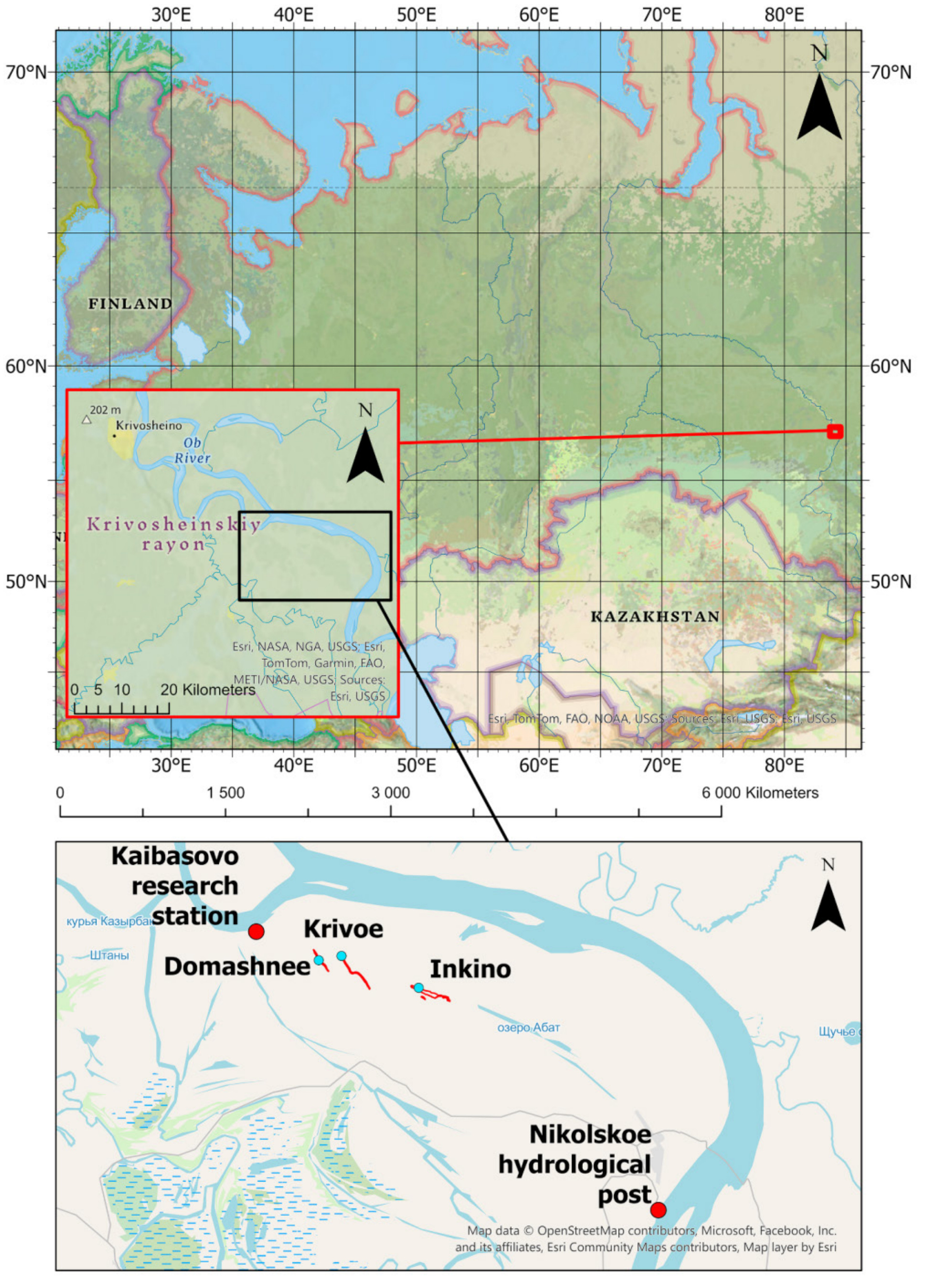

Figure 1. Schematic map showing the location of the studied lakes.

The region has a continental climate with an annual precipitation of 457-707 mm and an average temperature of -0.5 °C (Zemtsov 1988). The landscape is mainly formed by wide manes separated by deep hollows, as well as islands forming a dynamic network of watercourses and channels (Lvov 1963). Channel type in this section of the Ob River is defined as incomplete meandering (Petrov 1979). Lakes located in the Ob River floodplain occupy an average of 7.3% of the total floodplain area. They function in close connection with River regime phases. The Ob River inundation is a leading environmental factor (Petrov 1979). The main phase is the spring flood. This period sees the floodplain inundated by meltwater. At peak water levels, lakes can fully connect to the river network, forming a single system. Most often, hydraulic connection in closed lake is observed from 2 to 24 days. In the studied area, meltwater can maintain a hydraulic connection between the lakes and the Ob River from mid-April to the end of June. Consequently, the lakescape can fluctuate by up to 20% over the course of a year.

Field Surveys

The aquatic plants was surveyed in July and September 2025 using standard methods for sampling, herbarization, and description of aquatic macrophytes (Katanskaya 1981; Papchenkov 2003). During the field works, 27 geobotanical descriptions were.

Geobotanical descriptions were conducted on standard plots (100 m²) or within the boundaries of a community. Projective cover (PC) was estimated as a percentage and subsequently converted into the Braun-Blanquet scale: r – ≤ 0.01%, + – 0.1–1.0%, 1 – 2–5%, 2 – 6–25%, 3 – 26–50%, 4 – 51–75%, 5 – 76–100%. For vegetation classification, we applied the methodological approaches of the Braun-Blanquet school.

To construct bathymetric chart and determine the morphometric characteristics of the lakes, we used field depth measurements obtained with a GARMIN echo sounder. Based on these data, depth maps were created by interpolation using triangulation method (Fig. 3), and main morphometrical parameters were calculated (Table 1). The shoreline boundaries were delineated in QGIS using Landsat satellite imagery. All morphometrical parameters were derived using standard GIS tools in the QGIS environment.

Laboratorium inspection

The data are treated by IBIS 7.2 software package (Zverev 2007). Vascular plants were identified with reference to standard floras (Flora Sibiri 1988–1997; Lisitsyna and Papchenkov 2000) and monographs (Taylor 1989; Wiegleb and Kaplan 1998). The taxonomic nomenclature of vascular plant follows The International Plant Names Index (IPNI; www.ipni.org). All voucher specimens are deposited in the Herbarium of Tomsk State University (TK).

Syntaxonomic analysis was performed in accordance with the International Code of Phytosociological Nomenclature (Weber et al. 2000). Distribution data were obtained from the Global Biodiversity Information Facility (GBIF) and Moscow University Herbarium. To automate the literature search, we used the Sonar Large language model (Perplexity AI), with subsequent expert verification of the results. Spatial analysis was conducted in ArcGIS software, involving Multi-scale Hotspot Analysis performed with a third-party plugin (Plugin ID: 1181).

Results

GBIF database and the Moscow University Herbarium (MW) for the 18 plant species forming the "aquatic core" of the flora, identified in our study, revealed only 212 occurrence records within the Ob River floodplain across 37 points. Of these, eight records dated to 2023 are located at Lake Domashnee within the Kaibasovo Carbon Polygon, highlighting the poor level of prior research in this area (Fig. 2B). Thus, the data presented here supplement the published literature with novel findings. Distribution of occurrences for each species is presented in Suppl. material 1: Fig. S1.

Morphometrical characteristics (Fig.3, Table 1). The studied water bodies exhibit an elongated shape. Inkino Lake has the largest surface area and volume among the surveyed lakes; for analysis, it was divided into western and eastern sections. The smallest surface area and water volume, both during the flood period and in the low-water season, were recorded for Lake Domashnee, which also has the greatest depth. Lake Krivoe is the only drainage one of the presented lakes, which has a hydraulic connection with the Ob River during high water.

Table 1. Morphometric characteristics of the studied lakes

Parameter	Lake Domashnee	Lake Inkino	Lake Krivoe
Coordinates	57.2387°N 84.2134°E	57.2312°N 84.2599°E	57.2374°N 84.2255°E
Surface area (low-water season), m^2	63909	255207	129951
Perimeter, m	3329	5913	5459
Length, L, m	1335	W - 1372 / E - 758	2480
Average width, B, m	50.2	W - 144 / E - 60.1	51.5
Elongation, L*=L/B	27	10 / 12	48
Shape	Elongated groove	W – elongated groove, E – oblong	Elongated groove
Average depth (low-water season), m	1.61	1.22	1.10
Average depth (high-water season), m	1.83	1.31	N/A

Parameter	Lake Domashnee	Lake Inkino	Lake Krivoe
Maximum measured depth (low-water season), m	4.25	3.65	3.25
Hydraulic connection to the Ob River	None	None	Yes, depending on the water content of the year

Note: W – western part, E – eastern part.

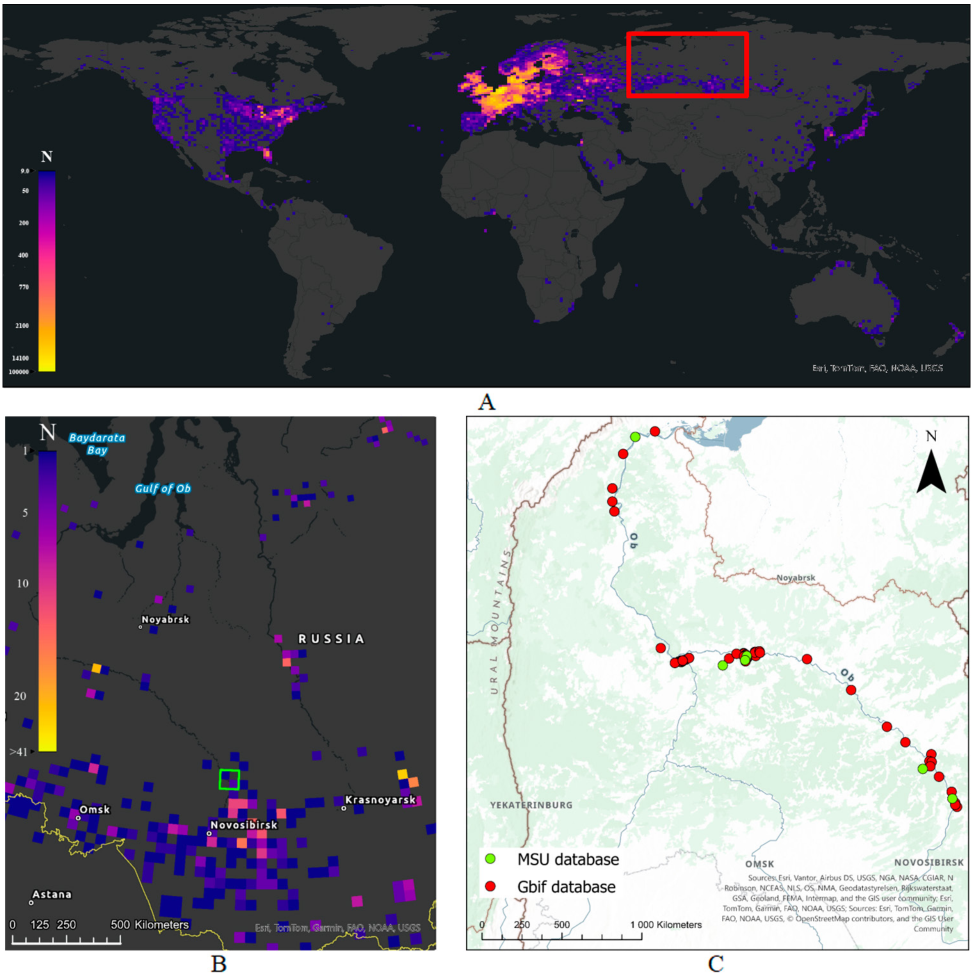

Figure 2. Distribution of occurrences. a) spatial distribution of occurrences from the GBIF database; b) spatial distribution of occurrences from scientific publications and the GBIF database in Western Siberia; c) map of occurrences in the Ob River floodplain from the GBIF database and the Moscow University Digital Herbarium (MW).

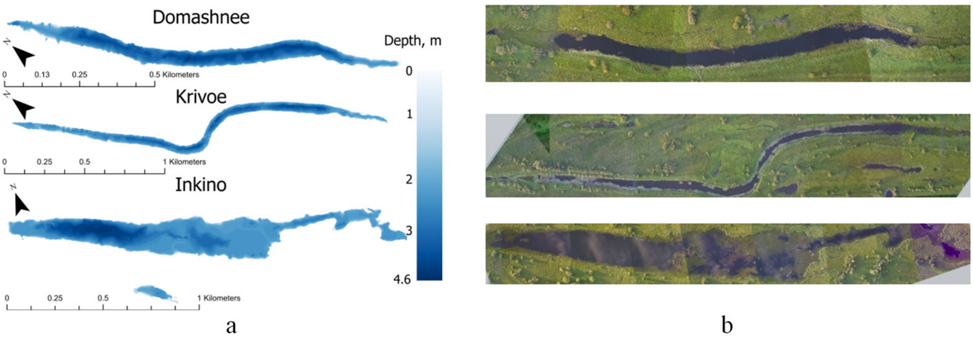

Figure 3. The studied lakes: a) bathymetric chart; b) aerial survey images from a UAV.

Floristic diversity (Fig. 4). A total of 40 species of aquatic and coastal-aquatic plants from 30 genera, 19 families, and 3 divisions were recorded in the studied lakes. A list of the recorded species is shown below. Species within families are listed in alphabetical order. For each species, the following information is provided: the Latin name, the main synonyms (optional), a list of occurrences (LD – Lake Domashnee; LI – Lake Inkino; LK – Lake Krivoye), and its ecological group (I – hydrophytes, II – helophytes, III – hygrohelophytes, IV – hygrophytes, V – hygromesophytes, VI – mesophytes).

The list begins with macroalgae, followed by ferns, and then flowering plants. The order of the spermatophyta follows the APG IV system (Chase 2016).

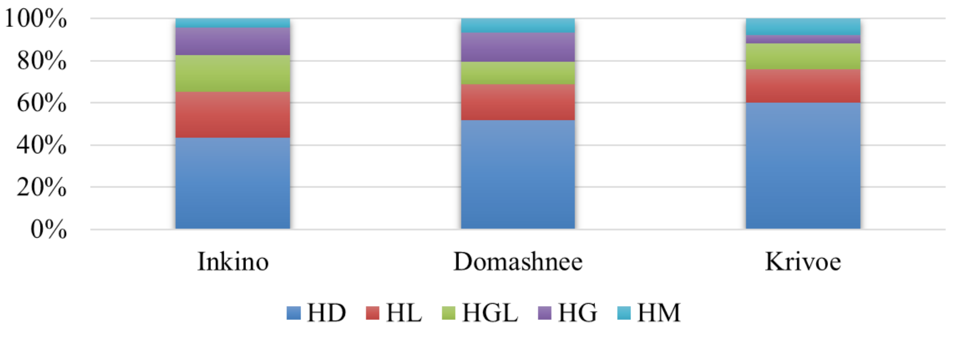

Figure 4. Ecological spectra of the flora of the studied lakes. HD – hydrophytes, HL – helophytes, HGL – hygrohelophytes, HG – hygrophytes, HM – hygromesophytes.

Below is a list of species of aquatic and coastal-aquatic plants growing in the studied floodplain reservoirs of the Middle Ob.

CHLOROPHYTA

ULVOPHYCEAE

Cladophoraceae: *Cladophora* sp. – LD, LK; I.

STREPTOPHYTA

EQUISETOPSIDA

Salviniaceae: *Salvinia natans* (L.) All. – LI, LD, LK; I.

SPERMATOPHYTA

MAGNOLIOPSIDA

Nymphaeaceae: *Nuphar lutea* (L.) Sm. – LI, LD, LK; I; *Nymphaea tetragona* Georgi – LD; I.

Cyperaceae: *Carex acuta* L. – LI, LD, LK; III; *Carex nigra* (L.) Reichard – LI; IV; *Carex pseudocyperus* L. – LI; III; *Carex vesicaria* L. – LD, LK; III; *Eleocharis palustris* (L.) Roem. et Schult. – LD, LK; II; *Schoenoplectus tabernaemontani* (CC Gmel.) Palla – LD; II.

Poaceae: *Calamagrostis purpurea* (Trin.) Trin. – LD; V; *Phalaris arundinacea* L. (*Phalaroides arundinacea* (L.) Rauschert) – LI, LD; IV; *Phragmites australis* (Cav.) Trin. ex Steud. – LI, LD, LK; II.

Typhaceae: *Sparganium* sp. – LI; II; *Typha angustifolia* L. – LI, LD, LK; II; *Typha latifolia* L. – LI, LD, LK; II;

Araceae: *Calla palustris* L. – LI; II; *Lemna minor* L. – LI, LD, LK; I; *Lemna trisulca* L. – LD, LK; I; *Spirodela polyrhiza* (L.) Schleid. – LD, LK; I.

Hydrocharitaceae: *Hydrilla verticillata* (L. f.) Royle – LK; I; *Hydrocharis morsus-ranae* L. – LI, LD, LK; I; *Stratiotes aloides* L. – LI, LD, LK; I.

Potamogetonaceae: *Potamogeton berchtoldii* Fieber – LD; I; *Potamogeton compressus* L. – LI, LD, LK; I; *Potamogeton lucens* L. – LI; I; *Potamogeton natans* L. – LI; I; *Potamogeton trichoides* Cham. et Schltdl. – LD, LK; I.

Ceratophyllaceae: *Ceratophyllum demersum* L. – LI, LD, LK; I.

Rosaceae: *Comarum palustre* L. – LI; III.

Onagraceae: *Epilobium palustre* L. – LI; IV.

Haloragaceae: *Myriophyllum sibiricum* Kom. – LD, LK; I.

Polygonaceae: *Persicaria lapathifolia* (L.) Delarbre – LK; V; *Rumex aquatics* L. – LI, LD; V.

Primulaceae: *Lysimachia thyrsiflora* L. (*Naumburgia thyrsiflora* (L.) Rchb.) – LI, LD, LK; III.

Lamiaceae: *Lycopus europaeus* L. – LD; IV; *Stachys palustris* L. – LD; IV.

Lentibulariaceae: *Utricularia minor* L. – LK; I; *Utricularia vulgaris* L. – LI, LD, LK; I.

Asteraceae: *Bidens tripartita* L. – LK; VI.

The largest families in the flora are: Cyperaceae (6 spp.), Potamogetonaceae (5 spp.), Araceae (4 spp.), Poaceae, Typhaceae, and Hydrocharitaceae (3 spp. each). Most genera contain 1–2 species, and only the genera *Potamogeton* and *Carex* contain 5 and 4 species. The number of species in the studied lakes ranges from 29 in Domashnee Lake to 25 in Krivoye Lake and 23 species in Inkino Lake. In terms of species diversity, the greatest similarity is observed between Domashnee and Krivoye lakes (Jaccard index (J) = 0.550) – these water bodies have more than half of the common species from the general combined list. Intermediate similarity for the pairs Inkino – Krivoye is observed (J = 0.429) and Inkino – Domashnee (J = 0.417).

The common core of the flora consists of 12 species found in all three lakes. The species include: *Salvinia natans*, *Nuphar lutea*, *Carex acuta*, *Phragmites australis*, *Typha angustifolia*, *Typha latifolia*, *Lemna minor*, *Hydrocharis morsus-ranae*, *Stratiotes aloides*, *Ceratophyllum demersum*, *Lysimachia thyrsiflora*, and *Utricularia vulgaris*.

In the ecological spectrum of the flora, hydrophytes (19 spp.), helophytes (7 spp.), and hygrohelophytes (5 spp.) predominate, forming the aquatic flora (77.5% of the floristic composition). Mainly, these are widespread and ecologically plastic species: hydrophytes (*Cladophora* sp., *Lemna minor*, *Lemna trisulca*, species of the genus *Potamogeton*, *Phragmites australis*, members of the Cyperaceae family, etc.). Hygrophytes (5 spp.), as well as hygromesophytes (3 spp.) and mesophytes (1 sp.), which are less demanding of aquatic conditions, account for just over 20% of the floristic composition and are included as associated species in coastal-aquatic plants communities.

The ratio of ecological groups in lake floras varies. The highest proportion of aquatic plants (hydrophytes and helophytes) is found in the flora of Krivoye Lake, accounting for 76% of all species recorded in the lake, while the lowest is in Inkino Lake (65%) (Fig. 4).

Syntaxonomy

Five communities of aquatic plants belonging to 2 alliances, 2 orders, and 2 classes were identified in the studied lakes:

- Class *Lemnetea*: assoc. *Stratiotetum aloidis*, assoc. *Hydrocharitetum morsus-ranae*.
- Class *Potamogetonetea*: assoc. *Nymphaeo albae–Nupharetum luteae*, assoc. *Potamogetonetum compressi*, assoc. *Potamogetonetum natantis*.

Prodromus of the aquatic vegetation of three floodplain lakes within the Shegarsky reach of the Ob River:

Class *Lemnetea* de Bolós et Masclans 1955

Order *Hydrocharietalia* Rübel 1933

Alliance *Stratiotion* Den Hartog et Segal 1964

Assoc. *Stratiotetum aloidis* Miljan 1933

Assoc. *Hydrocharitetum morsus-ranae* van Langendonck 1935

Class *Potamogetonetea* Klika in Klika et Novák 1941

Order *Potamogetonetalia* W. Koch 1926

Alliance *Nymphaeion* albae Oberd. 1957

Assoc. *Nymphaeo albae–Nupharetum luteae* Nowiński 1928

Alliance *Potamogetonion* Koch 1926

Assoc. *Potamogetonetum compressi* Tomaszczuk 1979

Assoc. *Potamogetonetum natantis* Hild 1959

The structure and composition of communities

Plants completely immersed in water (*Hydrilla verticillata*, *Myriophyllum sibiricum*, *Potamogeton berchtholdii*, *Potamogeton compressus*, *Potamogeton lucens*, *Potamogeton trichoides*, *Utricularia minor*, *Utricularia vulgaris*), usually, form multi-species complexes consisting of 2-5 species, and are often found in association with species floating on the surface of the water. However, *Potamogeton lucens* mainly forms monospecific formations. Species with leaves floating on the surface of the water

(*Hydrocharis morsus ranae*, *Salvinia natans*, *Lemna minor*, *Spirodela polyrhiza*, etc.) are concentrated, typically, in the coastal zone, except *Potamogeton natans*, which forms communities in the central area of the water body (Fig. 5e).

Extensive thickets both along the shores and in the central part of Domashnee and Krivoe lakes form the communities *Nuphar lutea* (Fig. 5c) and *Nymphaea tetragona*. Stratiotes aloides dominates in all the studied water bodies, forming extensive thickets along the shores (Fig. 5a, b). It is characterized by a polymorphic life form, in which individual plants can be simultaneously submerged and partially emergent.

Discussion

Floodplain water bodies are the product of a dynamic floodplain environment, which has a significant impact on their vegetation cover, which significantly distinguishes them from lakes located on drainage divide (inland). It floods vast expanses of the floodplain, during high water, "washing away" seeds, vegetative propagules and fruits from plants through entire floodplain area. Consequently, the flora of floodplain water bodies is constantly being updated and enriched with species from a wide variety of ecotopes (meadows, swamps, forests), which supports a high alpha diversity in water bodies.

Among the studied water bodies, only Lake Krivoe has a hydraulic connection with the Ob River in some high-water years. Therefore, these water bodies are characterized by a relatively stable level regime, their depth and water area do not change significantly during the warm season (Table 1). In addition, the absence of strong currents and the high content of suspensions in the waters reaching these lakes during high water contribute to the formation of a significant layer of loose silt in the bottom sediments (Taran 2008). All these factors, along with the small average depth and vast area of the littoral zone, are favorable for the growth and development of vegetation in the water body. A high alpha diversity is observed in the vegetation cover of the studied lakes – from 23 to 29 species per water body, while the share of the "water core" in the flora ranges from 65 (Inkino) to 75% (Krivoe). In total, 31 species of aquatic plants (hydro-, gelo- and hygrogelophytes) were found in the three studied floodplain water bodies. At the same time, according to A.A. Bobrov and D.F. Filippov (2024), only 14 species were found in the Middle and Lower Ob riverbed. The high species diversity of aquatic vegetation in the non-flowing floodplain water bodies of the Middle Ob was also noted in his works by G.S. Taran (1996, 2008).

The flora is dominated by representatives of the following families: Potamogetonaceae, Araceae – crucial families for submerged and floating-leaved vegetation; Cyperaceae – typical representatives of the coastal zone.

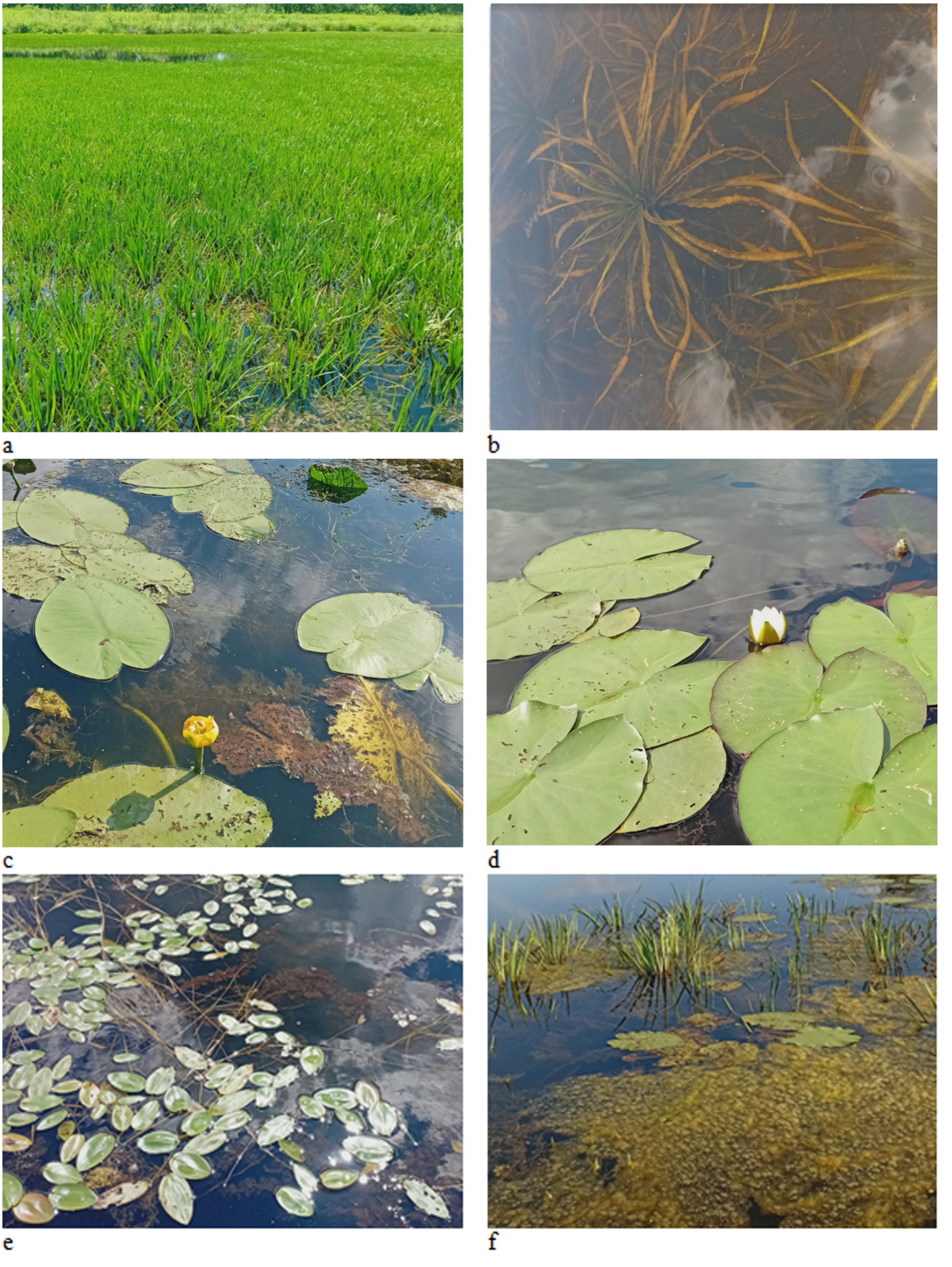

Figure 5. Vegetation of floodplain lakes of the Middle Ob River: a, b – thickets of *Stratiotes aloides* of different ages, c – *Nuphar lutea*, d – *Nymphaea tetragona*, e – *Potamogeton natans*, f – *Cladophora* sp.

Water level fluctuations, mechanical stress during high water and freshets, siltation contribute to the dominance of species with high ecological plasticity: *Salvinia natans*, *Potamogeton berchtoldii*, *Carex acuta*, *Phragmites australis*, *Typha angustifolia*, *Typha latifolia*, *Lemna minor*, *Stratiotes aloides*, and *Ceratophyllum demersum*. *Nuphar lutea*, one of the most typical species of the Ob oxbow lakes, is widespread in all studied lakes.

The cyclic drying of shallow areas of oxbow lakes during the low-water season results in the presence of species typically characteristic of wet meadows and mires (*Carex nigra*, *Lycopus europaeus*, *Rumex aquaticus*, *Persicaria lapathifolia*, *Calamagrostis purpurea*, *Bidens tripartita*), which can complete their full life cycle on the exposed bottom during the season.

The studied lakes are characterized by high floristic similarity, with 12 species of aquatic and coastal-aquatic plants being common to all lakes. This indicates the presence of a stable core flora formed under the influence of a similar hydrological regime and geographic location. Differences in abundance of species are likely related to the morphometric features of the lakes and the degree of their hydrological connectivity with the main river channel.

The aquatic vegetation of the lakes comprises 5 associations belonging to 2 alliances, 2 orders, and 2 classes. Communities of the associations *Stratiotetum aloidis* and *Nymphaeo albae–Nupharetum luteae* dominate in all the lakes; according to Georgy S. Taran (2008), these are typical for water bodies of the inner areas of ancient floodplains.

The studied water bodies show a complex morphology (oblong shape, varying depths and widths, and different flow rates) inherited from the stages of river channel meandering. Consequently, the plant communities in these water bodies are arranged not merely in concentric rings but in complex patches that correspond to the bottom microrelief. In the central part (the pelagic zone), both communities of submerged macrophytes (*Potamogeton lucens*) and floating-leaved (*Nuphar lutea*, *Potamogeton natans*) are found. Floating-leaved communities dominate along the shores as well; however, in certain areas, they are replaced by *Stratiotes aloides* communities, which occupy significant areas both along the shoreline and at the ends of the water bodies. The coastal zone is represented by a belt of *Phragmites australis*, *Typha angustifolia*, and *Carex*. In a single oxbow lake, one can simultaneously observe all stages of overgrowth – from initial stages (submerged *Potamogeton lucens* communities at depth) to transitional stages (*Stratiotes aloides* communities) and final stages (grass-sedge wet meadows).

Conclusion

The conducted study for the first time provides a holistic view of the floristic composition and structure of higher aquatic vegetation communities of the floodplain lakes of the Shegarsky reach of the Middle Ob River. The work revealed a high level of alpha diversity (up to 29 species per water body) and described 5 syntaxa of aquatic vegetation. The identified syntaxa (*Stratiotetum aloidis*, *Nymphaeo albae–Nupharetum luteae*, *Hydrocharitetum morsus-ranae*, *Potamogetonetum compressi*, *Potamogetonetum natantis*) are typical for aquatic ecosystems of Western Siberia; however, their specific distribution and species composition are determined by local morphometrical and hydrological conditions.

The flora and vegetation of the floodplain water bodies of the Middle Ob River are more than just a set of species and communities in the water. They represent a dynamic, open, and pulsating system directly dependent on general floodplain processes, the most important of which is the annual high-water season. It is the hydrological regime of the floodplain that shapes the features of the vegetation cover of oxbow lakes, distinguishing them from any other lakes in the region. The core adaptive traits include the dominance of ecologically plastic species and the presence of a stable floristic core.

The obtained data serve as a basis for monitoring the state of aquatic ecosystems under conditions of climate change and the functioning of the Tomsk Carbon Polygon. Prospects for further research are seen in a detailed study of the seasonal dynamics of vegetation, assessment of macrophyte productivity and their contribution to the carbon balance of wetland systems, as well as in the expansion of research to other sections of the vast Ob River floodplain.

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Supplementary material 1

Figure S1. Spatial distribution of occurrences from the GBIF database

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Data type: maps

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