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Article

Dynamics of restoration of higher aquatic and semi-aquatic vegetation of Lake Manzherokskoye after its dredging in 2018

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Abstract. The generalized retrospective and modern data represent dynamics of aquatic and semi-aquatic vegetation of Lake Manzherokskoye in recent years. It is shown that before implementation of the dredging works, the aquatic vegetation of Lake Manzherokskoye was distinguished by high species and coenotic diversity. However, the state of the water chestnut population worsened by 2007, as compared to the 1970s. Dredging caused a drastic decline in species and coenotic diversity of aquatic and semi-aquatic vegetation. For instance, species diversity of vascular plants (hydro- and helophytes) reduced from 25 to 12 species, while coenotic one – from 10 to 3 associations. Previously extensive thickets of water lily *Nymphaea candida* completely disappeared. In the first years after dredging, a rapid restoration of the macrophyte component of the aquatic ecosystem of Lake Manzherokskoye occurred, i.e. a drastic increase in species and coenotic diversity. In 2018–2022, species diversity of hydro- and helophytes increased from 12 to 24 species, and coenotic diversity – from 3 to 12 associations. Though the water chestnut population had recovered by 2022, today Lake Manzherokskoye remains the only reservoir in the Republic of Altai where the unique population *Trapa pectinata* exists. Thus, the lake should be preserved as a special protected natural area. Along with water chestnut, conservation of rare species of the floating mats (*Sparganium subglobosum* and *S. glomeratum)* is also of great importance.

Keywords: Republic of Altai, macrophytes, flora, species diversity, coenotic diversity

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Научная статья

Динамика восстановления высшей водной и прибрежно-водной растительности озера Манжерокское после дноуглубительных работ 2018 г.

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Аннотация. В результате обобщения ретроспективных и современных данных получена картина динамики водной и прибрежно-водной растительности озера Манжерокского за последние годы. Показано, что до начала дноуглубительных работ водная растительность озера отличалась высоким видовым и ценотическим разнообразием, однако к 2007 г. состояние популяции водяного ореха *Trapa pectinata* ухудшилось по сравнению с 1970-ми годами. Дноуглубительные работы, проведенные в 2018 г., привели к катастрофическому падению видового (с 25 до 12 видов) и ценотического (с 10 до 3 ассоциаций) разнообразия гидро- и гелофитной растительности. С водоема полностью исчезли заросли кувшинки чисто-белой. В первые годы после завершения работ показатели разнообразия резко выросли и к 2022 г. достигли 24 видов и 12 ассоциаций соответственно. Несмотря на то, что к 2022 г. произошло восстановление популяции водяного ореха, на сегодняшний день озеро Манжерокское является единственным в Республике Алтай водоемом с уникальной популяцией *Trapa pectinata*, поэтому необходимо его сохранение в статусе особо охраняемой природной территории. Кроме охраны популяции *Trapa pectinata*, необходимо сохранение редких видов сплавинного комплекса – *Sparganium subglobosum* и *S. glomeratum*.

Ключевые слова: Республика Алтай, макрофиты, флора, видовое разнообразие, ценотическое разнообразие

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Introduction

Lake Manzherokskoye has been a natural monument of regional significance since 1978. This status was approved by the Decree of the Government of the Republic of Altai dated February 16, 1996[1]. Later, the Decree of the Government of the Republic of Altai[2] and the Order of the Ministry of Natural Resources of the Republic of Altai[3] confirmed its status of a natural monument of republican significance.

Lake Manzherokskoye is the only reservoir in the Republic of Altai where water chestnut (chilim) *Trapa natans* L. s.l., included in Appendix 1 of the Berne Convention[4], grows. The species was included in the Red Book of the USSR (Krasnaya kniga..., 1984), the Red Data Book of the RSFSR (Krasnaya kniga..., 1988), the book “Rare and Endangered Plants of Siberia” (1980), the Red Data Book of Altai Territory (Krasnaya kniga..., 2016) and the Red Data Book of the Republic of Altai (Krasnaya kniga..., 2017). In terms of a more detailed view of the genus *Trapa*, water chestnut from Lake Manzherokskoye belongs to the species *Trapa pectinata* V. Vassil., which is endemic to the Altai-Sayan botanical-geographical province and found only in this lake (Flora of the USSR, 1949; Il’in, 1982; Kuminova, 1960). Another species – *T. kasachstanica* V. Vassil, is believed to grow in Lake Kolyvanskoye (Il’in, 1987).

In the 1970s, the studies of the flora and vegetation of Lake Manzherokskoye were carried out by V.V. Il’in (1982) and in 2010 – by E.Yu. Zarubina and M.I. Sokolova (2016). In 2018, a project for clearing and dredging the lake was realized in order to slow down the lake overgrowth and to provide its basin filling with silts rich in organic matter (Bezmaternykh et al., 2020a; Robertus et al., 2021). As a result, the maximum depth of the reservoir increased by more than 2 m (to 5.66 m), and the volume of water more than doubled (to 1.16 million m^3). It was expected to improve the oxygen regime and decrease the concentration of nutrients (Bezmaternykh et al., 2020a, b). Dredging works drastically changed the lake's ecosystem, including aquatic vegetation. In 2018, the lake was in the state of anthropogenic metabolic regression (low metabolic rate of biocenosis) because of decreased biodiversity, abundance and biomass of all main components of the aquatic ecosystem (Bezmaternykh et al., 2020b). Since a repeated dredging is planned, the transformation of the ecosystem has not been completed yet. Hence, the study of the current state of this unique lake is especially relevant and can serve as the basis for further restoration of its vegetation cover.

The purpose of this work was to summarize the data on dynamics of species and coenotic richness of aquatic and semi-aquatic vegetation after dredging. Special attention in this study was paid to dynamics of the water chestnut population (*Trapa pectinata* V. Vassil.).

[1] Decree of the Government of the Republic of Altai dated February 16, 1996 No.38 “On approval of the natural monuments of republican significance”.

[2] Decree of the Government of the Republic of Altai dated June 27, 2007 No. 126 “On the natural monument of republican significance “Lake Manzherokskoe”.

[3] Order of the Ministry of Natural Resources of the Republic of Altai dated May 6, 2019 No. 416 “On approval of the Regulations and boundaries of the natural monument of republican significance “Lake Manzherokskoe”.

[4] The Convention on the conservation of European Wildlife and Natural Habitats, Bern, 19.IX.1979.

Materials and methods

Lake Manzherokskoye is located on the right bank of the Katun River, in 1.75 km from its bed, 1.5 km east of the village Manzherok, at the foot of Mount Sinyukha in the Mayminsky region of the Republic of Altai. The elliptical lake stretches from southwest to northeast for 1112 m, its maximum width is 430 m, and the surface area – 37.6 ha (Tsimbalei, 2008). The lake basin was formed by damming the ancient Katun River valley with a lateral glacier moraine (Seledtsov, 1963) that is evidenced by the structure of its banks and elongation in the direction of the valley. Lake Manzherokskoye is located in the Chemal-Maima forest-steppe region (Kuminova, 1960). By hydrochemical composition, its waters belong to the type of calcium bicarbonate ultra-fresh (0.08 g/dm^3) soft (0.95–1.15 mEq/dm^3) neutral and slightly alkaline (pH 6.9–8.5) (Robertus et al., 2021). Surface runoff of precipitation, streams from the slopes of Mount Sinyukha, and groundwaters provide the reservoir alimentation (Robertus et al., 2021; Tsimbalei, 2014). The minimum permissible water level in the lake is 375.2 m, and the normal headwater one is 375.5 m (Robertus et al. 2021). To the southeast of the lake, where mixed forests are located (deluvial-proluvial plume and the slopes of Mount Sinyukha), the “Manzherok” ski complex is being developed: administrative and residential buildings are constructed. Like other small water bodies in Altai foothills (Aya and Kolyvanskoye), the study lake is under heavy recreational pressure. Of course, it greatly affects the ecological state of these reservoirs (Bezmaternykh et al., 2020a).

This work is based on the results of our field studies performed in August 2017, July and August 2018, July 2020, August 2021 and 2022. During these investigations, we employed an inflatable boat, hydrobotanical rakes, a portable Garmin eTrex Vista navigator (with a GPS receiver), and a waterproof Pentax camera. A white Secchi disk was used to measure transparency, while an Altami PS0745-T stereoscopic microscope with a camera – to identify plants. Identification of vascular plants was carried out due to the keys and descriptions of L.I. Lisitsyna and V.G. Papchenkov (2000), and A.A. Bobrov (Opredelitel'..., 2020). To assess the state of the water chestnut population in 2019, the data from the report of L.V. Pozhidaeva et al. (2019) were involved. To study long-term dynamics, the data obtained earlier by other researchers were analyzed (Il'in, 1982; Zarubina and Sokolova, 2016). In this work, the nomenclature of taxa for higher plants corresponds to the data from the “Catalogue of life” website[5] (2022). A volume of the species *Trapa pectinata* V. Vassil was assumed in accordance with N.N. Tsvelev (1993), whereas the ecogroups (hydrophytes, helophytes, amphibian species, hygrohelophytes, hygrophytes) – according to the classification of V.G. Papchenkov et al. (2006). The collection of the material (by coenotic composition of vegetation) and its processing were performed based on general guidelines of ecological and floristic classification (Braun-Blanquet, 1964).

Results

Characteristics of aquatic and semi-aquatic vegetation before dredging

Water transparency of Lake Manzherokskoye before dredging varied seasonally from 60 cm in June–July to 180 cm in August (Il'in, 1982). The concentration of suspended solids in 2015 was 0.035 g/dm^3 (Robertus et al., 2021).

Due to its shallow water and good warming in summer, the lake had high floristic and coenotic diversity. For instance, the floristic diversity of aquatic and semi-aquatic plants in 2010 was represented by 34 species (Table 1[6]). Hydrophytes demonstrated the greatest species diversity in the flora of the reservoir (16 species, or 47%) (Zarubina and Sokolova, 2016). In 2010, *Sparganium subglobosum* Morong was found in Lake Manzherokskoye. In August 2021, we (Kipriyanova and Volobaev, 2023) confirmed the finding of this East Asian element of the flora with its disjunctive range (Belyakov and Zarubina, 2020). Plants formed sparse communities on the floating mats in the southwestern part of the lake.

[5] Catalogue of life: The most complete authoritative list of the world's species, 2022. Web page. URL: https://www.catalogueoflife.org (accessed: 23.05.2023).

[6] The hygrohelophytic component of the lake's vegetation and bryophytes received less attention in our study compared to the hydrophytic component and vascular plants, so their absence in the list does not necessarily mean their actual absence in the lake.

Table. 1. Higher aquatic and semi-aquatic plants noted in the Lake Manzherokskoe in different years of research. + – species noted, ++ – species forms communities, +++ – communities form extensive thickets, * – species is most likely also present, but was not noted in the descriptions.

Species	Dates of the study (according to the literature and own data)						
	1976 (based on: Il'in, 1982)	2010 (from: Belyakov and Zarubina, 2021; Zarubina and Sokolova, 2016)	15.08.2017	08.08.2018	26.07.2020	26.08.2021	01.08.2022
Unrooted hydrophytes							
Ceratophyllum demersum L.	+	+	.	.	.	.	.
Hydrocharis morsus-ranae L.	+	++	++	++	++	++	++
Lemna minor L.	+	+	+	+	+	+	+
L. turionifera Landolt	.	.	.	.	.	.	+
Riccia fluitans L.	.	.	+	.	.	+	.
Spirodela polyrhysa (L.) Schleid.	.	.	+	+	+	+	+
Utricularia minor L.	.	++	.	.	.	.	.
U. vulgaris L.	+	.	+	+	.	.	.
Submerged rooted hydrophytes							
Callitriche palustris L.	.	.	+	.	.	.	+
Fontinalis anthipyretica Hedw.	++	.	.	.	.	.	.
Hydrilla vericillata (L. fil.) Royle	++	+++	++	.	.	.	.
Potamogeton alpinus Balb.	.	.	.	.	.	.	+
P. berchtoldii Fieb.	.	+	+	.	.	.	++
P. compressus L.	+	+	.	.	.	.	.
P. gramineus L.	.	.	+	.	.	.	+
P. obtusifolius Mert. et Koch	.	.	.	.	.	+	.
P. perfoliatus L.	+	++	++	.	.	.	+
P. praelongus Wulfen	+	++	+	.	.	.	+
Rooted hydrophytes with floating leaves							
Nymphaea candida C. Presl.	++	+++	+++	++	.	.	+
N. tetragona Georgi	+	+	++	.	.	+	++
Nuphar pumila (Timm) DC.	+	+	++	.	.	.	.
Persicaria amphibia (L.) Gray	.	.	.	+	++	++	+
Potamogeton natans L.	++	++	+	.	+	.	++
Sagittaria natans Pall.	++	++	+	.	.	++	++
Trapa pectinata V. Vassil.	+++	+	+	.	++	++	+++
Total amount of hydrophytes species	15	15	18	6	6	9	16
Total amount of hydrophytes associations	6	8	6	2	3	4	6

Species	Dates of the study (according to the literature and own data)						
	1976 (based on: Il'in, 1982)	2010 (from: Belyakov and Zarubina, 2021; Zarubina and Sokolova, 2016)	15.08.2017	08.08.2018	26.07.2020	26.08.2021	01.08.2022
Semi-aquatic							
Helophytes							
Acorus calamus L.	.	.	++	.	.	.	.
Eleocharis mamillata (Lindb.) Lindb.	.	.	+	+	+	++	++
E.palustris (L.) Roem. et Schult.	,	+					
Equisetum fluviatile L.	+	+	+	.	.	.	.
Phragmites australis (Cav.) Trin. ex Steud.	++	.	++	+	.	.	.
Schoenoplectus lacustris (L.) Palla	++	+	.	.	.	.	.
Scirpus radicans Schkuhr	.	+	++	++	++	++	++
Sparganium emersum Rehm.	+	.	.	.	+	++	++
S. erectum L.	.	.	.	.	.	++	**
S. glomeratum (Laest.) Neuman	.	.	.	.	.	+	*
S. natans L.	.	.	.	.	.	+	.
S. subglobosum Morong	.	+	*	*	*	++	**
Typha angustifolia L.	.	++	.	+	+	+	+
T. latifolia L.	++	+	++	+	+	++	++
Total amount of helophytes species	5	7	7	6	6	9	8
Total amount of helophytes associations	3	1	4	1	1	6	6
Hygrohelophytes and hygrophytes							
Bidens cernua L.	.	.	+	.		++	+
B. tripartita L.	.	.	+	+	+	+	++
Calla palustris L.	++	++	+	+	.	+	++
Carex atherodes Spreng.	.	.	++	.	.	.	.
Carex spicata Huds. (synonym *C. contigua* Hoppe)	.	+	.	.	.	.	.
C. lasiocarpa Ehrh.	.	++	.	.	.	.	.
C. pseudocyperus L.	.	++	.	.	.	.	.
C. rhynchophysa C.A. Mey.	.	+	++	.	.	.	.
C. riparia Curt.	.	.	+	.	.	.	.
Comarum palustre L.	.	.	+	++	++	+	+
Cicuta virosa L.	.	.	+	+	.	+	+
Drepanocladus aduncus (Hedw.) Warnst.	.	+	.	.	.	.	.
Echinochloa crus-galli (L.) P. Beauv.	.	.	.	.	.	.	+

Species	Dates of the study (according to the literature and own data)						
	1976 (based on: Il'in, 1982)	2010 (from: Belyakov and Zarubina, 2021; Zarubina and Sokolova, 2016)	15.08.2017	08.08.2018	26.07.2020	26.08.2021	01.08.2022
Epilobium palustre L.	.	.	.	+	.	.	+
Equisetum palustre L.	.	.	+	.	.	.	.
Galium trifidum L.	.	+	.	.	.	.	.
Glyceria lithuanica (Gorski) Gorski (synonym *G. triflora* (Korsh.) Kom.)	.	.	.	.	.	.	+
Leersia oryzoides (L.) Sw.	.	.	.	.	.	.	+
Lycopus europaeus L.	.	.	+	+	.	+	.
Lycopus exaltatus L. fil.	.	.	.	+	.	.	+
Lysimachia vulgaris L.	.	.	.	+	.	.	.
Menyanthes trifoliata L.	++	++	.	+	.	+	.
Persicaria hydropiper (L.) Spach.	.	.	+	+	.	+	++
Persicaria lapathifolia (L.) S.F. Gray	.	.	.	+	.	.	+
Phalaris arundinacea L.	.	.	+	+++	.	.	.
Rorippa sylvestris (L.) Besser	.	.	.	.	.	.	+
Scolochloa festucacea (Willd.) Link	+	+	.	.	.	.	.
Scutellaria galericulata L.	.	.	+	.	.	.	.
Sphagnum magellanicum Brid.	.	+	.	.	.	.	.
Stachis palustris L.	.	.	.	+	.	.	+
Thelypteris palustris (Salisb.) Schott	.	++	++	++	+	+	+

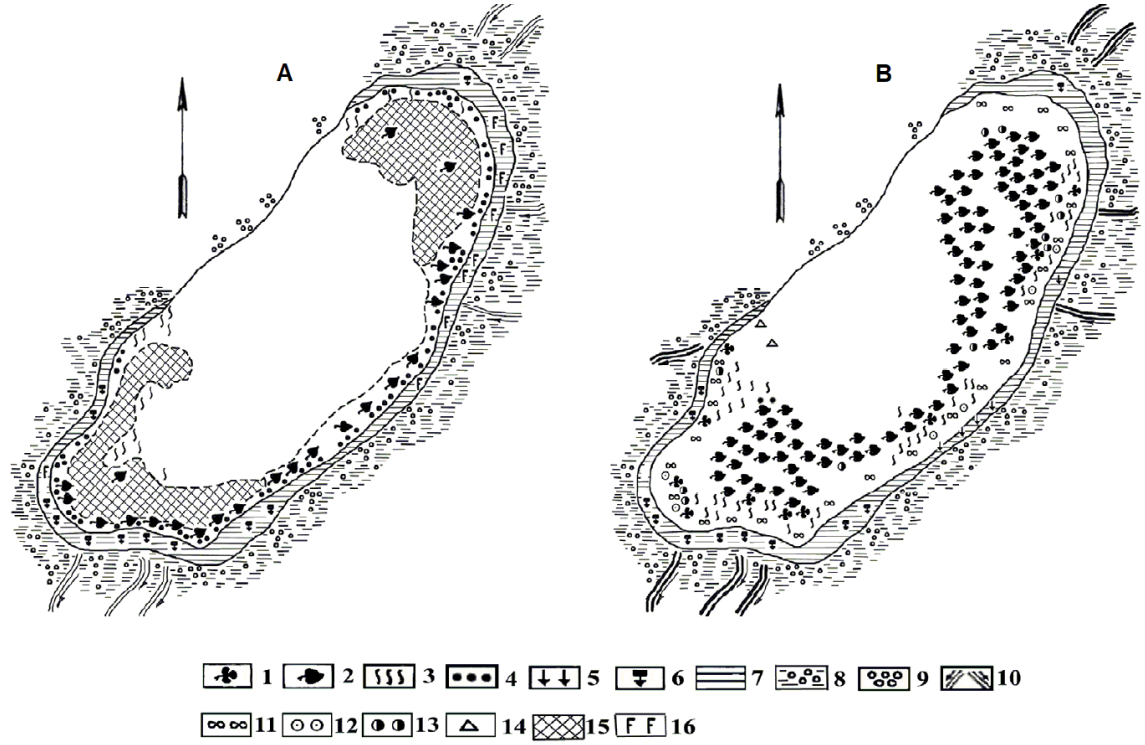

Fig. 1. Schemes of overgrowth of Lake Manzherokskoye: **A** – according to: Il'in, 1982, **B** –according to: Zarubina and Sokolova, 2016. 1 – thickets of *Trapa pectinata*; 2 – *Nymphaea candida*; 3 – *Hydrilla verticillata*; 4 – *Scirpus lacustris*; 5 –*Typha angustifolia*; 6 – *Typha latifolia*; 7 – floating mats (*Menyanthes trifoliata*, *Calla palustris*, *Carex* spp.); 8 – swampy shore; 9 – shrubs (*Salix* sp., *Padus* sp., *Viburnum* sp.); 10 – streams; 11 – *Hydrocharis morsus-ranae*; 12 – *Utricularia minor*; 13 – *Potamogeton natans*; 14 – *Potamogeton praelongus*; 15 – *Trapa pectinata*; 16 – *Phragmites australi*s.

In recent years, the size of the water chestnut population in Lake Manzherokskoye has decreased significantly. About 40 years ago *Trapa pectinata* was the main coenosis-former here (ass. **Trapetum natantis** Kárpáti 1963); the total area of its thickets reached 13% of the water area (Fig. 1**A**) (Il'in, 1982). At the beginning of the 20th century, its state deteriorated significantly. In 2007, during field studies implemented within the program on the compiling the list of Important Plant Areas (Kipriyanova, 2009), water lily *Nymphaea candida* was the main former of coenosis. The area of chilim thickets reduced sharply, but the communities of the area exceeding 100 m^2 were still preserved (own data). In 2010, during the vegetation mapping of the reservoir, E.Yu. Zarubina did not register water chestnut communities at all; chilim was listed as the accompanying species of water lily communities (Fig. 1**B**) (Zarubina and Sokolova, 2016).

A year before the planned "rehabilitation" (2017), we found only single specimens of water chestnut during a survey of Lake Manzherokskoye. According to our rough estimate, its number did not exceed 300–500 specimens. Water lily *Nymphaea candida* dominated (ass. **Nymphaeetum candidae** Miljan 1958) forming extensive thickets of high coverage (Fig. 2). In 2017, coenoses were also formed by *Hydrocharis morsus-ranae* (ass. **Hydrocharitetum morsus-ranae** van Langendonck 1935), *Hydrilla vericillata* (ass. **Hydrilletum verticillatae** Tomaszewicz 1979), *Potamogeton perfoliatus* (ass. **Potamogetonetum perfoliati** Miljan 1933), *Nuphar pumila* (ass. **Nupharetum pumilae** Miljan 1958) (Fig. 3), *Nymphaea tetragona* (ass. **Nymphaeetum tetragonae** Ito et Umezawa 1970), *Acorus calamus* (ass. **Acoretum calami** Dagys 1932), *Phragmites australis* (ass. **Phragmitetum australis** Savich 1926), *Thelypteris palustris* (ass. **Thelypterido palustris – Phragmitetum australis** Kuiper ex van Donselaar et al. 1961 (Table 1). Species and coenotic diversity of the aquatic vegetation was quite high (18 and 6, respectively) and with helophytic one – 25 species and 10 types of communities (Figs. 4, 5). From our measurements, water transparency was within 80 cm.

Fig. 2. Coenoses of *Nymphaea candida*, dominant in the lake vegetation before dredging (15.08.2017).

Fig. 3. Communities of *Nuphar pumila* in Lake Manzherokskoye in August 2017.

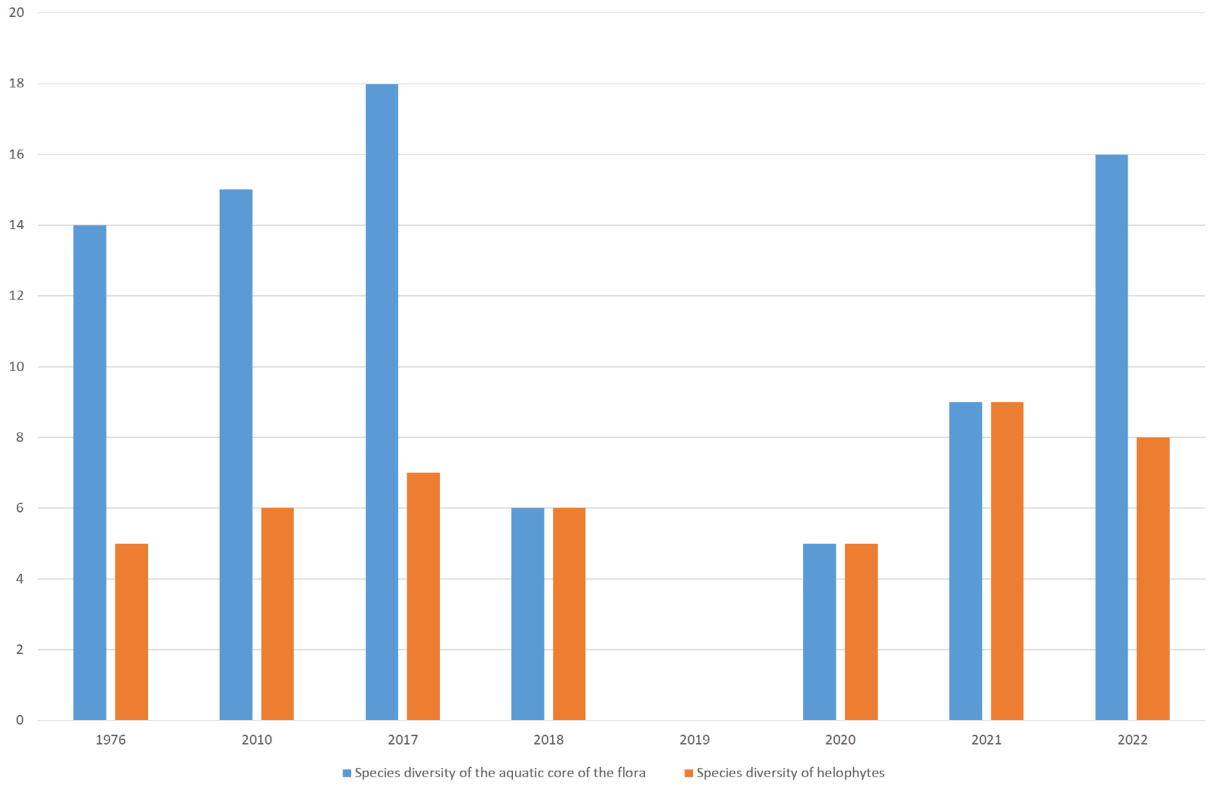

Fig. 4. Dynamics of species diversity of higher plants of Lake Manzherokskoye in 1976–2022.

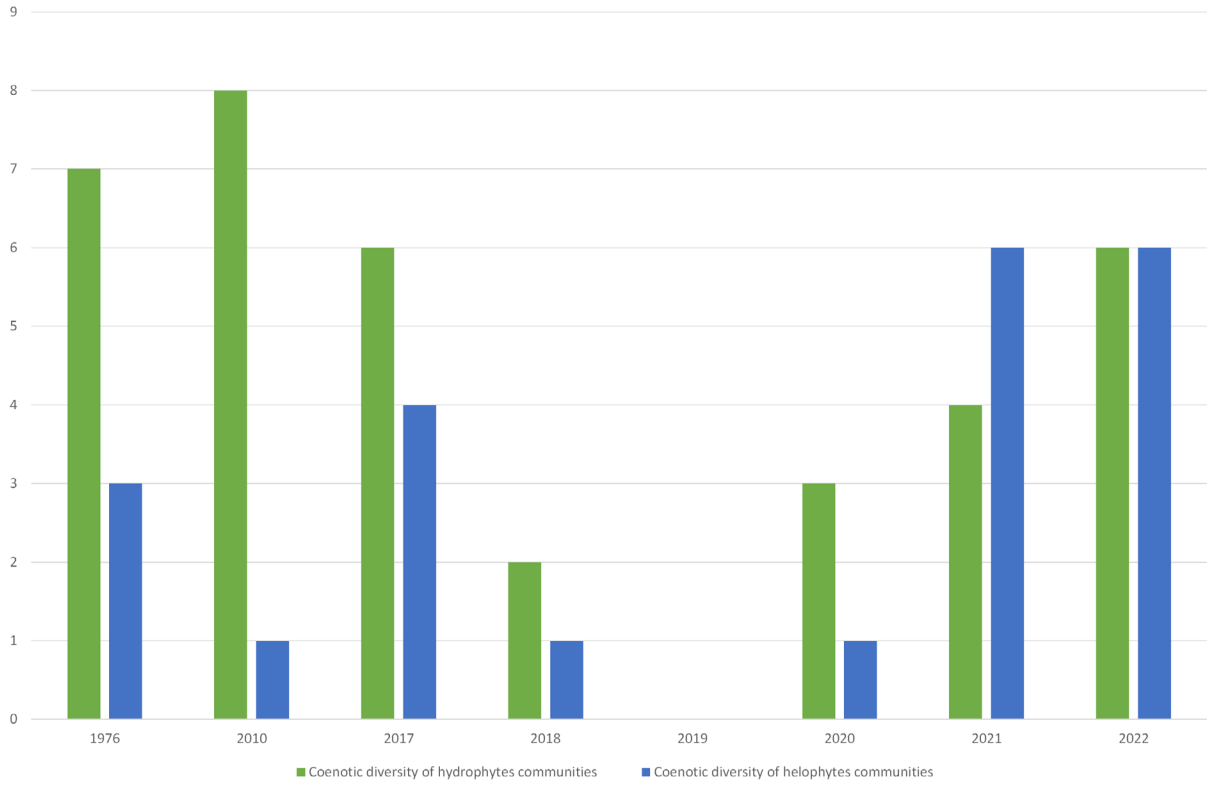

Fig. 5. Dynamics of coenotic diversity of vegetation of Lake Manzherokskoye in 1976–2022.

Characteristics of aquatic and semi-aquatic vegetation after dredging

2018

In August 2018, a month after ground excavation, water transparency by the Secchi disk was 0.5–1.0 cm and the concentration of suspended solids – 2.830 g/cm^3 (Robertus et al., 2021).

Only plant communities composed of practically unaffected by dredging semi-aquatic plants (mainly hygrohelophytes) were relatively stable in August 2018. We gave a description of the communities of *Thelypteris palustris* (Fig. 6) and *Comarum palustre*. In August 2018, only 5 species were recorded out of total hydrophytes previously discovered in Lake Manzherokskoye (14 species of the aquatic core of the vascular flora in 1976 (Il'in, 1982), 15 in 2010 (Zarubina and Sokolova, 2016)). These were *Nymphaea candida*, *Spirodela polyrhiza*, *Lemna minor*, *Hydrocharis morsus-ranae* and *Utricularia vulgaris*. When analyzing the species list, most attention was paid to the absence of submerged hydrophytes – pondweeds and *Hydrilla verticillata*, for which the conditions were especially unfavorable. In 2018, the communities of submerged aquatic vegetation were not detected. The vegetation mapping data showed that silt removal did not destruct (as expected) the main habitats of water lily. In 2018, as compared to the previous periods, water lily coenoses had a low projective cover (i.e. under 35%, on average 10–15%) and a weak flowering. Among other coenoses of aquatic plants, only association **Hydrocharitetum morsus-ranae** formed by *Hydrocharis morsus-ranae* – an unrooted species with leaves floating on the water surface, was recorded.

Thus, dredging caused a catastrophic decline in species and coenotic diversity of aquatic and semi-aquatic vegetation. For vascular plants (hydro- and helophytes), this indicator dropped from 25 to 12 species, and for coenotic diversity – from 10 to 3 associations (Figs. 4, 5).

2019

According to available data, the suspended solid concentration for August 2019 made up 0.215 g/cm^3 (Robertus et al., 2021). When examining Lake Manzherokskoye and assessing the state of the water chestnut population, 198 specimens of *Trapa pectinata* were identified (Pozhidaeva et al., 2019). As compared to 2017, the population size decreased by more than 2 times (Kipriyanova, 2017). Most water chestnut plants were in a depressed state: the size of floating rosettes and individual leaf blades was 2–3 times less than normal; some plants had yellowed and brown leaves; flowering was absent despite the corresponding phenological period. The population of *Nymphaea candid*a decreased to an extremely low number, i.e. less than 30–35 specimens (Pozhidaeva et al., 2019).

2020

From direct observations, transparency (by the Secchi disk) in late July was 15 cm, and suspended solids concentration in July – 0.098 g/cm^3 (Robertus et al., 2021). Throughout 2020, a water level (376.2 m) was high (Robertus et al., 2021).

From our data it follows that chilim number in the lake did not exceed 300 specimens in 2020; small groups of *Trapa pectinata* were noted for the first time. In addition to water chestnut, *Persicaria amphibia* also formed small communities and *Hydrocharis morsus-ranae* provided narrow stripes along the banks and edges of the floating mats.

2021

In late August, water transparency was 15 cm. A sharp drop in water level was associated with the construction of a new road dam at the southwestern tip of the lake and under-the-dam tubing. As a result, large areas of the near-shore shallow waters were exposed and at the end of August occupied by the communities of annual plants – *Persicaria hydropiper*, *P. lapathifolia*, *Bidens cernua*, *B. tripartita*. That year, usually floating mats stayed on the ground and did not float at the water surface. The appearance of massifs of *Spirogyra* sp. thickets was indicative of high water trophicity.

Despite a drastic drop in a water level and dry off of numerous water chestnut rosettes on the exposed near-shore shallows, dynamics of the water chestnut population remained positive. In 2021, chilim encountered at least 1800 (own data) and formed small thickets in some places. A gradual recovery of biodiversity of aquatic plants started. Thus, along with cenoses of *Hydrocharis morsus-ranae*, *Trapa pectinata* and *Persicaria* sp., communities of *Sagittaria natans*, *Sparganium emersum*, and *Eleocharis mamillata* were discovered. The last species was recorded for the first time in the Republic of Altai (Kipriyanova and Volobaev, 2023). Massifs of *Spirogyra* sp. thickets were also noted, as in previous years after dredging.

Fig. 6. Coenoses of the *Thelypteris palustris* on Lake Manzherokskoye in 2018.

Fig. 7. Massifs of *Trapa pectinata* thickets in the southwestern part of Lake Manzherokskoye in 2022.

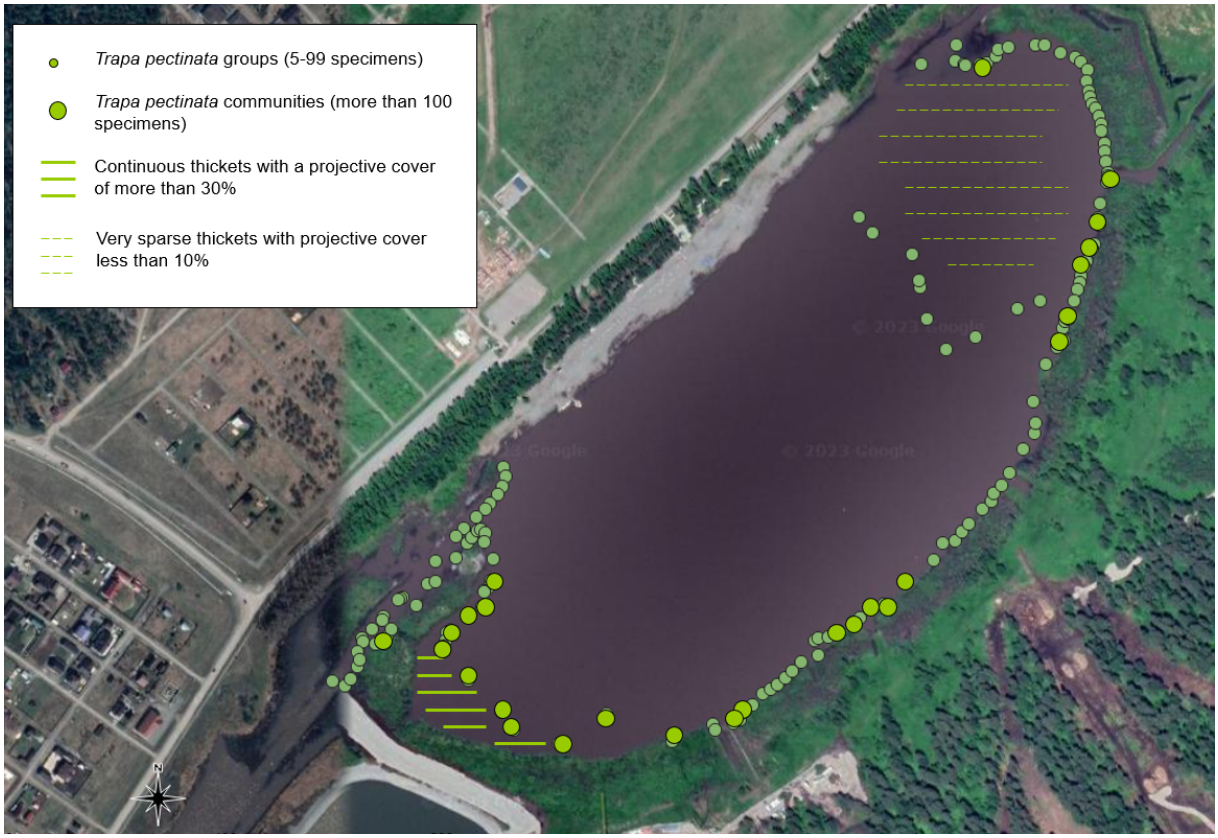

Fig. 8. Scheme of water chestnut locations on Lake Manzherokskoye in 2022.

2022

Water transparency (by Secchi disk) was about 18 cm. Small communities of *Potamogeton berchtoldii* and *P. natans*, as well as *Nymphaea tetragona* were found along with those recorded in 2021. The area of water chestnut increased significantly resulting in the formed continuous thickets in the southwestern part of the lake (Figs. 7, 8). As in 2021, large areas of coenoses of annuals – *Persicaria hydropiper*, *P. lapathifolia*, *Bidens cernua*, *B. tripartita* were noted along the banks. The formation of large-area coenoses of *Hydrocharis morsus-ranae* (Fig. 9) and small coenoses of *Sagittaria natans* (Fig. 10) continued as well.

The generalized data on dynamics of species and coenotic diversity of aquatic and semi-aquatic vegetation suggest a fairly rapid restoration of vegetation cover of the lake. Here, species diversity of hydro- and helophytes in 2018–2022 increased from 12 to 24 species (Fig. 4), and the coenotic diversity – from 3 to 12 associations (Fig. 5).

The water chestnut population underwent the most dynamic changes after dredging. If in the year of dredging chilim was not observed at all, by 2022, it occupied vast spaces in the southwestern part of the reservoir.

Discussion

Over the past 50 years, in addition to significant anthropogenic dynamics, a natural vegetation transformation in Lake Manzherokskoye took place. For example, V.V. Il'in (1984) reported about the communities formed by moss *Fontinalis anthipyretica* sp. However, in thirty years even single specimens of this species were not recorded, probably, because of a low flow and high trophicity of waters. *Hydrocharis morsus-ranae* strengthened its position (which usually happens in succession old lakes), but in the 1970s, this plant was found only sporadically. In the 21st century, it formed stable cenoses covering large areas. Instead of the mentioned by V.V. Il'in (1982) *Scirpus lacustris* (*Schoenoplectus*

Fig. 9. Coenoses of *Hydrocharis morsus-ranae* and *Typha latifolia* in 2022.

Fig. 10. Communities of *Sagittaria natans* in 2022.

lacustris) and more often found in rivers and succession young lakes of Western Siberia, the communities of *Scirpus radicans* appeared. The latter are characteristic of the later succession stages of lake vegetation. Previously not recorded in Lake Manzherokskoye (Il'in, 1976; Zarubina and Sokolova, 2016) *Spirodela polyrhysa* during our studies was found in the communities of aquatic plants near the floating mats.

For aquatic plants of the lake, it would be better to remove silt in autumn because water settling during winter is able to provide more favorable living conditions for active plant growth. We forecasted a step-by-step restoration of the macrophyte component of the Lake Manzherokskoye ecosystem due to seeds, rhizomes, and turions present in the silt (Bezmaternykh et al., 2020b).

It is worth noting that a sharp reduction in chilim number occurred also before dredging (Zarubina and Sokolova, 2016; own data). The decline in its abundance is logically associated with the use of pedal boats in the lake. Being annuals with weak roots, water chestnut plants are easily pulled out of the ground, in contrast to water lily with its powerful perennial and hard-to damage rhizomes. That is why the lake before the "rehabilitation" was of a "water lily" type (Figs. 1, 2). In order to create some reserve populations of *Trapa pectinata,* it would be reasonable to transfer its fruits to water bodies with relatively similar habitat conditions before dredging works.

After dredging, the water chestnut population quickly recovered. By 2022, it became abundant and occupied large areas. However, taking into account the growing anthropogenic impact on the lake, including the transformation of its ecosystem as a result of ongoing construction works at the "Manzherok" mountain ski complex in the protected water zone, as well as shore and bottom cleaning activities, this species needs protection badly.

The most noticeable negative consequence of dredging works was a dissapearance of thickets of water lily *Nymphaea candida*, which previously occupied a large water area and increased the recreational value of the lake. According to Yu.V. Robertus, their loss was associated with a sharp rise in a water level in 2020 (Robertus et al., 2021). Since it is an important habitat-forming component of the aquatic ecosystem having high decorative value, we recommend to reintroduce water lily in Lake Manzherokskoye.

A partial preservation of the floating mats complex (e.g. in the form of an equipped ecological trail) as the basis for the conservation of relict species of plants and animals able to increase the recreational attractiveness of Lake Manzherokskoye is also of importance. On the floating mats, such iconic plants of sphagnum communities as cranberry (*Vaccinium oxycoccus* L.), sundew (*Drosera rotundifolia* L.), cotton grass (*Eryophorum* sp.), etc. are growing. In opinion of O.E. Kosterin (2021), the shoreline is still suitable for the habitat of the relict saffron dragonfly *Sympetrum croceolum* Selis, 1883 listed in the Red Book of the Republic of Altai. The East Asian species with a disjunctive range (*Sparganium subglobosum)* was recently discovered just on the floating mats complex; this species may be a relic for Lake Manzherokskoye. Because of great remoteness of this population from the main range, we recommend to include it in the next edition of the Red Data Book of the Region (Kipriyanova and Volobaev, 2023). Besides, *Sparganium glomeratum* (Laest.) Neuman – a rare species for the Republic of Altai, was noted only in the floating mats. The latter are not only the habitat for rare species of plants and animals, they are also natural biofilters preventing the influx of nutrients and other pollutants from the catchment undergone the greatest man-induced transformation in recent years. The floating mats complex serves as a buffer zone and thereby mitigates catastrophic hydrological events associated with runoff from the basin.

In the Republic of Altai, Lake Manzherokskoye is known as the unique natural object, the only large water body in the foothills, the powerful center of biodiversity and the Important Plant Area (Kipriyanova, 2009).

To combine the interests of tourism and nature conservation, "a rest zone for chilim" in Lake Manzherokskoye by means of installed barrier buoys to limit the movement of pedal boats and other water transport should be established. Moreover, it is necessary to create several reserve populations of *Trapa pectinata* in Altai reservoirs, where this species is absent (to avoid crossing), and suitable for their growth.

Conclusion

Before dredging works (2018), the aquatic vegetation of Lake Manzherokskoye was distinguished by high species and coenotic diversity. However, the state of the water chestnut population worsened, as compared to the 1970s. Dredging works caused a catastrophic decline in species and coenotic diversity of aquatic vegetation; previously extensive thickets of water lilies *Nymphaea candida* completely disappeared. Water transparency, even four years after the works completion, was about 18 cm. In the first years just after these works, a rapid restoration of the macrophyte component of the aquatic ecosystem of Lake Manzherokskoye, accompanied by a sharp increase in species and coenotic diversity, was observed. By 2022, the water chestnut population had recovered. Currently, Lake Manzherokskoye is the only reservoir with its unique population of *Trapa pectinata*. Surely, the lake should have the status of the special protected natural area.

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