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Article

Long-term dynamics of vegetation cover of Lake Manzherokskoye (Republic of Altai) under high antropogenic load on the reservoir and its basin

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Abstract. In the second, third and fifth years after implemented dredging and bottom sediments removal (August 2020, 2021 and 2023), species diversity of aquatic and semi-aquatic vegetation, type and degree of lake Manzherokskoye overgrowth, productivity of dominant species were studied, and the indices of species diversity and saprobity were calculated. Based on literature data, the long-term (almost for 60 years) dynamics of vegetation cover and the features of lake overgrowth were defined. Particular attention was paid to studying water chestnut (*Trapa natans*), a species included in the Red Book of the Republic of Altai. In the fifth year after dredging, a partial restoration of macrophytes diversity was noted. Further clearing of the lake's bottom and its shores in 2023 caused the destruction of the floating mats complex and the reduction in the number of floating mats-forming species. In 2023, water chestnut dominated in terms of overgrowth area and price-formation. A massive appearance of polymorphic multi-leaf forms of water chestnut, forming rosettes with 40 or more leaves, occurred. Analysis of the water chestnut population dynamics for a long period (including one after dredging) showed the high potential for self-recovery of this species. In the case of implementation of special measures on mitigation of recreational load impact on the areas of *Trapa natans* distribution, in the next 5 years the return of the lake importance as its main habitat, and, consequently, the preservation of the natural monument "Lake Manzherokskoye" is expected.

Keywords: anthropogenic transformation, water chestnut *Trapa natans*, productivity, biodiversity indices, assessment of ecological state

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Научная статья

Многолетняя динамика растительного покрова озера Манжерокского (Республика Алтай) в условиях высокой антропогенной нагрузки на водоем и его водосборный бассейн

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Аннотация. В августе 2020, 2021 и 2023 гг., на второй, третий и пятый года после дноуглубительных работ и удаления донных отложений, проведено исследование видового разнообразия водной и прибрежно-водной растительности, характера и степени зарастания оз. Манжерокского, продуктивности доминирующих видов, рассчитаны индексы видового разнообразия и сапробности. На основе литературных данных изучена многолетняя динамика растительного покрова и особенности зарастания озера за почти 60 лет. Особое внимание уделено изучению водяного ореха (*Trapa natans*) – вида, включенного в Красную книгу Республики Алтай. Выявлено, что на пятый год после проведения дноуглубительных работ произошло частичное восстановление видового разнообразия макрофитов. Однако продолжающаяся на озере в 2023 г. расчистка дна и берегов привела к разрушению сплавин и сокращению численности видов-сплавинообразователей. Доминантом по площади зарастания и основным ценозобразователем на озере в 2023 г. был водяной орех. Отмечено массовое появление полиморфных многолистных форм водяного ореха, формирующих розетки из 40 и более листьев. Анализ динамики популяции водяного ореха за многолетний период, в том числе и после проведения дноуглубительных работ, показал высокий потенциал самовосстановления этого вида. При условии проведения специальных мероприятий по снижению воздействия рекреационной нагрузки на участки распространения *Trapa natans* есть основание для прогноза возвращения в ближайшие 5 лет значимости озера как его основного места обитания и, следовательно, сохранения памятника природы «Озеро Манжерокское».

Ключевые слова: антропогенная трансформация, водяной орех *Trapa natans*, продуктивность, индексы биоразнообразия, оценка экологического состояния

Финансирование. Исследования проведены в ходе выполнения государственного задания ИВЭП СО РАН (№ гос. регистрации проекта 0306-2021-0001) при частичной финансовой поддержке Министерства природных ресурсов и экологии Республики Алтай и ОАО «Всесезонный курорт Манжерок» по проекту «Оценка современного экологического состояния озера Манжерокского, перспектив его развития и функционирования».

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Introduction

Lake Manzherokskoye is located in the foothills of Altai and geographically refers to the western slope of the mountain range Iolgo that is 18 km southwest of Gorno-Altai. The lake occupies a high ancient terrace on the right bank of the Katun River at 90–92 m above its water edge and at an altitude of 376–380 m a.s.l. (Tsimbaley, 2008). The lake's catchment area is 7.67 km². It is fed by temporary surface runoff from Mount Sinyukha, atmospheric precipitation and groundwater. The low-flow reservoir has a retarded water exchange. A stream Ozerny (second order tributary of the Katun River) outflows from the southwest of the lake. The average annual discharge from the surface into the lake makes up 5.75 thous. m³, the average evaporation reaches 55 thous. m³ per year (Robertus et al., 2021).

Due to the ancient origin and isolated location of lake Manzherokskoye, its flora and fauna differs significantly from other lakes of mid- and low-mountains of Altai (Ilyin, 1982). In 1978, by Decree of the Government of the Republic of Altai dated February 16, 1996, a natural monument of the regional significance was established to maintain this unique complex in its natural state, to prevent its ecosystem degradation and preserve the rare species of the flora and fauna¹. The lake is home to water chestnut (*Trapa natans* L. (syn. *Trapa pectinata* V. Vassil.)), which is currently not found anywhere else in the Republic of Altai. Water chestnut (chilim) is listed in the Red Book of the Republic of Altai (2017) and has rarity status 1: endangered species.

In recent decades, human disturbance of the basin (plowing of the territory, deforestation, construction of tourist facilities) has resulted in an increased runoff of terrigenous material from the basin, a reduction in the surface area, shores swamping, and a deterioration of oxygen regime thereby creating the pressing environmental problem in the region. The hydrological and hydrogeological conditions of lake Manzherokskoye have also transformed and affected its water-sedimentation regime and aquatic vegetation (Puzanov et al., 2015; Robertus et al., 2021). Currently, the lake is one of the popular water tourist sites of the Republic. For instance, the all-season resort "Manzherok" is being actively developed in the southeastern part of the lake.

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

In 2018, in order to slow down the overgrowth and fill the lake bowl by silt rich in organic matter, a project for its environmental rehabilitation was implemented. In the central (free from water chestnut) part of the lake, 217.3 thous. m³ of bottom silt were removed from the area of 150 thous. m². The average and maximum depth of clearing made up 1.34 and 2.06 m, respectively (Robertus et al., 2021). According to the “Criteria for assessing the environmental situation of territories...” and the results of environmental studies performed immediately after these works (August 2018), it was reported about the “emergency ecological situation” in lake Manzherokskoye (Bezmaternykh et al., 2020b)². Among positive consequences of a partial withdrawal of bottom silt was a noticeable increase in water levels (2020), probably, associated with an activation of groundwater sources (springs) at the bottom and in the eastern section of the lake owing to the reservoir clearing. Another positive aspect of the rehabilitation was a partial restoration of the lake flow due to constructed spillway canals in its northeastern and southwestern sections (Robertus et al., 2021). In 2023, the second stage of the lake clearing began, during which species diversity of aquatic and semi-aquatic vegetation, a degree of overgrowth and productivity of dominant communities were investigated.

The purpose of the work was to study the long-term dynamics of species diversity of aquatic and semi-aquatic vegetation, including the overgrowth degree of lake Manzherokskoye under conditions of heavy anthropogenic pressure on the reservoir and its basin. Particular attention was paid to the water chestnut population.

Materials and methods

This article is based on the results of field studies of the flora of lake Manzherokskoye conducted in August 2020, 2021 and 2023. The investigations were carried out using the standard methods of collection, herbarization, description and mapping of higher aquatic vegetation (Katanskaya, 1981; Papchenkov, 2003). The level of productivity of aquatic phytocenoses was determined by their biomass on mowing plots of 0.25 m² in 2–4 fold repetitions. In laboratory, the specimens were dried at $t = 85\text{ }^{\circ}\text{C}$ to completely dry weight in accordance with the method of I.M. Raspopov (2006). A total of 13 specimens were made in six dominant plant communities.

Vascular plants identification was performed according to the floristic reports (Flora Sibiri, 1987–2003; Flora SSSR, 1949; Lisitsyna and Papchenkov, 2000). The nomenclature of vascular plant taxa is given from Plants of the World Online³. In this work, we consider water chestnut within the scope accepted in the “Flora of Siberia” (Vlasova, 1996) as *Trapa natans* L. s. l. with the proviso of further comprehensive research of plants found in Siberia.

The lake flora is a set of natural species of aquatic and semi-aquatic plants of a water body. Aquatic plants are those for which an aquatic environment or water-covered soil serve as an optimal habitat. Aquatic plants are hydrophytes, including hydatophytes (submerged plants) and pleistophytes (plants with floating leaves). Aquatic plants also include helophytes or semi-submerged plants (Papchenkov et al., 2006).

When assessing the lake ecosystem state, we applied the Shannon and Simpson species diversity indices calculated from species abundance by the Drude scale using the PAST 4.13 program. To assess the degree of organic pollution of the lake, the Pantle-Buck saprobity index was calculated (Unifitsirovannye metody issledovaniia..., 1977). The ecological state of the reservoir was evaluated according to the “Criteria for assessing the ecological situation of territories...”² and O.P. Oksiyuk et al (1993).

To characterize the living conditions of plant communities, we determined a depth of species growth, water transparency by a Secchi disk, temperature of the surface water layer, concentrations of dissolved oxygen, percentage of water saturation with oxygen, pH value, mineralization (by NaCl) and BOD₅ (for 5 days) using the portable water analyzers Anion 7051 and MARK 302E calibrated before the measurements.

² Criteria for assessing the environmental situation of territories to identify zones of environmental emergency and zones of environmental disaster (approved by the Ministry of Natural Resources of the Russian Federation on November 30, 1992).

³ POWO. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew, 2023. Web page. URL: <http://www.plantsoftheworldonline.org/> (accessed: 15.02.2024).

Results and discussion

The first studies of the flora and vegetation of lake Manzherokskoye were performed by V.V. Ilyin in 1964–1976 (Ilyin, 1982), who reported about the species atypical for low-mountain lakes, i.e. tetrahedral and white water lilies (*Nymphaea tetragona* and *N. candida*), water chestnut (*Trapa natans* (syn. *T. pectinata*)), small water lilies (*Nuphar pumila*), whorled hydrilla (*Hydrilla verticillata*), etc. In total, he indicated 25 species from 21 genera and 17 families (Table 1).

In 2010, 34 plant species from 24 genera and 20 families were identified (Zarubina and Sokolova, 2016). Over a period of more than 45 years, a significant transformation of the lake's vegetation cover occurred. Some of the species indicated by V.V. Ilyin as “rare” and “less abundant” (*Chara vulgaris*, *Utricularia vulgaris*, *Sparganium emersum*, *Fontinalis antipyretica*) were not found at all. For the first time in Altai, an East Asian species, i.e. the narrow-leaved burberry (*Sparganium subglobosum* Morong),

Table 1. List of species of the aquatic and semi-aquatic flora of lake Manzherokskoye in 1976–2023. Categories of species abundance: 1 – sparse species, represented by single specimens in the communities or in open shallow waters; 2 – low-abundant, accompanying species, not included in the number of dominants or co-dominants of phytocenoses; 3 – abundant species, usually co-dominant or forming small flower beds scattered throughout shallows; 4 – highly abundant, dominant in phytocenoses, forming extensive thickets; “–” – species not found.

Taxon	1964–1976 (Ilyin, 1982)	2010 (Zarubina and Sokolova, 2016)	2018 (Bezmaternykh et al., 2020)	2020	2021	2023
Hydatophytes						
<i>Chara vulgaris</i> L.	1	–	–	–	–	–
<i>Nitella syncarpa</i> Kutz.	1	1	–	–	–	1
<i>Drepanocladus aduncus</i> (Hedw.) Warnst.	–	2	–	–	–	–
<i>Fontinalis antipyretica</i> Hedw.	2	–	–	–	–	–
<i>Potamogeton berchtoldii</i> Fieb.	–	1	–	–	–	–
<i>P. compressus</i> L.	1	1	–	–	–	–
<i>P. perfoliatus</i> L.	2	3	–	–	–	3
<i>P. praelongus</i> Wulf.	1	3	–	–	–	–
<i>Hydrilla verticillata</i> (L. fil) Royle	3	4	–	–	–	–
<i>Ceratophyllum demersum</i> L.	1	1	–	–	–	–
<i>Utricularia minor</i> L.	–	3	–	–	–	–
<i>U. vulgaris</i> L.	1	–	1	–	1	–
Pleistophytes						
<i>Potamogeton natans</i> L.	3	3	–	1	–	3
<i>Sagittaria natans</i> Pall.	2	3	1	1	1	3
<i>Hydrocharis morsus-ranae</i> L.	1	3	2	3	3	2
<i>Lemna minor</i> L.	1	1	1	–	1	2
<i>Spirodela</i> <i>polyrhiza</i> (L.) Schleid.	–	–	1	–	1	1
<i>Persicaria amphibia</i> (L.) Delabre	–	–	1	2	1	1

Taxon	1964–1976 (Ilyin, 1982)	2010 (Zarubina and Sokolova, 2016)	2018 (Bezmaternykh et al., 2020)	2020	2021	2023
<i>Nuphar pumila</i> (Timm) DC.	1	1	–	–	–	–
<i>Nymphaea candida</i> J. Presl.	3	4	1	1	–	1
<i>N. tetragona</i> Georgi	1	1	–	–	–	1
<i>Trapa natans</i> L.	4	2	1	1	2	4
Helophytes						
<i>Equisetum fluviatile</i> L.	1	1	–	1	1	1
<i>Typha angustifolia</i> L.	–	3	2	2	1	–
<i>T. latifolia</i> L.	2	2	2	2	1	2
<i>Alisma plantago-</i> <i>aquatica</i> L.	–	–	–	–	1	1
<i>Sagittaria sagittifolia</i> L.	–	–	–	–	3	1
<i>Sparganium emersum</i> Rehm.	2	–	1	2	2	2
<i>S. subglobosum</i> Morong	–	2	1	1	1	–
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	2	–	1	1	1	1
<i>Schoenoplectus lacustris</i> (L.) Palla	3	1	–	–	–	–
<i>Callitriche palustris</i> L.	–	–	–	–	1	–
<i>Cicuta virosa</i> L.	–	–	–	3	2	2
Hydrogelophytes						
<i>Sphagnum magellanicum</i> Brid.	–	2	2	2	2	1
<i>Thelypteris palustris</i> (Salisb.) Schott	–	3	3	3	3	2
<i>Leersia oryzoides</i> (L.) Sw.	–	–	–	–	–	2
<i>Scolochloa festucacea</i> (Willd.) Link	1	1	–	–	1	–
<i>Carex pseudocyperus</i> L.	–	3	–	2	2	1
<i>Eleocharis palustris</i> (L.) Roem. et Schult.	–	2	2	2	3	1
<i>Scirpus radicans</i> Schkuhr.	–	2	2	3	3	3
<i>Calla palustris</i> L.	3	3	3	3	3	1
<i>Comarum palustre</i> L.	–	–	–	3	3	2
<i>Menyanthes trifoliata</i> L.	3	3	2	2	2	1
<i>Rorippa palustris</i> (L.) Besser	–	–	–	1	3	1
Hygrophytes and hygromesophytes						
<i>Carex contigua</i> Hoppe	–	2	–	–	–	–
<i>C. lasiocarpa</i> Ehrh.	–	3	–	–	–	–
<i>C. rhynchophysa</i> C.A.Mey	–	1	–	–	–	–
<i>Persicaria hydropiper</i> (L.) Delarbre	–	–	–	2	4	3

Taxon	1964–1976 (Ilyin, 1982)	2010 (Zarubina and Sokolova, 2016)	2018 (Bezmaternykh et al., 2020)	2020	2021	2023
<i>P. lapathifolia</i> (L.) Delarbre	–	–	–	2	4	2
<i>P. scabra</i> (Moench) Moldenke	–	–	–	2	4	3
<i>Epilobium palustre</i> L.	–	–	–	2	2	2
<i>Galium trifidum</i> L.	–	2	2	1	1	–
<i>Bidens cernua</i> var. <i>radiata</i> DC.	–	–	–	2	4	3
Total number of species	25	34	20	28	33	33

was discovered on the floating mats in the southwestern coast of the lake (Belyakov and Zarubina, 2020). The ecological spectrum of the flora altered as well. The total number of aquatic species of hydatophytes and pleistophytes remained virtually unchanged. Species diversity of semi-submerged plants of helophytes, including semi-aquatic and near-aquatic ones, namely hygrophytes (the floating mats), hygrophytes and hygromesophytes (plants of wet habitats and highly flooded coastal zone), increased significantly (Table 1). In the structure of vegetation cover, there was a change in dominants. For instance, the *Trapa natans* community previously prevailing in the reservoir according to V.V.Ilyin 1982), was replaced by *Nymphaea candida* and *Hydrilla verticillata*, covering about 35–40% of the water area (Fig. 1). Such a transformation of the flora and vegetation structure was probably induced by a reduction in the water area and coastal swamping because of water level rise.

In 2018, dredging and removal of bottom silts (sapropels) in the central part of the lake caused water pollution with turbid organic silts that brought to higher concentrations of suspended solids (up to 4.6 g/dm³) and lower water transparency by a Secchi to 0.5–2.0 cm. Note that previously this indicator was 1.0–1.5 m (Table 2). Values of pH dropped to typical for slightly acidic waters (Table 2), owing obviously to weak photosynthesis in turbid water and induced-by-dredging supply of humic acids from bottom sediments. In terms of physical and chemical indicators, the quality of the lake water deteriorated significantly (Bezmaternykh et al., 2020a) that adversely affected aquatic vegetation. Species diversity of the lake flora drastically declined, mainly due to submerged and floating species. After silt removal, 16 recorded earlier plant species were not detected in the reservoir anymore. These were hydatophytes *Potamogeton berchtoldii*, *P. compressus*, *P. perfoliatus*, *P. praelongus*, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Utricularia minor*, *Nitella syncarpa*, as well as several species of pleistophytes *Nuphar pumila*, *Potamogeton natans*, *Nymphaea tetragona*. In August 2018, only the floating mats communities consisted of semi-submerged and semi-aquatic plants were relatively stable and practically unaffected by dredging (Bezmaternykh et al., 2020b). Apparently, the absence of submerged and floating species during this period was most likely related with a mechanical removal of plants during sludge excavation, high turbidity, very low transparency and high concentrations of pollutants present in water (Bezmaternykh et al., 2020a) hindering the normal development of plants.

In the second year after dredging (2020), water transparency increased significantly (to an average of 0.15 m), the concentration of dissolved oxygen and BOD₅, characterizing the amount of easily oxidized organic pollutants in water, corresponded to MPS (maximum permissible concentration) in fisheries⁴. At the same time, water turbidity was still high. For the past two years, a partial restoration of vegetation was obvious. Though submerged species (hydatophytes) were still absent in the water area, plants with floating leaves (pleistophytes) were growing in the floating mats complex and undisturbed

⁴ Order of the Ministry of Agriculture of the Russian Federation dated December 13, 2016 No. 552 "On approval of water quality standards for water bodies of fishery importance, including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery importance" (with amendments and additions).

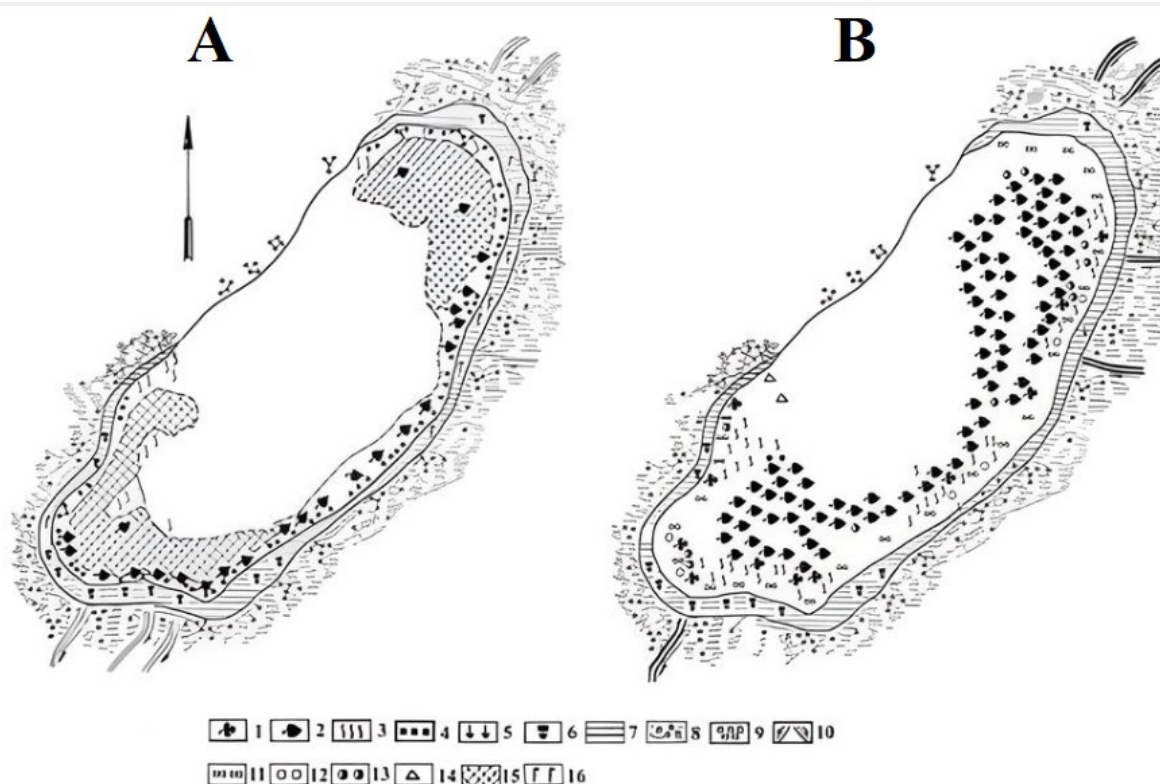


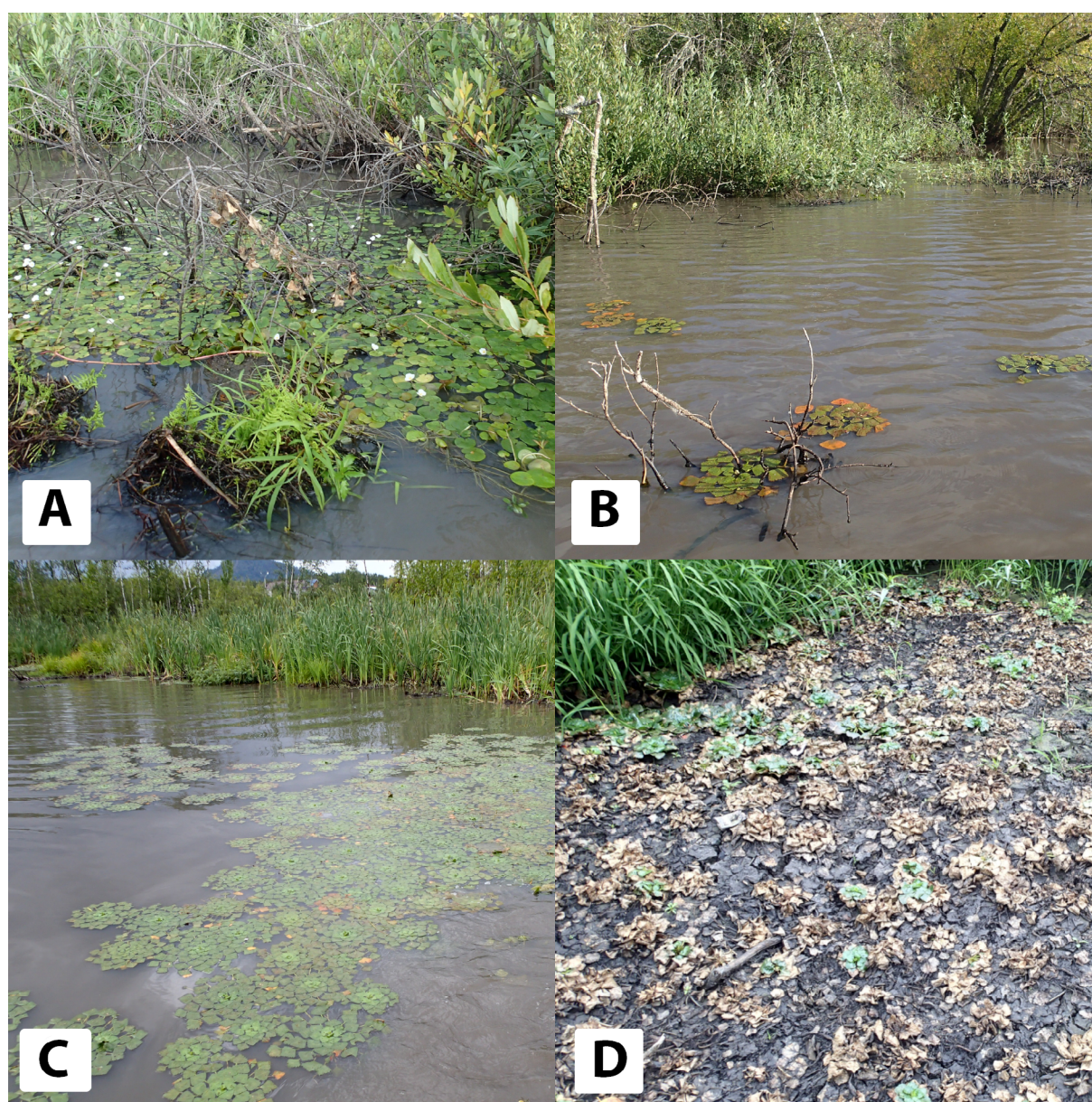
Fig. 1. Scheme of overgrowth of lake Manzherokskoye. A – 1964–1976 (according to Ilyin, 1982), B – 2010 (Zarubina and Sokolova, 2016). 1 – *Trapa natans*; 2 – *Nymphaea candida*; 3 – *Hydrilla verticillata*; 4 – *Potamogeton natans*; 5 – *Typha angustifolia*; 6 – *Typha latifolia*; 7 – *Thelypteris palustris*, *Menyanthes trifoliata*, *Calla palustris*; 8 – alloy; 9 – *Salix* sp., *Padus* sp., *Viburnum* sp.; 10 – streams; 11 – *Hydrocharis morsus-ranae*; 12 – *Utricularia minor*; 13 – *Potamogeton natans*; 14 – *Potamogeton praelongus*; 15 – gr. *Trapa natans*; 16 – *Phragmites australis*.

shoreline of the lake. Among them, *Hydrocharis morsus-ranae* was quite abundant (Fig. 2A). *Persicaria amphibia* was recorded for the first time on the flooded trees and shrubs, as well as in the lake water column. The green filamentous alga *Cladophora* sp. developed en masse. All these species are typical for disturbed and eutrophic water bodies. In the northeastern tail of the lake, near the floating mats, the only specimen of water lily *Nymphaea candida* in a depressed state, with deformed leaves and flowers was found. In addition, *Trapa natans* were sporadically present on the floating mats (Fig. 2B). Dredging did not have a drastic impact on the flora; almost all species noted before 2018 were revealed in 2020 as well. In general, 27 species from 22 genera, 20 families and 4 orders were recorded in the lake that year, including 22 species of semi-submerged and semi-aquatic plants. In 2019–2020, a 1 m rise in water level (induced by an increased groundwater influx after dredging) resulted in inundation of a large (overgrown with trees and shrubs) coastal part, including some floating mats.

In the third year after dredging (2021), further revegetation was observed. A total of 33 species of aquatic and semi-aquatic plants from 28 genera, 22 families and 4 orders were discovered. As compared to 2020, species diversity increased due to the appearance of non-rooted submerged and floating plants: *Utricularia vulgaris*, *Lemna minor* and *Spirodela polyrhiza* represented by small groups in the floating mats. According to the Chepinoga classification (2015), all pleistophytes growing on the lake during that period (except for *Trapa natans*) were anthropotolerants (resistant to anthropogenic factors) or anthropophiles (forming the synanthropic communities). White water lily, the number of which sharply declined after dredging (2018), was not recorded in 2021. The water chestnut population showed its several times reduction. Perhaps, short period since the mechanical removal of plants during dredging of 2018 was responsible for low species diversity and abundance of true aquatic plants in 2021. One of the limiting factors for a rapid restoration of aquatic vegetation was a very

Table 2. Hydrophysical and hydrochemical characteristics of lake Manzherokskoye* – according to Bolbukh (2016), ** – according to Bezmaternykh et al. (2020a).

Years of observations	Transparency, m	pH	O ₂ , mg/l	O ₂ , %	BOD ₅ , mgO ₂ /l
2003*	1.0–1.5	8.4	–	–	3.8–6.9
2018**	0.005–0.02	5.7–6.7	–	–	–
2020	0.1–0.2	5.6–6.3	6.3–6.4	73–75	0.6–1.0
2023	0.1–0.25	7.4–8.0	5.2–6.3	60–74	0.4–2.1

**Fig. 2.** Aquatic vegetation of lake Manzherokskoye. 2020: **A** – cenoses of *Hydrocharis morsus-ranae*, **B** – single specimens of *Trapa natans*. 2021: **C** – *Trapa natans* communities in the northeastern part, **D** – dead *Trapa natans* plants on the exposed shore after a sharp drop in water level.

low transparency of water (10 cm by a Secchi disk), associated with the presence of a large amount of suspended substances in the water column after withdrawal of bottom soils. The floating mats complex, developing along the coastline, was a characteristic feature of the lake overgrowth. The main floating mats-formers were *Sphagnum magellanicum*, *Menyanthes trifoliata*, *Thelypteris palustris*, *Calla palustris*, *Carex lasiocarpa*, *C. pseudocyperus*, *C. rhynchophysa*, *Typha angustifolia* and *T. latifolia*. Here, we also found the rare for Altai bur reed *angustifolia*. In 2021, the implemented irrigation and dredging contributed to a considerable drop of water level, which resulted in the reduction of the floating mats area and partial drying of shallows. At the same time, the communities dominated by ruderal species, i.e. *Persicaria hydropiper*, *P. lapathifolia*, *P. scabra* and *Bidens cernua* var. *radiata*, started to invade the anthropogenically disturbed areas of the coastal strip.

In 2023, species diversity of aquatic and semi-aquatic vegetation remained unchanged. The flora of the lake included 33 species from 27 genera, 22 families and 5 orders. Water transparency was still low, but pH values corresponded to neutral or slightly alkaline waters, being an indirect indicator of the photosynthesis intensification due to phytoplankton. Meanwhile, low oxygen concentrations in waters (below MPC) and low BOD₅ (Table 2) pointed to the beginning of the reservoir ecosystem restoration. This was confirmed by the finding of aquatic species *Nitella syncarpa*, *Potamogeton natans* and *P. perfoliatus*, *Nymphaea candida* and *N. tetragona* considered to be extinct or significantly reduced in abundance after the dredging works of 2018. It is worth noting that all these species (except for *P. natans*) did not reach their usual size. As a result of the coastal works at the territory of the “Manzherok” resort, the floating mats disappeared in the eastern and southeastern sections. In turn, it brought to a significant reduction of helo- and hygrohelophytes habitats, a decrease in their abundance or even loss from vegetation cover (Table 1). In 2023, an invader of the newly appeared ecological niche – *Leersia oryzoides*, was first discovered in the lake. In Western Siberia, this perennial hygrohelophyte was identified solely in the vicinity of villages Novo-Belokurikha (low mountains of Altai) and Kyzyl-Ozek (Maiminsky region) located not far from lake Manzherokskoye (Flora Sibiri, 1990, 2003).

Lake Manzherokskoye is now the only known place of distribution of water chestnut (chilim) in the Republic of Altai. This species was first mentioned as *Trapa pectinata* V. Vassil. in the report “Flora of the USSR” (1949) and as an endemic of Altai, growing in lakes Doingol (Altai name for lake Manzherokskoye) and Kanonerskoye at the city of Biysk in the valley of the Katun River. The presence of this species in lake Manzherokskoye was later confirmed by V.V. Ilyin (1982). Currently it is a synonym of *Trapa natans* var. *natans*, native to Eurasia and Northwestern Africa⁵. In Russia and neighboring states, this species has a disjunctive range and grows in the European part, the Caucasus, Siberia, Kazakhstan and the Far East (Bolotova, 2014; Vasiliev, 1960). In many European countries, the species is rare and protected, but in some regions of the world it is considered to be an aggressive invasive plant (Markovic et al., 2015; Tall et al., 2011).

Trapa natans L. has been included in the Red Book of the USSR (1984) but not listed in the new edition of the Red Data Book of the Russian Federation (2008). Water chestnut (chilim) has been included in the report “Rare and Endangered Plants of Siberia” (Redkie i ischezayushchie..., 1980) and the Red Data Book of the Republic of Altai (Krasnaya kniga..., 2017). In the latter, it has status 1: endangered species. The limiting factors for chilim development are active economic activities (construction of hydraulic structures) and excessive recreational loads.

Water chestnut is an annual plant forming its rosettes from a large number of rhombic mosaic leaves floating on the water surface. The underwater leaves are thread-like, the stem is attached to the ground by thread-like roots and last year's nut, like an anchor. Viability of its fruits in silt lasts up to 10, or even 50 years. Nuts dried or frozen below –8...–10 °C lose their viability (Solovyeva and Lapirov, 2013). The most favorable areas for *T. natans* development are shallow waters protected from wind, up to 1.5–2.0 m deep, with silty soils. Plants can withstand significant fluctuations of water levels (Dementieva and Petushkova, 2010; Markovic et al., 2015). At the beginning of the 20th century, water chestnut in lake Manzherokskoye was found more than once, as evidenced from V.V. Ilyin (1982), herbarium collections of the Tomsk University and the Central Botanical Garden of SB RAS. In 1964–1976, a water chestnut group was the largest and most typical for this water body. It consisted of two parts with a total area of about 13% of the water area, confined mainly to depths of 1.4–1.8 m in the northeastern and southwestern tails of the lake (Ilyin, 1982).

⁵ IPNI, 2024. International Plant Names Index. Web page. URL: <http://www.ipni.org> (accessed: 15.02.2024).

In 2010, water chestnut was a low-abundant and accompanying species of the white water lily community dominated in the lake (Zarubina and Sokolova, 2016). Among floating plants, floating pondweed and floating arrow leaf were often found in these communities, while among submerged plants - long-leaved pondweed and pierced-leaved pondweed, submerged hornwort and whorled hydrilla. The lake overgrowth reached 35–40% of its water area. Only the central part of the reservoir and the site along the western coast and its beach remained free from vegetation (Fig. 1).

Dredging and silt removal in 2018 affected the main habitats of *Nymphaea candida* and *Trapa natans*. Previously dominant communities of *Nymphaea candida* were distinguished by a largely reduced distribution area, a low projective cover (on average 10–15%) and single rosettes of *Trapa natans*.

In the second year after reclamation activities (2020), the restoration of the *Trapa natans* population began. The plants did not form large thickets. They were found mainly along the floating mats as single rosettes, had normal size and green fruits (Fig. 2B).

When surveying the lake in 2021, further recovery of the water chestnut population was marked. Communities of *Trapa natans* formed two areas in the southwestern and northeastern parts of the lake, connected by a narrow strip along the floating mats at the eastern shore. Chilim was represented by small groups, mainly 8–12 specimens, at a distance of 2–15 m from each other, generally on the floating mats. In some shallow sites, thickets of water chestnut were not attached to the bottom; they freely floated on the water surface. Almost all the plants had green fruits. Again, water chestnut predominated, but its spread in the reservoir was less intensive than in 1964–1972. (Fig. 2C). Dredging induced a sharp drop in water level, exposure of a large part of the shallows, and death of numerous water chestnuts (Fig. 2D).

In 2023, the main thickets of macrophytes were also concentrated in the northeastern and southwestern shores. The highest species diversity and overgrowth were observed in the northeastern part. Here, in the coastal strip at a depth of 0.15–0.30 m, the communities of rooting reed (*Scirpus radicans*), broadleaf cattail, and rice leersia dominated. Biomass in mixed communities of reeds and rice leersia ranged from 496 to 584 g/m² in the absolutely dry weight with a projective cover of up to 100%, and in monodominant cenoses of rice leersia – from 320 to 584 g/m². At the northern disturbed coast, the projective cover and biomass in the broadleaf cattail communities made up 30% and 320 g/m², whereas in the undisturbed areas of the northeastern part these indicators reached 60% and 528 g/m², respectively.

The communities of perforated pondweed forming spots of 2–4 m² in size at a depth of 0.4–0.5 m were revealed at the northern coast. Water chestnut, floating arrow leaf, and duckweed were accompanying species in these communities. The total projective cover accounted for 80%, but the absolutely dry biomass was low (208–232 g/m²).

Water chestnut, forming extensive thickets at a depth of 0.5–1.2 m with a projective cover of up to 90%, prevailed in the northeastern part of the lake (Fig. 3). Among water chestnuts, floating pondweed and floating arrow leaf along with duckweed were quite common. They formed some spots with a high projective coverage (up to 85%). Specimens of white and tetrahedral water lilies were sporadically identified. Despite the high projective cover, the productivity of cenoses of floating pondweed ranged as 64–88 g/m², and of floating arrow leaf – from 90 to 112 g/m². In general, the overgrowth of the northeastern section of the lake was about 45–50%.

As for the eastern part, there was no vegetation in the coastal strip and along the water edge because of the floating mats destruction and shore clearing. The fragments of the floating mats moved throughout the lake as small drifting islands with an area of 2–4 m² occupied by marsh vegetation (*Sphagnum magellanicum*, *Thelypteris palustris*, *Cicuta virosa*, *Comarum palustre*, *Menyanthes trifoliata*). Here, water chestnut was represented by single specimens or formed small spots of associations of individual specimens located at a distance of 2–4m from each other.

The second distribution area of chilim was in the southwestern section of the lake occupying vast water areas with a very high projective cover (up to 100%) (Fig. 3). Apart from water chestnut, other types of macrophytes were practically not recorded, with the exception of a narrow strip of broadleaf cattail and arrowhead, which remained in the former habitats of the floating mats destroyed during the construction works. As in the northeastern part of the lake, chilim dominated here. The overgrowth of the southwestern section reached 40–45%. The central part of the lake was almost free from vegetation.

Interestingly, unusual polymorphic multi-leaf forms of water chestnut appeared on the water surface forming rosettes with 40 or more leaves (Figs. 4B, C). Note that usually the number of leaves in a rosette

is about 20 (Fig. 4A). During the study period, such plants in the northeastern and southwestern parts of the lake were abundant (Fig. 4D). In the southwestern section, leaves of water chestnut attracted lots of phytophilic insects.

Macrophytes productivity of the lake during the studied period was estimated (Oksiyuk et al., 1993) as the average (Table 3). Similar was the biomass of submerged species in the shallows of Kamginsky Bay of lake Teletskoye (Zarubina et al., 2005), floating and semi-submerged – with biomass of macrophytes in lakes of Gorny Altai (original data), being 2.5–6.5 times lower than that in the lakes of the Middle Volga Region (Papchenkov, 2001).

Conclusion

Lake Manzherokskoye is the natural monument of the regional significance in the Republic of Altai. One of the reasons for classifying the lake as the protected area was the unique species diversity of its aquatic and semi-aquatic vegetation, as well as the only habitat of water chestnut (*Trapa natans*) in this region. Nowadays, the all-season resort “Manzherok” is located at the lake.

Over the almost 60 years from the first published data on the flora and vegetation of the lake, heavy anthropogenic loads have altered species diversity and overgrowth area greatly. In 2010, a change in the dominants was recorded – *Trapa natans* were replaced by the *Nymphaea candida* and *Hydrilla verticillata* communities. In addition, species diversity of aquatic and semi-aquatic vegetation has increased.

As a result of the first stage of implemented dredging and bottom silt removal (2018), many previously widespread submerged species in the lake almost completely disappeared. Among pleistophytes only anthropotolerant and anthropophilic plant species survived. These works did not have a significant effect on semi-aquatic plants and the floating mats.

By the time of the second stage of dredging (2023), species diversity of macrophytes had partially recovered, and the state of the aquatic and semi-aquatic vegetation of the lake was satisfactory, but nevertheless disturbed and unstable. In 2023, 30 species of aquatic and semi-aquatic plants were noted in the flora of the lake, including several species believed to be extinct after 2018. Partial restoration of aquatic biocenoses of lake Manzherokskoye after hydraulic engineering works was reported by other researchers involved in zoobenthos studies (Vdovina et al., 2022).

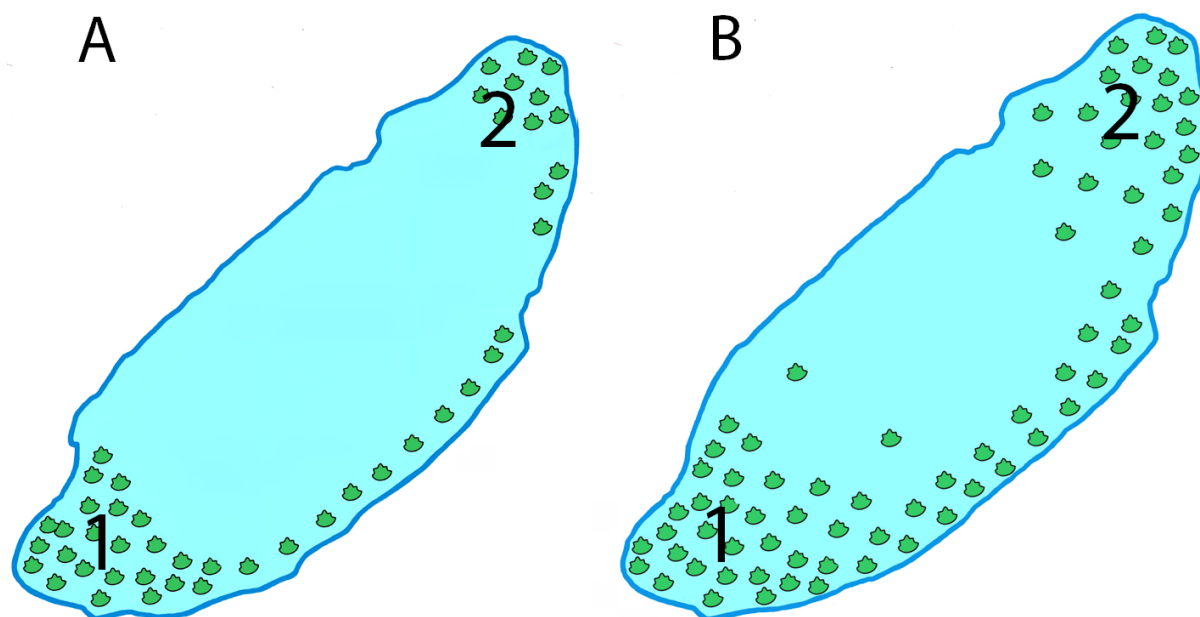


Fig. 3. Scheme of distribution of water chestnut *Trapa natans* in lake Manzherokskoye. **A** – 2021, **B** – 2023. 1 – southwestern area, 2 – northeastern area.

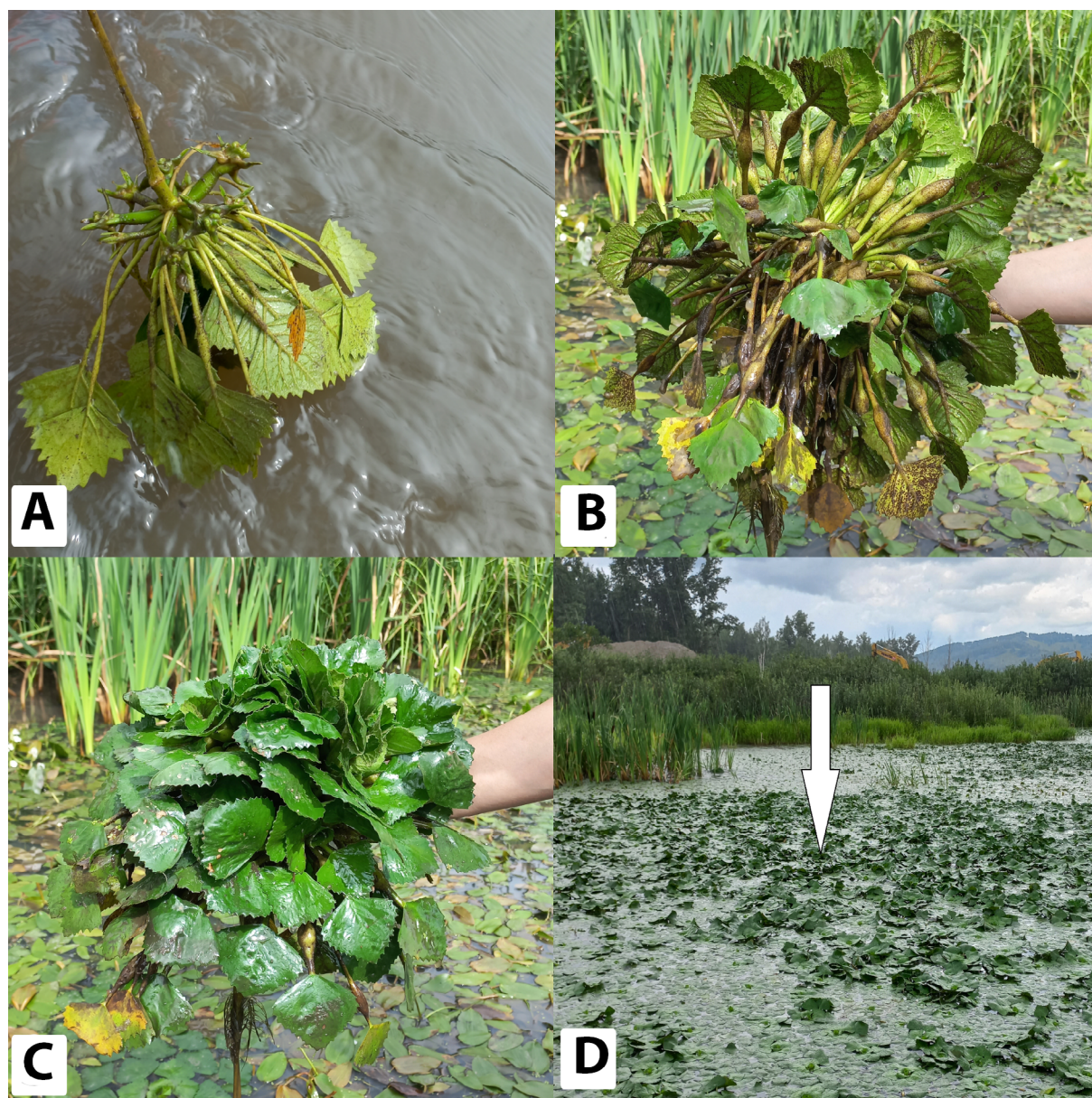


Fig. 4. Various biomorphs of water chestnut (*Trapa natans*) in lake Manzherokskoye (August 2023). **A** – classic biomorph, **B**, **C** – biomorph with an increased number of leaves in a rosette, **D** – concentration of modified water chestnut biomorphs in cenoses (indicated by an arrow).

Further works on clearing the lake (2023) destroyed the floating mats along the eastern and southeastern coasts; just small drifting fragments of plants were found throughout the lake. The transformation of the coastal strip and shores ruined the plant habitats, reduced the number (or caused even disappearance) of some species in vegetation cover. Dominated ruderal species started to invade the disturbed shores. Among them, was also *Leersia oryzoides*. Most native species demonstrated low abundance. Along with predominance of species-poor families in the flora and appearance of invasive species, it indicated the reservoir ecosystem instability.

Over the past period, a change in dominants took place twice. The *Trapa natans* (*pectinata*) communities prevailing in the lake in 1964–1976 were replaced by *Nymphaea candida* – *Hydrilla verticillata* in 2010. In 2023, the lake was once again dominated by the *T. natans* communities, forming two habitats in the northeastern and southwestern parts of the lake with a projective cover of up to 100%. Moreover, single water chestnuts were found throughout the lake. Currently, this species is the

Table 3. Macrophytes characteristics and water quality assessment of lake Manzherokskoye in August 2023

Biomass and indices	Value	Values' gradation	Water quality class	Trophic category
Number of species	25	average	–	–
Overgrowth of shallows area, %	40	average	–	–
Average wet biomass, kg/m ²	2.4 ± 1.5	above average	–	–
Shannon index	3.38	high	clean	–
Simpson index	0.97	high	clean	–
Pantle–Buck saprobity index	1.8	–	3 – satisfactory clean	mezotrophic
BOD, mgO ₂ /l	1.3	–	3 – satisfactory clean	mezotrophic
O ₂ saturation, %	67.8	–	4 – polluted	polytrophic
Transparency, m	0.2	-	4 – polluted	polytrophic

main cenose-former, as it was about 60 years ago (Ilyin, 1982). It should be noted that polymorphic multi-leaf forms of water chestnut found in masses on the lake is, probably, the consequences of unfavorable living conditions for this species. However, judging from a rapid recovery of water chestnut, it has a high potential for self-regeneration. In case of implementation of the planned special measures on mitigating the negative effect of recreational activities on chilim development⁶, it is expected in the next 5 years to return the importance of the lake as the main habitat of *Trapa natans* – one of the main cenosis-formers of the vegetation of the natural monument “Lake Manzherokskoye”.

Species diversity of macrophytes and degree of shallow waters overgrowth (Oksiyuk et al., 1993) can be assessed as moderate, but as compared to other lakes in the low mountains of Altai they are quite high. Biomass of macrophytes of lake Manzherokskoye is above average and comparable to that for Altai lakes. According to the Shannon and Simpson species diversity indices, the waters of lake Manzherokskoye belong to the class of pure, while according to the saprobity index and BOD₅ –satisfactory pure. In terms of saturation with oxygen and transparency, the waters are characterized as polluted (Table 3). Thus, the main limiting factors for submerged macrophytes are most likely low water transparency impeding the development of submerged species, as well as ongoing dredging responsible for mechanical destruction of plants.

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⁶ Decree of the Head of the Altai Republic, Chairman of the Government of the Altai Republic No. 98-u dated March 30, 2023 “On the creation of a protective zone of a specially protected natural area of republican significance, the natural monument of republican significance «Manzherokskoe Lake»”.

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