



Article

Restoration of macrozoobenthos after dredging on Lake Manzherokskoe (Republic of Altai, Russia)

Olga N. Vdovina*^{id}, Dmitry M. Bezmaternykh^{id},
Evgeniya N. Krylova^{id}

Institute for Water and Environmental Problems, Siberian Branch of Russian Academy of Science, ul. Molodezhnaya 1, Barnaul, Altai Krai, 656038 Russia

*olgazhukova1984@yandex.ru

Received: 23.03.2022
Revised: 04.04.2022
Accepted: 05.04.2022
Published online: 18.05.2022

DOI: 10.23859/estr-220323
UDC 556.555.6 + 574.58

Translated by D.M. Martynova

Abstract. Dredging is the activity of excavating soil and performing other soil operations in order to expand and increase the depth of water bodies. Under conditions of increased pollution, dredging operations may cause certain damage to aquatic ecosystems in general and to particular aquatic species. The changes in the composition and structure of benthic invertebrate communities have been studied in Lake Manzherokskoe in different periods: before dredging (2007), two weeks after the dredging has been started (2018), and 3 years after the dredging activities have been finished (2021). In 2021, there was an increase in species diversity and quantitative indicators of the development of benthic communities comparing to the period of dredging completion. Our data indicated the restoration of macrozoobenthos community in the lake to a certain extent. Later, this process may end in complete restoring with an increase in the water level in the lake and a significant decrease in the technogenic load on bottom communities.

Keywords: hydrotechnical works, lakes, water quality, benthic invertebrates.

To cite this article. Vdovina, O.N. et al., 2022. Restoration of macrozoobenthos after dredging on Lake Manzherokskoe (Republic of Altai, Russia). *Ecosystem Transformation* 5 (2), 26–34. <https://doi.org/10.23859/estr-220323>

Introduction

Dredging in water bodies has a strong impact on aquatic ecosystems and aquatic life. Under conditions of increased pollution, dredging operations may cause certain damage to aquatic ecosystems in general and to certain aquatic species, both directly via their capture by dredging gear and indirectly as a result of disruption of the biocoenosis structure, the impact of turbidity on bottom organisms, and

secondary pollution of water bodies (Shkodin and Sal'nikov, 1996).

Lake Manzherokskoe is located in the foothills of Altai Mountains, on the terrace of the right bank of the Katun River, at an altitude of 373 m above sea level; since 1978 it has been a natural monument of regional significance. The lake is actively used for recreational purposes; in recent decades, its silting and overgrowing has been observed. In 2017–2018, in order to slow

down the overgrowth and to remove silts with a high content of organic matter, there was a project implemented to clean and to drench the lake. The measures taken led to an increase in the depth of the reservoir, from less than 3 m to 5.66 m, and to a subsequent increase of the lake water volume from 0.569 million m³ to 1.16 million m³ (Bezmaternykh et al., 2020).

Comprehensive environmental studies are necessary to solve the issues of anthropogenic impact on the biota of natural and artificial water bodies. Benthic organisms are the most convenient and indicative object for assessing the ecological state of water bodies using bioindication methods. Bottom invertebrates are ubiquitous, they are characterized by a sufficiently high abundance, relatively large size, and lifespan long enough to accumulate pollutants over a long period (Bezmaternykh, 2007).

The study aims to identify patterns of changes in the main characteristics of the macrozoobenthos of Lake Manzherokskoe during the period of hydraulic engineering works and after their completion.

Materials and methods

In Lake Manzherokskoe, zoobenthos was surveyed in August 2018 (two weeks after the dredging has been finished), in April and July 2021. The data provided by L.V. Yanygina for March 2007 allowed to identify the changes in the composition and structure of the zoobenthos of the lake (Bezmaternykh et al., 2019, 2020). In the central part of the lake, where dredging was carried out most intensively, the type of bottom sediments was changed: instead of sapropel, coarse plant detritus prevailed, which was quite unfavorable for the development of benthos. In this regard, in July 2021, the number of sampling stations was increased. In total, 40 quantitative and 11 qualitative samples of macrozoobenthos were taken (Table 1). Biological material was collected and processed according to standard hydrobiological methods (Rukovodstvo..., 1992). Quantitative samples were taken with a Peterson grab (capture area of 0.025 m²). The samples were washed through nylon mesh (350×350 μm) and fixed with 70% ethanol. After reaching a constant weight, the samples were sorted

into systematic groups, the specimens were counted, and their weight was determined at a VT-500 torsion balance. The species were identified in accordance to taxonomic keys (Opredelitel'..., 1994–2004). In April 2021, chaoborid larvae were taken into account in the composition of the zoobenthos, since in autumn they descended to the near-bottom area, burrowed into the silt, and wintered at the bottom of the reservoir; therefore, they could be considered as facultative zoobenthos for this period. Oligochaete index suggested by Goodnight and Whitley was calculated to assess the ecological state (Goodnight and Whitley, 1961). The species diversity index (in terms of macrozoobenthos abundance) was assessed according to Shannon and Weaver (Shannon and Weaver, 1963). Belonging of the macrozoobenthos species to a particular trophic group was set in accordance to the classification suggested by O. Moog and A. Hartmann (2017), a modified version of Cummins' classification (Cummins, 1973) for insects (Cummins et al., 2008). The trophic level of the lake was determined according to the scale proposed by S.P. Kitaev (2007).

Results

The first information about the zoobenthos of the Lake Manzherokskoe were obtained in the under-ice period of 2007. Low development of the benthic community was noted, which was represented by four species of heterotopic animals: two species of chironomids (*Chironomus* gr. *plumosus* and *Procladius* (*Holotanypus*) *ferrugineus* Kieffer, 1919), one species of biting midges (*Sphaeromias fasciatus* (Meigen, 1804), and representative of Chaoboridae (*Chaoborus* (*C.*) *flavicans*) (Meigen, 1830)) (Bezmaternykh et al., 2019, 2020). In 2007, the maximum biomass of zoobenthos was observed in the central part of the lake, amounting to 2.5 g/m². Such a pattern was associated with the discovery of a single specimen of *Chironomus* gr. *plumosus*. In the other parts of the reservoir, the biomass of benthic organisms did not exceed 0.7 g/m², where biting midge *S. fasciatus* dominated. The distribution of the abundance of zoobenthos in different parts of the lake had a smooth character.

Table 1. Number of zoobenthos samples.

| Year and month of research | Number of stations | Quantitative samples | Qualitative samples | Total number of samples |
|----------------------------|--------------------|----------------------|---------------------|-------------------------|
| August 2018 | 5 | 10 | 3 | 13 |
| April 2021 | 4 | 8 | – | 8 |
| July 2021 | 11 | 22 | 8 | 30 |
| Total | | 40 | 11 | 51 |

In August 2018, after dredging in Lake Manzherokskoe, seven species of benthic invertebrates belonging to two classes were identified: Oligochaeta (one species) and Insecta (6 species). Oligochaetes were represented by *Limnodrilus* spp., insects, by dipterans (chironomids *Cricotopus* gr. *tibialis* and *Glyptotendipes glaucus* (Meigen, 1818), and midges (*Palpomyia* spp.)), beetles (imago of *Graphoderus* sp., larva of the Hydrophilidae family), as well as dragonflies (*Somatochlora* spp.).

The zoobenthos abundance ranged from 0 to 1.48 thousand ind./m², biomass, from 0 to 1.56 g/m² (Table 2). Chaoborid and chironomid larvae were not found. *Limnodrilus* sp. and *Palpomyia* sp. formed the basis of abundance throughout the lake area, oligochaetes were the dominant group (noted in 50% of samples). The remaining taxa of zoobenthos were noted in coastal thickets of aquatic vegetation (qualitative samples only). The maximum abundance and biomass were observed on silty sediments (stations nos. T4 and T5) (Fig. 1), the minimum values, on silty sediments with detritus.

The species diversity index varied as 0–0.98 bit/ind., which probably characterized the habitat conditions as unfavorable. The value of the oligochaete index in the lake varied widely, reaching 100% in some areas (water quality class V, “extremely dirty”). The zoobenthos biomass was low, which formally corresponded to the oligotrophic type of the reservoir. All these indicators, as well as the presence of oligochaetes of the Tubificidae family testified to unfavorable conditions for the zoobenthos development.

The studies conducted in April 2021 also evidenced on low quantitative indicators and a simplified structure of the zoobenthic communities of Lake Manzherokskoe. Five species of benthic invertebrates belonging to two classes were found in macrozoobenthos: Oligochaeta (2 species) and Insecta (3 species). All the taxa recorded in March 2007 were found also in April 2021, except *Chironomus* gr. *plumosus* (only head capsules were found).

S. fasciatus was the most common species in the lake (noted in 50% of samples); oligochaetes

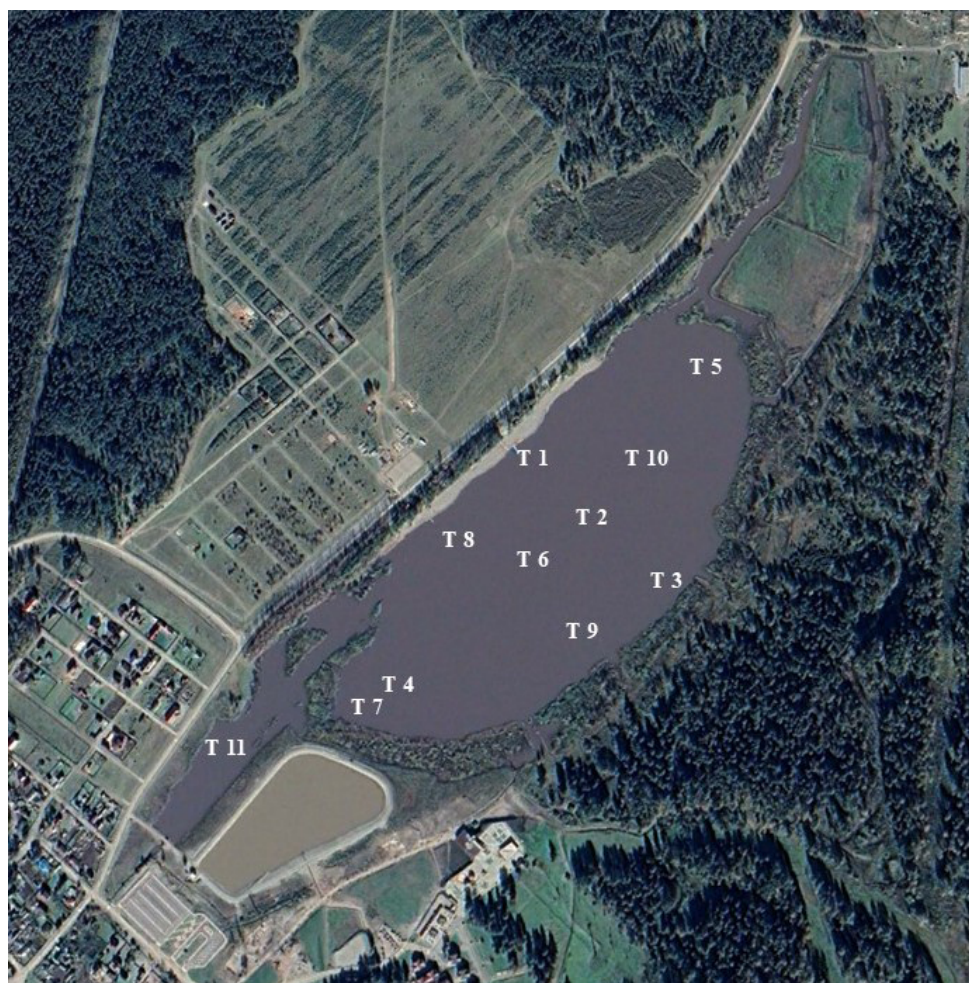


Fig. 1. Location of sampling stations in Lake Manzherokskoe.

Table 2. Main characteristics and bioindicative indexes of the zoobenthos of the lake Manzhherokoe in August 2018. H – Shannon index, calculated by abundance; Ko – oligochaeta index of Goodnight and Whitley, water quality class: I – conditionally clean; II – slightly polluted; III – contaminated; IV – dirty; V – extremely dirty.

| Station | Soil type | Number of species in the sample | Identified taxa | Abundance, ind./m ² | Biomass, g/m ² | H, bit/ind. | Co, % |
|---------------------|-------------------------------|---------------------------------|--|--------------------------------|---------------------------|--------------------|----------------|
| T. 1 | muddy with detritus and gruss | 0–1 | <i>Limnodrilus</i> sp. | 0–40 | 0–0.04 | 0 | 0–100 (VI) |
| T. 2 | muddy with detritus | 0–1 | <i>Palpomyia</i> sp. | 0–40 | 0–0.04 | 0 | – |
| T. 3 | muddy with detritus | 0–1 | <i>Limnodrilus</i> sp. | 0–40 | 0–0.16 | 0 | 0–100 (VI) |
| T. 4 | muddy | 0–1 | <i>Palpomyia</i> sp. | 0–520 | 0–0.48 | 0 | – |
| T. 5 | muddy | 0–2 | <i>Limnodrilus</i> sp. <i>Palpomyia</i> sp. | 1240–1480 | 1.44–1.56 | 0.98 | 43–58 (III–IV) |
| Lake average | muddy with detritus | 0.80 ± 0.25 | – | 336.00 ± 178.70 | 0.30 ± 0.19 | 0.19 ± 0.13 | 30 (I) |

Table 3. Main characteristics and bioindicative indexes of the zoobenthos of the lake Manzhherokoe in April 2021. Designations as in Table 2.

| Station | Soil type | Number of species in the sample | Identified taxa | Abundance, ind./m ² | Biomass, g/m ² | H, bit/ind. | Co, % |
|---------------------|----------------------------|---------------------------------|--|--------------------------------|---------------------------|--------------------|------------------|
| T. 1 | muddy with detritus | 0–3 | <i>S. fasciatus</i> , <i>P. (H.) ferrugineus</i> <i>Ch. (C.) flavicans</i> | 0–160 | 0–0.24 | 0–1.50 | 0 |
| T. 2 | muddy with detritus | 1–2 | <i>L. hoffmeisteri</i> <i>S. fasciatus</i> | 200–240 | 0.36–0.44 | 0–0.91 | 66.6–100 (III–V) |
| T. 3 | muddy with detritus | 0–2 | <i>S. fasciatus</i> <i>P. (H.) ferrugineus</i> | 0–80 | 0–0.06 | 0–1.0 | 0 |
| T. 4 | muddy with detritus | 0–2 | <i>N. variabilis</i> <i>S. fasciatus</i> | 0–80 | 0–0.04 | 0–1.0 | 0–50 (I–II) |
| Lake average | muddy with detritus | 1.4 ± 0.46 | – | 95.00 ± 34.00 | 0.14 ± 0.06 | 0.55 ± 0.21 | 27 (I) |

Table 4. Main characteristics and bioindicative indexes of the zoobenthos of the lake Manzherokskoe in July 2021. Designations as in Table 2.

| Station | Soil type | Number of species in the sample | Identified taxa | Abundance, ind./m ² | Biomass, g/m ² | H, bit/ind. | Co, % |
|---------------------|---|---------------------------------|--|--------------------------------|---------------------------|--------------------|---------------------|
| T. 1 | dark brown silt with brown silt (fine detritus) | 2–4 | <i>D. dorsalis</i> , <i>N. variabilis</i> , <i>Cryptochironomus</i> sp., <i>P. (H.) ferrugineus</i> | 840 | 0.16–0.24 | 0.45–1.45 | 61.90–90.40 (III–V) |
| T. 2 | brown silt, detritus | 1–2 | <i>N. variabilis</i> , <i>S. fasciatus</i> | 80–120 | 0.06–0.024 | 0–0.50 | 0–50 (I–II) |
| T. 3 | dark brown silt, detritus | 1 | <i>S. fasciatus</i> | 40–240 | 0.02–0.10 | 0 | 0 (I) |
| T. 4 | liquid dark brown silt (fine detritus) | 2–5 | <i>D. dorsalis</i> , <i>D. stagnalis</i> , <i>N. variabilis</i> , <i>S. fasciatus</i> , <i>Cryptochironomus</i> sp. | 200–3400 | 0.08–0.68 | 0.97–1.42 | 40–94.1 (II–V) |
| T. 5 | liquid dark brown silt, detritus | 3–4 | <i>D. dorsalis</i> , <i>L. hoffmeisteri</i> , <i>S. fasciatus</i> , <i>Cryptochironomus</i> sp., <i>P. (H.) ferrugineus</i> | 760–1320 | 1.40–3.50 | 0.93–1.19 | 73.60–78.80 (IV) |
| T. 6 | brown silt, detritus | 1–5 | <i>N. variabilis</i> , <i>S. fasciatus</i> , <i>P. (H.) ferrugineus</i> | 40–200 | 0.02–0.068 | 0–1.52 | 0–40 (I–II) |
| T. 7 | liquid gray silt, detritus | 2–5 | <i>D. dorsalis</i> , <i>D. stagnalis</i> , <i>L. hoffmeisteri</i> , <i>N. variabilis</i> , <i>S. fasciatus</i> | 280–1560 | 0.18–1.06 | 0.86–1.79 | 71.7–97.4 (IV–V) |
| T. 8 | gray silt with brown silt, coarse detritus | 0–2 | <i>S. fasciatus</i> , <i>P. (H.) ferrugineus</i> | 0–120 | 0–0.06 | 0–0.91 | 0 (I) |
| T. 9 | dark brown silt with brown silt (fine detritus) | 3 | <i>D. dorsalis</i> , <i>N. variabilis</i> , <i>S. fasciatus</i> , <i>P. (H.) ferrugineus</i> | 280–1240 | 0.11–0.22 | 1.14–1.37 | 28.5–96.7 (I–V) |
| T. 10 | liquid dark brown silt (fine detritus) | 5–7 | <i>D. dorsalis</i> , <i>D. stagnalis</i> , <i>L. hoffmeisteri</i> , <i>N. variabilis</i> , <i>T. tubifex</i> , <i>S. fasciatus</i> , <i>Cryptochironomus</i> sp., <i>P. (H.) ferrugineus</i> | 720–3120 | 0.7–1.54 | 1.38–2.02 | 83.3–96.1 (IV–V) |
| T. 11 | dense black silt (sand, detritus) | 2–5 | <i>D. stagnalis</i> , <i>P. (H.) ferrugineus</i> , <i>Ch. (C.) flavicans</i> , <i>Sigara</i> sp., <i>V. cristata</i> , <i>S. fasciatus</i> | 1200–1320 | 0.18–0.48 | 0.19–1.4 | 0–13.3 (I) |
| Lake average | muddy with detritus | 2.95 ± 1.38 | – | 814.50 ± 199.71 | 0.49 ± 0.17 | 0.88 ± 0.13 | 46 (II) |

Limnodrilus hoffmeisteri Claparede, 1862 and chironomids *P. (H.) ferrugineus* were found in 25% of samples; the lowest frequency of occurrence was noted for chaoborids (*C. (C.) flavicans*) and oligochaetes (*Nais variabilis* Piguët, 1906), 12.5% each. Abundance varied as 0–240 ind./m², biomass, 0–0.44 g/m² (Table 3). The development of bottom zoocenoses corresponded to the ultraoligotrophic type of water bodies. In terms of abundance and biomass, oligochaetes dominated, followed by biting midges. The average abundance and biomass of zoobenthos in April 2021 (95 ind./m², 0.14 g/m²) were lower than the corresponding values in 2007 (300 ind./m², 0.9 g/m²).

The number of zoobenthos species varied from 0 to 3 species per sample, averaging 1.4. The species diversity index was 0–1.5 bit/ind., indicating unfavorable conditions. The Goodnight-Whitley oligochaete index reached 100% in some areas (water quality class V, “extremely dirty”); however, average value for the entire lake was 27%, which corresponded to class I and characterized the water as relatively clean.

In July 2021, 11 species of benthic invertebrates belonging to 4 classes were identified: Nematoda (1 species), Oligochaeta (4 species), Gastropoda (1 species), and Insecta (5 species). Of Nematoda, *Dorylaimus stagnalis* Dujardin, 1845 was noted. Oligochaetes were represented by *Dero dorsalis* Ferroniere, 1899, *L. hoffmeisteri*, *N. variabilis*, and *Tubifex tubifex* (O.F. Müller, 1773). Gastropods were represented by one species *Valvata cristata* O.F. Müller, 1774. The insects comprised bug larvae (one species: *Sigara* sp.) and Diptera (4 species), represented by Chironomidae (*P. (H.) ferrugineus* and *Cryptochironomus* sp.), Ceratopogonidae (*S. fasciatus*), and Chaoboridae (*Ch. (C.) flavicans*). During the study period, biting midge *S. fasciatus* and chironomids *P. (H.) ferrugineus* were the most common in the lake (noted in 68% and 45.5% of samples, respectively). In oligochaetes, *D. dorsalis* (41%), *N. variabilis* (41%), and *L. hoffmeisteri* (27%) were the most common; in other taxa, the frequency of occurrence did not exceed 22%.

Total zoobenthos abundance varied as 0–3400 ind./m², biomass, 0–3.5 g/m² (Table 4). In general, the development of bottom zoocenoses in the lake corresponded to the ultraoligotrophic and beta-oligotrophic types, except station no. T5, where it corresponded to the alpha-mesotrophic type of the reservoir due to the mass development of *L. hoffmeisteri*.

Oligochaetes dominated both in terms of abundance and biomass, followed by biting midges. The number of zoobenthos species increased (from 0 to 7 species per sample, averaging 2.95).

The species diversity index varied from 0 to 2.02 bit/ind., averaging 0.88 ± 0.13 for the lake. The Goodnight-Whitley oligochaete index in the lake varied from 0 to 97.4% (up to class V water quality, “extremely dirty”), averaging 46% (class II, “slightly polluted”).

The species composition of the phytophilic benthos found in the coastal thickets of macrophytes of the Lake Manzherokskoe was the richest: 33 invertebrate species were noted here, most of which belong to insects (17 species). Two families of Diptera prevailed, Chironomidae (7 species) and Ceratopogonidae (1 species). In addition, 3 species of waterbugs, 2 species of mayflies, dragonflies, and beetles were noted. Other classes of invertebrates were represented by Oligochaeta (9 species), Hydracarina (4), Bivalvia (1), and Gastropoda (2).

Discussion

In July 2021, there were significant changes in the composition and structure of the zoobenthos of Lake Manzherokskoe, compared to the results of studies conducted immediately after the dredging was completed (August 8, 2018). The number of species of benthic invertebrates increased from 2 to 11 in the water area and from 5 to 33 species in macrophyte thickets. The number of species in the sample increased from 1.4 ± 0.46 to 2.95 ± 1.38, as well as Shannon–Weaver index, from 0.19 bits/ind. in August 2018 to 0.88 bits/ind. in July 2021, on average. In addition, there was a gradual increase in the quantitative indicators of macrozoobenthos: for example, the average biomass increased from 0.3 g/m² (2018) to 0.49 g/m² (July 2021). The dominant taxa did not change: Oligochaetes and biting midges formed the basis of abundance and biomass throughout the lake.

The increase in species diversity and quantitative indicators of benthic invertebrates noted in July 2021 compared to 2018 suggests that restoration of zoocenoses may occur with a decrease in the technogenic load. First of all, the restoration of benthic communities was manifested in an increase in the number of species, later, in a gradual increase in the abundance of oligochaetes. A similar trend was noted during the restoration of the zoobenthos of the Neva Bay (Susloparova et al., 2013).

In July 2021, the number of zero catches at the deep stations located at the dredging site decreased compared to surveys performed in April 2021; oligochaetes were noted in addition to Diptera larvae. Predatory dipteran larvae dominated by abundance and biomass at these sites. The dominance of predators in these areas of the lake was most likely due to the relatively high ecological flexibility of the taxa found, as noted previously for some of them (Yakovlev, 2005). Oligochaetes dominated in shallow

intertidal pristine areas. According to the way of feeding, oligochaetes belong to the group of collecting detritus-feeders; this group usually dominates in the littoral zones of small lakes, where detritus sedimentation prevails. A similar trend was noted in August 2018 (Bezmaternykh et al., 2019, 2020).

Changes in various hydrobiont communities under the influence of technogenic factors are largely similar: a decrease in the total number of species, abundance and biomass, a change in dominants, and a disruption in the seasonal course of the dynamics of the abundance and biomass of the community (Tsar'kova, 2016). Similar changes were observed for the macrozoobenthos of the Lake Manzherokskoe after dredging in 2018. The restoration of benthic communities is slow, accompanied by the loss of some species and by a decrease in the biomass of benthos down to 60% of the initial value (Kudersky and Lavrent'eva, 1996; Susloparova and Tereshenkova, 2010; Zhigulsky et al., 2013, 2014a, 2014b). The formation and settlement of a new biotope on a damaged area of the bottom usually takes several years, from 3 to 8 years (5 years on average), but in some cases it may take up to 25 years (Lesnikov, 1986). Since the increase both in species diversity and in the average quantitative indicators of benthic community has been noted on the Lake Manzherokskoe after three years after the dredging, we assume that the benthic communities in the reservoir have begun to restore; if the anthropogenic load is significantly reduced, this process may proceed until the community will reach the initial stage (Bezmaternykh et al., 2021).

Conclusions

Three years after the dredging works on Lake Manzherokskoe, the number of species of benthic invertebrates increased from 2 to 11 in the water area of the lake. Shannon–Weaver species diversity index has increased several times. The increase in species diversity was manifested both in general increase in the number of species and in a gradual increase in the abundance of oligochaetes.

In 2021, the average quantitative indicators of benthic invertebrate communities have increased compared to the same period of 2018. Oligochaetes and biting midges remained the dominant taxa in terms of abundance and biomass throughout the lake.

The increase in species diversity and quantitative indicators of benthic communities noted in July 2021, comparing to 2018, generally indicates the restoration of the zoobenthos of Lake Manzherokskoe.

Acknowledgments

The authors express sincere gratitude to Dr. V.V. Kirillov, Dr. M.I. Koveshnikov and the staff of

the Institute of Water and Environmental Problems for assistance in sampling. Special thanks go to Prof. L.V. Yanygina for the courtesy of data for 2007.

Funding

The study was supported by the Russian Science Foundation, grant no. 22-27-20134.

ORCID

Olga N. Vdovina [ID 0000-0002-2479-3338](https://orcid.org/0000-0002-2479-3338)

Dmitry M. Bezmaternykh [ID 0000-0002-7747-4939](https://orcid.org/0000-0002-7747-4939)

Evgeniya N. Krylova [ID 0000-0002-9796-4310](https://orcid.org/0000-0002-9796-4310)

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