Assessment of the ecological state of the Boguchany reservoir by zoobenthos organisms

A V Andrianova
Institute of Computational Modeling, Siberian Branch of the Russian Academy of Sciences, Academgorodok Str., 50, Krasnoyarsk, 660036, Russia
E-mail: andrav@icm.kras.ru

Abstract. Zoobenthos communities had been studied in the middle and lower parts of the Boguchany reservoir for five years (2014-2015, 2017-2019). The benthic fauna was chironomid-gammarid in nature with a predominance of chironomids. The littoral communities are qualitatively and quantitatively much richer than in the profundal. With a decrease in depth, there was an increase in the number of invertebrates by about 6 times due to the small-sized species of chironomids. The trophic status of the Boguchany reservoir in 2018 corresponded to the mesotrophic type of medium food capacity (III class), in other years - to the oligotrophic type of low food capacity (II class). Currently, the formation of bottom fauna is at the stage of biocenosis stabilization. An integrated approach was used to assess water quality according to bottom communities. The fundamental criterion for the selection of indices was the consideration of the benthocenosis structural organization, i.e. the development degree of indicator taxa. Water quality, assessed by the state of zoobenthos communities, corresponded to III class, “Moderately polluted”, β-mesosaprobic zone.

1. Introduction
Regulation of river flow is necessary for the rational use of river resources. That is why large reservoirs are located in areas of intensive economic development, where there is a high demand for water resources for energy, communal, recreational and technical purposes [1]. However, the construction of hydroelectric power station and the creation of reservoirs cause a number of negative consequences, such as land flooding, the transformation of aquatic and terrestrial ecosystems, and the replacement of a high-grade fish population by ichyooecenosis of low value. In addition, after creating reservoirs, the quality of the water changes significantly, water blooms, blue-green algae multiplies, oxygen-free zones and fish kills occur in the ice period, and the sanitary and hygienic parameters of water deteriorate due to the discharge of sewage waters from cities and villages. The river control and the operation of reservoirs cause a change in habitat for river biota. The habitat conditions of aquatic organisms can change and form over several years, therefore, it is necessary to monitor the state of aquatic biological communities regularly.

In the system of Russian meteorological service, the quality control of the aquatic environment is carried out mainly through chemical and physical-chemical methods that do not give a complete characterization of the harmful effects of anthropogenic factors on biological communities.

In many foreign countries, chemical control of water quality gives way to biological control because the priority of assessing the ecosystems state by biological indicators has become obvious [2-4]. In fact,
zoobenthos organisms (invertebrates that live at the bottom of water bodies) are widely used as promising indicators for assessing pollution of aquatic ecosystems. A significant advantage of assessing the water quality by the composition of zoobenthos is that longer life expectancy of benthic animals makes it possible to estimate the quality of water even from reconnoitering surveys.

Currently, there is a cascade of reservoirs on the Angara River, which includes four hydroelectric power stations: Irkutsk, Bratsk, Ust-Ilimsk and Boguchany. The Boguchany reservoir became the fourth, lower level of the Angarsk cascade of hydroelectric power stations. The construction of the Boguchany hydroelectric complex began in 1980, and after a long break, it was resumed in 2006. The filling of the Boguchany reservoir began in May 2012, and in June 2015 its level reached a design value of 208 m.

Information on the current state of biological resources of the Boguchany reservoir is extremely scarce [5, 6], and studies of zoobenthos were carried out only before filling the Boguchany reservoir [7, 8]. The aim of this study is to assess the water quality of the Boguchany reservoir according to the state of bottom communities.

2. Materials and methods
The Boguchany reservoir is located in the Krasnoyarsk Region and the Irkutsk Region. According to landscape conditions, the reservoir is wooded, according to the genesis of the basin, it is a riverbed valley-growing. Other indicators of the reservoir define it as a flat and northern, large and deep, with seasonal flow regulation, low evacuation of water level and low water retention time. The water-surface area is 2326 km², the length of the reservoir along the main channel is 380 km, the maximum depth is 75 m, and the average depth is 25 m. The Boguchany HPS has a dam of run-of-river-type, which includes a right-bank rock-fill dam, a channel dam and a left-bank spillway dam. Water supply to the working units is carried out through nine water inlets; water runs into the dam turbine from the reservoir from a horizon of 23.5-45.0 m.

Zoobenthos samples had been taken during the growing season for five years (2014-2015, 2017-2019) at 12 stations located in the middle and lower parts of the reservoir. The bottom fauna was studied in two main ecological zones characterizing the vertical disjointedness of the reservoir: littoral — inshore shallow water and profundal — abyssal zone, covering the largest part of the bottom. The reservoir profundal was investigated in 2014, 2015 and 2017; littoral was studied in detail in 2018 and 2019. Macroinvertebrate samples were taken using standard hydrobiological methods [9], using a Dulkeyt circular scraper (the capture area is 1/22 m²) and a Petersen bucket bottom scoop (the capture area is 1/40 m²). Shannon’s biodiversity index was calculated according to number of invertebrates. The trophic status of the Boguchany reservoir was estimated by the zoobenthos biomass using the “trophicity scale” of S.P. Kitaev [10].

To assess water quality according to the state of the bottom communities, the Mayer index and adaptation of the Shannon’s index were used and saprobological analysis was performed using the Pantle – Bucca index modified by Sladechek [11]. Categories and classes of water quality were determined according to [12]. The Mayer and Shannon indices do not have strict gradations and can only be roughly correlated with the accepted division into water quality classes (table 1).

| Water quality class | Mayer index | Saprobity index | Shannon index |
|---------------------|-------------|-----------------|---------------|
| I – Very clear       | >22         | <1.00           | 5.1-6.5       |
| II – Clear           | 17-22       | 1.00-1.50       | 3.1-5.0       |
| III – Moderately polluted | 11-16      | 1.51-2.50       | 2.1-3.0       |
| IV – Polluted        | 5-10        | 2.51-3.50       | 1.1-2.0       |
| V – Dirty            | <10         | 3.51-4.00       | 0.5-1.0       |
| VI – Very dirty      | <10         | >4              | <0.5          |

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3. Results and discussion

3.1. Characteristic of zoobenthos communities

It is known that the main conditions, determining the species composition and quantitative development of the bottom fauna, are the nature of the soil, the composition and abundance of higher aquatic vegetation, as well as the depth of particular sections of the reservoir. The main factor for the formation of the benthos structure in most limnic ecosystems is the vertical zoning of the reservoir. The presence of phyto-detritus in the littoral zone of the Boguchany reservoir determined the zoobenthos structure. The soil of the reservoir is represented mainly by a soft sandy-silt fraction, in some places there was fine pebble. Thus, psammopelophilic benthos communities with phytophilic fauna elements formed in the littoral zone. In the deep part of the channel soft silty deposits predominated at the bottom. Pelophilic communities developed here.

During the studied period, 75 species and taxa of a higher rank of invertebrate animals were identified in the bottom communities of the reservoir. The largest number of species (39) was noted among dipteran insects of the family Chironomidae. Second place according to qualitative diversity belonged to caddis flies - 11 species; the oligochaete class included 9 species. The remaining systematic groups of the bottom population were represented by 1-4 species.

The littoral zoobenthos (at the depth of 3 m) is qualitatively and quantitatively traditionally much richer than in the profundal (from 3 to 20 m). (table 2). In the deep-water part, 24-27 species of bentonts were revealed, while in the shallow-water part - twice as many. The average number of species in the sample from profundal was 2-3, in the littoral - 6-7. The Shannon index in the littoral is significantly higher than in the profundal (p <0.05).

Table 2. Characteristics of bottom communities in the profundal and littoral of the Boguchany reservoir.

| Reservoir area        | Number of species in a community | n | H   | Abundance, thous.ind./m² | Biomass, g/m² |
|-----------------------|----------------------------------|---|-----|--------------------------|---------------|
| Profyndal (2014-2015 г.) | 27                               | 2.9 ± 0.3 | 0.93 ± 0.13 | 0.39 ± 0.11 | 2.46 ± 0.82 |
| Profundal (2017 г.)   | 24                               | 2.2 ± 0.2 | 1.11 ± 0.07 | 0.21 ± 0.03 | 1.60 ± 0.34 |
| Littoral (2018 г.)    | 50                               | 6.2 ± 0.5 | 1.67 ± 0.10 | 2.23 ± 0.36 | 2.76 ± 0.39 |
| Littoral (2019 г.)    | 52                               | 7.5 ± 0.4 | 2.10 ± 0.09 | 1.48 ± 2.05 | 2.02 ± 0.24 |

*Number of species in a sample.

Shannon biodiversity index.

The dominant complex of species specific to the reservoir littoral was formed by the chironomids *Camptochironomus pallidivittatus* (Malloch), *Chironomus cingulatus* Meigen, *Cladotanytarsus gr. mancus*, *Cryptochironomus gr. defectus*, *Polypedilum gr. nubeculosum*, as well as amphipods *Gmelinoides fasciatus* (Stebbing) and *Micruropus sp*. Representatives of *Chironomus* and amphipods *G. fasciatus* were most common in profundal.

Chironomids had an advantage in numbers in the reservoir, both in shallow water and in deep areas (figure 1). Their percent in the total number varied from 49% to 51% on average in the reservoir in different years of research. Amphipods were in second place in benthic communities. In 2017, their percent in zoobenthos reached 47%, but in the remaining years, it was only 16-19% of the total number. Chironomids also formed the basis of biomass (39-62%), but the percent of amphipods increased (19-37%). It should be noted that large species of chironomid larvae live in the profundal, whereas small-sized species live in the littoral, but in large numbers.

The trophic status of the Boguchany reservoir, estimated by the average biomass of zoobenthos (table 2), in 2018 corresponded to the mesotrophic type of medium food capacity (III class), in other years - to the oligotrophic type of low food capacity (II class).
Figure 1. The abundance and biomass of the main groups of zoobenthos in various years of research in the Boguchany reservoir.

It is known that the formation of the bottom fauna of large reservoirs goes through several stages [1]:
1) The stage of destruction of terrestrial and aquatic biocenoses of the area that fell into the flood zone. It is characterized by the predominance of earthworms in the benthos of flooded land areas and the uneven distribution of phytophilic and rheophilic species that have lost their habitat.
2) The stage of temporary biocenosis of bloodworm, or the "bloodworm stage". Its duration is usually from 1-2 to several years, characterized by the massive development of chironomids (mainly of the genus Chironomus) throughout the whole reservoir. This is associated with the occurrence of a large amount of detritus from flooded areas.
3) Stage of stabilization or permanent biocenosis. It occurs 3–5 years after the reservoir is filled. It is characterized by the constancy of the group composition of zoobenthos. In the Boguchany reservoir, the formation of bottom fauna is currently at the stage of stabilization of biocenosis.

3.2. Water quality assessment
During the examination of the water quality in a particular ecosystem, the necessary minimum of methods should be applied to obtain a certain set of indicators that give a reliable assessment even in reconnoitering studies. Methods of bioindication studies of fresh water reservoirs can be divided into simple and complex. Complex methods have a number of serious limitations in choosing indicator groups of organisms, type of a reservoir, research time, etc. Simple methods do not have these limitations, but allow estimating water quality very approximately. It is recommended to use these methods at the preliminary stage of bioindication studies, at the first acquaintance with a reservoir. These methods include the Mayer method, which is acceptable for any type of reservoir. It is based on the confinement of various groups of aquatic invertebrates to reservoirs with a certain level of pollution. Moreover, all organisms are divided into three indicator groups: inhabitants of clear, moderately polluted and polluted waters.

The choice of adequate methods for assessing the ecological state of the Boguchany reservoir is significantly complicated due to the low species diversity of bottom communities in the profundal zone. According to the guidance document [12], which governs the monitoring of the surface water condition on land, water quality on zoobenthos should be assessed using the Goodnight Oligochaete index and the Woodyvis biotic index. However, the extremely low percent of indicator groups, used to calculate these indices, makes their use impossible for the Boguchany reservoir. Therefore, the Mayer index was used in the profundal zone for reconnoitering assessment of water quality. Inhabitants from each indicator group were found here. Mayflies and caddis flies represented group 1, amphipods and dragonfly larvae - group 2, chironomid larvae and worms - group 3. The Mayer index in the studied water area was 12 points, which corresponds to the III quality class (moderately polluted water).

Saprobity is one of the most important indicators affecting the species composition and abundance of organisms in water bodies. Saprobity indicates the saturation degree of reservoir with decomposing organic substances that bind free oxygen. On the one hand, saprobity determines the need of hydrobionts
in organic nutrition, and on the other hand - the resistance of aquatic organisms to toxic compounds arising from the decomposition of organic substances (hydrogen sulfide, ammonia, urea, organic acids, hydrogen cations, etc.). Depending on the content of organic compounds in the water, the saprobity index and the reservoir status can be determined.

In the Boguchany reservoir, the saprobity index can be used only in the littoral zone, where a relatively high species richness of benthic fauna is recorded. For profundal, the use of the saprobity method is extremely limited, since the dominant species (representatives of the genus Chironomus) do not have individual saprobic valency. Most indicator species of zoobenthos from the Boguchany reservoir belong to β-mesosaprobic. According to the average values of the saprobity index (in 2018 - 2.03±0.04, in 2019 - 2.02±0.02), the littoral zone of the reservoir belongs to the III class of water quality, β-mesosaprobic zone.

It is known that in clear reservoirs, bottom communities in well-aerated bottom areas are characterized by high species diversity, which indicates the normal state of the aquatic ecological system. As pollution or eutrophication of the reservoir increases, species diversity decreases. The modification of the Shannon diversity index (H) proposed by Wilm and Dorris is used as an indicator of the water pollution degree. It has been affirmed that H>3 corresponds to clear water, H from 1 to 3 - to polluted water, H<1 - to dirty water [13]. The average values of the Shannon index in the studied years ranged from 0.93 to 2.10 (table 2), which characterize the reservoir as “Moderately polluted” of the III quality class with a tendency to switch to the IV quality class (“Polluted” water).

4. Conclusions
During the study period, 75 species and taxa of a higher rank of invertebrate animals were identified in the bottom communities of the Boguchany reservoir. Zoobenthos was chironomid-gammarid in nature with the predominance of chironomids. The littoral communities are qualitatively and quantitatively much richer than in the profundal. With a decrease in depth, there was an increase in the number of invertebrates by about 6 times due to the small-sized species of chironomids. The trophic status of the Boguchany reservoir in 2018 corresponded to the mesotrophic type of medium food capacity (III class), in other years - to the oligotrophic type of low food capacity (II class). Currently, the formation of bottom fauna is at the stage of bioenesis stabilization. Water quality, assessed by the state of zoobenthos communities, corresponded to III class, “Moderately polluted”, β-mesosaprobic zone.

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