ISSN 2079-0961, Arid Ecosystems, 2016, Vol. 6, No. 3, pp. 213–219. © Pleiades Publishing, Ltd., 2016.
Original Russian Text © B. Mendsaihan, A. Dulmaa, A.V. Krylov, D.B. Kosolapov, Yu.V. Slynko, A.A. Prokin, S. Demidsereeter, D.L. Lebedeva, B. Altantsetseg, Yu.Yu. Dgebuadze, 2016, published in Aridnye Ekosistemy, 2016, Vol. 22, No. 3(68), pp. 84–91.

Formation of the Lake-Type Ecosystem in Semidesert zone: Tayshir Reservoir in the Zavkhan River (Western Mongolia)

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Received October 25, 2015

Abstract—Plankton and benthos production were estimated on the basis of materials collected in the Tayshir Reservoir after its formation. The species ratio and the growth and diets of fish have been considered also. A high abundance and increased maximal sizes of Potanin's Altai osman (*Oreoleuciscus potanini*) were revealed. The benthic organisms dominated in the food of all three fish species inhabiting the Tayshir Reservoir: Potanin's Altai osman, Mongolian grayling (*Thymallus brevirostris*), and Siberian stone loach (*Orthrias barbatulus toni*).

Keywords: Mongolia, Tayshir reservoir, plankton, benthos, fish nutrition

DOI: 10.1134/S2079096116030082

INTRODUCTION

The beginning of the 21st century in Mongolia was marked by the rapid development of hydraulic power engineering. In only the first decade, 13 hydroelectric plants had been built in rivers, with nine plants situated in Western Mongolia. One of the largest is the Tayshir Hydroelectric Power Plant, which was launched in 2007. It is built in the upper reaches of the Zavkhan River, the largest water course of Western Mongolia. A dam 50 m high and 190 m long (crest length) was built. The planned output of the Hydroelectric Power Plant is 11 MW, and the output to be supplied to Goby-Altai and Zavkhan aimaks is to be 37.0 MW/h per year (*Mongolia: In-Depth* ..., 2011). At present, damming resulted in the fully formed Tayshir Reservoir with a maximum depth of 34 m. The Zavkhan River belongs to the Central-Asia drainless basin, which is characterized by an unstable water balance and extremely poor ichthyofauna.

The creation of reservoirs leads to modification of the climate of surrounding territories and a radical transformation of the biological conditions of watercourses. Thus, special problems under arid zone conditions arise, requiring special investigations. An investigation of changes in the biological situation of dammed watercourses is also necessary to elucidate general regularities of the formation of structure and functions of large-scale freshwater ecosystems at different stages of their genesis (Krylov and Mendsaihan, 2012; Krylov et al., 2012).

The goal of the present study is to characterize the state of the ecosystem of the Tayshir Reservoir after its filling.

MATERIALS AND METHODS

Hydrobiological and ichthyological studies in the Tayshir reservoir were carried out in August 2010–2014. Hydrobiological samples were taken in the center and at the coast of the upper and middle areas, near the dam, and in the medial of the Zavkhan River in about 1 km above water lockup and about 1 km below the dam. For microscopic analysis the water was preserved immediately after sampling with 40% formaldehyde until a final concentration of 2%, stored in the dark at 4°C, and studied for a month. The total abundance and size of heterotrophic bacteria were determined by epifluorescent microscopy with a Olympus

Table 1. Characteristics of sampling stations at the Tayshir Reservoir and the Zavkhan River. Depth (*h*, m), transparency (*p*, m), temperature (*T*°C), pH, and conductivity (EC_{18}, mS/cm)

No.	Stations	*h*	*p*	*T*°C	pH	EC_{18}
1	The Zavkhan (above backwater created by reservoir)	0.4	To the bottom	17.5	8.7	123.6
2	Stretch above the reservoir	1.5	To the bottom	17.8	8.4	153.8
3	Middle part of reservoir	6.0	3.7	22.9	8.7	202.9
4	Area near the dam	25.0	4.8	19.7	8.6	220.0
5	The Zavkhan below the dam	0.8	To the bottom	9.8	8.2	156.0

BX51 microscope (Japan) connected to a digital camera and a personal computer (Porter and Feig, 1980; Caron, 1983; MacIsaac and Stockner, 1993). The wet weight of microorganisms was calculated by multiplication of their abundance by the average cell volume. Zooplankton samples were taken at a depth of ≤1 m with a pail (100 L of water were strained through 64 μm mesh gauze); at other sites; they were taken with a Juday net (two hauls; aperture diameter of 12 cm, 64 μm mesh gauze). The samples were preserved with 4% formalin and processed in the laboratory by standard methods (*Metodika izucheniya* ..., 1975). Quantitative macrozoobenthos samples were taken by a Petersen Grabber with a sampled area of 0.025 m^2 (2010) and by a DAK-100 with and area of 0.01 m^2 (2013–2014), with two hauls for one sample. Post-processing was performed in the laboratory by standard methods (*Metodika izucheniya* ..., 1975).

The fish were caught with fixed gill nets with meshes of 20, 30, 40, 50, and 60 mm. In sites above and below the reservoir, the fish were caught by means electrofishing. Altogether, 2890 specimens were examined. Most fish underwent biological analysis immediately after capture. The fish were measured and weighted, the sex was determined, and the digestive tract was preserved. The age of Mongolia graylings was determined by scales, and that of Altai osman was determined by opercles (Chugunova, 1959; Pravdin, 1966). Food analysis was made according to standard methods (*Metodicheskoe posobie*..., 1974; Hyslop, 1980). The significance of particular food items in the food is calculated by the frequency of occurrence.

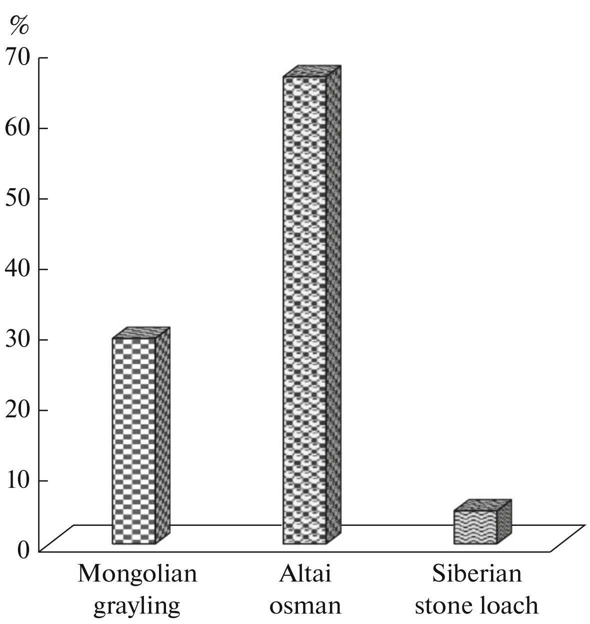

Fig. 1. Ratio of fish species in control catches in the Tayshir Reservoir.

RESULTS AND DISCUSSION

Hydrological parameters of sampling sites. The maximum depths were near the reservoir dam, and the minimum depths were in unregulated stretches of water courses. The maximal transparency is noted near the dam. In comparison with the river, the water temperature and conductivity were higher in the reservoir (Table 1).

Hydrobiological investigations. The plankton communities of hydrobionts of the Tayshir Reservoir were formed in 2010–2014. The mean abundance of bacterioplankton is 1.8 times higher than that in the Zavkhan River: 7.73 and 4.2 mln cells/mL, respectively. The bacteria in the river were larger: the mean cell volume in the river and in the reservoirs was 0.192 and 0.111 $μm^3$, respectively. Thus, mean values of bacteoplankton biomass in the reservoir (819 mg/m^3) and in the river (823 mg/m^3) turned out to be approximately identical. The bacterial abundance and biomass increase along the longitudinal profile of the reservoir. They were 6.15 mln cells/mL and 661 mg/m^3 on average in the upper reaches of the reservoir and 8.20 mln cells/mL and 838 mg/m^3, respectively, near the dam. Any noticeable differences in the level of quantitative development of bacterioplankton in the littoral and pelagial of the reservoir were not recorded. The mean values of abundance in the littoral and pelagial were 7.62 and 7.88 mln cells/mL, and those of the biomass were 868 and 853 mg/m^3, respectively. The abundance and biomass of bacterioplankton recorded in the Tayshir are characteristic of meso- and eutrophic water bodies (Kopylov and Kosolapov, 2007).

In zooplankton of the Zavkhan River–Tayshir Reservoir system, 47 species of invertebrates are recorded (24 Rotifera, 9 Copepoda, and 14 Cladocera). In different years the number of species varies insignificantly; the maximum number was noted in 2011. In 2012–2014, in comparison with the initial period, the number of Cladocera species increased. The trophic level coefficient (Maemets, 1980), which is based on analysis of the species composition, is characterized as mesotrophic in the Zavkhan River above the backwater caused by the reservoir and as pelagial near the dam. In the littoral of upper part of the reservoir and in the river below the dam, the coefficient value significantly increased and corresponded to hypertrophic waters. Other areas were characterized as eutrophic.

The distribution of zooplankton biomass along the longitudinal profile of the reservoir in the littoral zone and in the pelagic zone was different: the maximum values in the inshore zone were recorded in the upper reaches (on an average 0.15 g/m^3), which are characterized by shallow depths and the presence of greater vegetation, and in the pelagial zone near the dam (0.9 g/m^3), where the available food favored development of crustaceans. In the littoral zone of the reservoir, the following among dominants species are noted: *Brachionus quadridentatus brevispinus* Ehrenberg, *Polyarthra vulgaris* Carlin, *Euchlanis dilatata*, *E. meneta*, juvenile Cyclopoida, *Cyclops strenuus* (Fischer), and in deeper sites – *Conochilus hippocrepis* (Schrank), *C. unicornis* Rousselet, *Acanthodiaptomus denticornis* Wierzejski, *Daphnia* (*Daphnia*) *galeata* G.O. Sars, *D.* (*D.*) *hyalina* Leydig, and their hybrids. On the whole, the reservoir was characterized as a water body with scarce food resouces by zooplankton biomass (Pidgaiko et al., 1968).

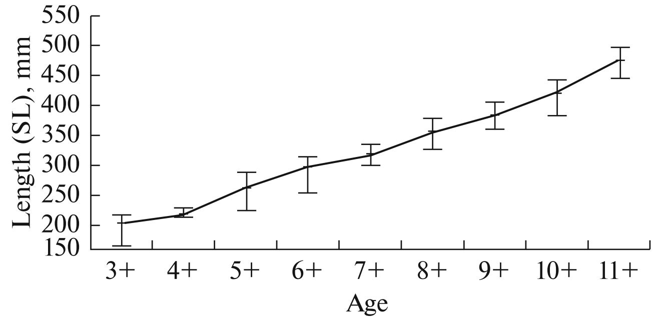

Fig. 2. Linear growth of Mongolian grayling (*Thymallus brevirostris*) in the Tayshir Reservoir.

Altogether, in the Tayshir Reservoir and adjacent parts of the Zavkhan River, no less than 75 species of benthic macroinvertebrates are found. Macrozoobenthos communities that were richer in species and number were formed under conditions of average littoral depth with decomposed inundated terrestrial vegetation, free of water-piling stress, and diverse microbiotopes were available. In the littoral of the upper, central, and near-dam sites, the total abundance of macrobenthic communities was lower and the biomass was higher than in the river above the reservoir. Here, chironomid are the principal invertebrate group. Up to 2014, the macrobenthos was not yet formed in the profundal of the central area; near the dam, it attained high biomass values (67.7 g/m^2) due to the development of colonies of *Spongilla lacustris* sponges—a periphytonic species readily populating hard stones. However, on average by macrozoobenthos biomass (Pidgaiko et al., 1968), the river above the reservoir and the littoral zone of the reservoir belonged to water

Table 2. Frequency (%) of food items in the Mongolian grayling (*Thymallus brevirostris*) diet in the Tayshir Reservoir

Food items	2011	2012
Fish	15.6	21.9
Chironomidae (larvae)	36.8	15.3
Simulidae (larvae)	89.4	53.8
Tipulidae (larvae)	5.2	7.6
Ephemeroptera (larvae)	5.2	7.6
Plecoptera (larvae)	5.2	7.6
Trichoptera (Brachycentridae) larvae	15.7	7.6
Gammarus lacustris	63.1	69.2
Mollusca	10.5	15.3
Coleoptera	10.5	15.3
Mean length of fish, mm	299 ± 63.5	318 ± 44.8
Variation range of length, mm	198–462	262–430
Number of examined stomachs:		
With food	29	11
Empty	9	6

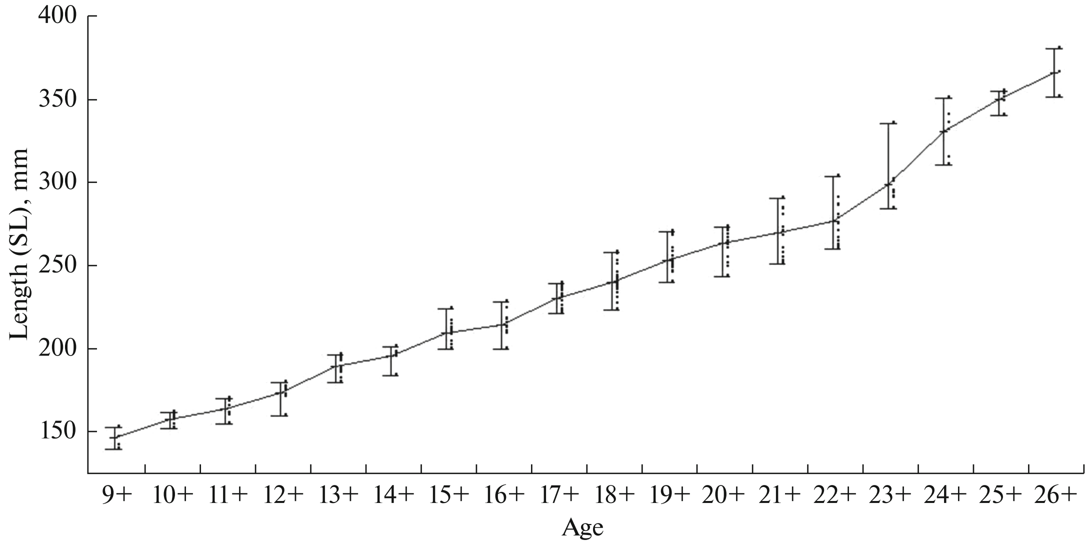

Fig. 3. Linear growth of Potanin's Altai osman (*Oreoleuciscus potanini*) in the Tayshir Reservoir.

bodies with scarce food resources, while the sublittoral and pelagial were water bodies with high food reserves.

Ichthyological Investigations

The Zavkhan is inhabited by three fish species: Potanin's Altai osman (*Oreoleuciscus potanini*), Mongolian grayling (*Thymallus brevirostris*), and Siberian stone loach (*Orthrias barbatulus toni*). By abundance and biomass, Altai osmans dominate (Fig. 1). The diverse environmental conditions of water bodies populated by Altai osmans and the fact the the ichthyofauna is extremely poor seem to result in great morphological and ecological variation of this group (Dashdorzh, 1976; Tugarina and Dilmaa, 1971; Dgebuadze, 1982; Baasanzhav et al., 1983, 1985; Borisovets et al., 1985; etc.).

Mongolian grayling. In the Tayshir Reservoir, it attains a standard length of 500 mm and weight of 1300 g. No significant differences are found in the sizes of male and female Mongolian grayling. The linear growth of studied fish's age classes was rather gradual (Fig. 2). In the upper reaches of the reservoir, the length of Mongolian grayling in catches did not surpass 188 mm, and the weight did not surpass 43 g. Below the dam, the Mongolian grayling was not found.

In Mongolian water bodies, the maximal size of Mongolian grayling is 650 mm, the maximal weight is up to 6 kg, and the maximal age is 16+. In control catches specimens aged up to 11+ occurred. The bulk of catches usually consisted of fish at the age 3+ (30.4%) and 4+ (21.4%). In 2013, specimens at the age 6+ to 7+ (41.6%) prevailed.

The sex ratio of Mongolian grayling in catches from the reservoir was 1 : 0.9 (51.6% males and 48.4% females). In the period of observations (August), 64.2% of analyzed fish had gonads at maturity stage II. Gonads were found at transitional stages II–III in ~14.4% and at stage III in 21.4%.

In the stomachs of the Mongolian grayling, ten food items were found (Table 2). By frequency of occurrence, blackfly larvae (Simuliidae) dominated (53.8–89.4%), as well amphipods (63.1–69.2%), and chironomid larvae (15.3–36.8%). The remainder consisted of larvae of stoneflies, mayflies crane flies (Tipulida), caddis flies, and mollusks. The fullness index of Mongolian graylings in the Tayshir Reservoir in August was 111–138‱.

Thus, benthic organisms dominated in the food of Mongolian graylings from the Tayshir Reservoir. By the frequency of occurrence, the fish comprised only 15.6–21.9%.

Potanin's Altai osman. After damming, the Altai osman is a dominant fish species and on control catches comprised 58.0–93.6%. The maximum standard length of Altai osman from the Tayshir reservoir increased from 348 mm in 2010 to 421 mm in 2014; the weight increased from 515 to 574 g, respectively.

In Mongolian water bodies, specimens of a predatory form of Altai osman live longer than 40 years and attain a length of 1000 mm and a weight of over 5 kg. For a herbivorous form, the age was noted as 34+, with a maximum length of ~500 mm and weight of ~1 kg (Baasanzhav et al., 1985). In our control catches, Altai osmans up to 23 years of age occurred, and 61.6% of all caught fish were specimens of the age 14+ to 18+. Below the reservoir, the size of osmans in electrofishing samples did not surpass 177 mm or a weight of 69 g. Thus, in the Tayshir Reservoir, Potanin's Altai osmans attain a large size and grow more rapidly than in the

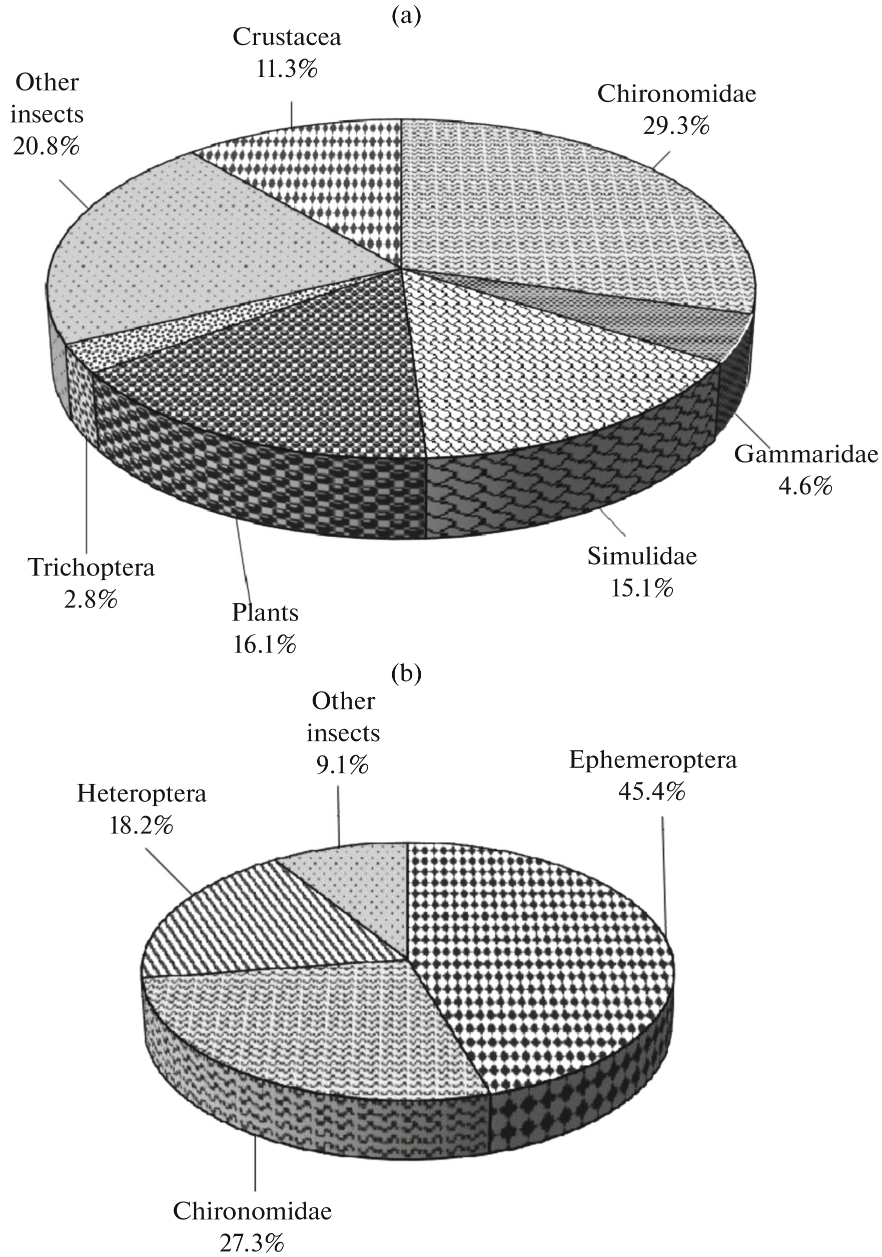

Fig. 4. Diet composition of Potanin's Altai osman (*Oreoleuciscus potanini*) (the ratio of food component of the frequency of occurrence). (a) In the Tayshir Reservoir, (b) in the Zavkhan River below the Tayshir Reservoir.

Zavkhan River. The acceleration of growth is especially obvious in specimens of elder age groups (Fig. 3).

The sex ratio of Altai osman in the Tayshir Reservoir is 1 : 1 (49.4% males and 50.6% females). In the period of sampling (August), 88.5% of the examined fish had gonads at maturity stages I–II; about 3.8% were at maturity stages II–III, and 7.7% were at stage III.

The bulk of Potanin's Altai osman food in the Tayship Reservoir consists of chironomid larvae, vegetation, blackfly larvae, and entomostracans (Fig. 4a). Below the reservoir, two food organisms dominated: mayfly larvae (Heptagenidae, Ephemerellidae) and chironomid larvae (Fig. 4b).

Siberian stone loach. Below the reservoir, the total length of stone loach in catches of electrofishing varied from 84 to 122 mm (the mean was 108 mm), and the average weight was 10.3 g (variations from 4 to 15 g). In August 2012–2013, in this stretch of the Zavkhan, ten food items were found in the intestines of Siberian stone loach. By the frequency of occurrence, larvae of chironomids, blackflies, and stoneflies dominated, and a small fraction consisted of larvae of tipulids, mayflies, caddis flies, and other insects. Some intes-

Table 3. Frequency (%) of food items in the Siberian stone loach (*Orthrias barbatulus toni*) diet in the Zavkhan River below the Tayshir Reservoir

Food items	2012	2013
Chironomidae (larvae)	100.0	100.0
Simulidae (larvae)	86.6	83.3
Culicidae	20.0	–
Tipulidae (larvae)	6.6	–
Ephemeroptera (larvae)	40.0	66.7
Plecoptera (larvae)	6.6	–
Trichoptera (Hydropschychidae) (larvae)	6.6	–
Gammarus lacustris	6.6	–
Fish eggs	–	16.7
Insect remain, not indentified	20.0	50.0
Mean length of fish, mm	9.2 ± 1.3	10.2 ± 1.2
Variation range of length, mm	7.8–11.9	8.4–11.2
Number of examined intestines:		
With food	16	12
Empty	4	9

tines contained eggs of osmans (Table 3). The index of fullness was 50–138‱.

CONCLUSIONS

The data indicate that the lake-type ecosystem is formed in the Tayshir Reservoir, with a bacterioplankton abundance and biomass characteristic of meso- and eutrophic water bodies.

By zooplankton biomass, the reservoir is generally characterized as a water body with scarce food resources.

By macrozoobenthos biomass, the Zavkhan River above the reservoir and the littoral zone of the reservoir belong to water bodies with poor food resources, while the sublittoral and pelagial belong to water bodies with rich food resources.

Damming of the Tayshir Reservoir created favorable conditions for the Mongolian grayling and Altai osman. Food of the reservoir fish is dominated by benthic organisms. In the reservoir, the size of Mongolian graylings and Altai osmans is increased in comparison with river populations. The increased growth rate of Altai osmans in the reservoir, which is already recorded in elder age groups, will probably lead to a morphological and ecological differentiation of fish, as has been observed in periodically desiccated lakes of Lake Valley in a related species, *Oreoleuciscus humilis* (Dgebuadze, 1995; Dgebuadze et al., 2012).

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Translated by N.N. Smirnov