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WATER ECOSYSTEMS OF ARID TERRITORIES

Current State and Long-Term Dynamics of Zooplankton of the Tsimlyansk Reservoir (Don River, Russia)

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Abstract—The structure and distribution of zooplankton of the Tsimlyansk Reservoir were studied in August–September 2018. It was found that the zooplankton abundance was halved in the upstream part of the reservoir (2.4 ± 0.8 g/m^3) as compared to the zone near the dam of the Tsimlyansk hydroelectric power plant (1.2 ± 0.6 g/m^3). Copepoda constituted 70% of the biomass. The Ponto-Caspian *Heterocope caspia* and the invasive species *Calanipeda aquaedulcis*, *Thermocyclops taihokuensis*, and *Acanthocyclops americanus* were abundant copepods. The dynamics of zooplankton abundance in the reservoir is analyzed for more than 65 years since its creation (1952–2018) based on the published data. A more than twofold (up to 2.1 ± 0.5 g/m^3) increase in the community biomass was revealed in 2015–2018 as compared with the 40-year period up to 2013 (0.8 ± 0.1 g/m^3). The trends in the dynamics of the zooplankton abundance in the Tsimlyansk Reservoir, including the importance of the Ponto-Caspian crustaceans and invaders from other regions, are discussed.

Keywords: Don River, Tsimlyansk Reservoir, zooplankton, invaders, structure, abundance, long-term dynamics

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INTRODUCTION

The Tsimlyansk Reservoir was filled in 1952–1953 and has been in operation for over 65 years. The zooplankton of the Don River was not studied prior to the creation of the reservoir (Livshits, 1954; Dzyuban, 1958). However, zooplankton have been monitored from the first years of the reservoir's existence to the present day (Livshits, 1954; Dzyuban, 1958; Sheinin, 1960; Kaftannikova, 1965; Glamazda, 1971a, 1974; Shevlyakova, 2002; Svistunova and Sayapin, 2010; Vekhov et al., 2014; *Predvaritel'nye materialy* ..., 2018; Golokolenova et al., 2019). It was found that brackish-water Copepoda began to displace freshwater Cladocera, which were characteristic of the Don River, at the end of the 1950s (Kaftannikova, 1965; Glamazda, 1971a), and the Ponto-Caspian Cladocera were introduced into the reservoir in the 1960s (Glamazda, 1969, 1971b).

The changes in the composition, structure, and abundance of the reservoir zooplankton community were analyzed in detail based on data from the 1950s to the 1970s (Dzyuban, 1958; Sheinin, 1960; Kaftannikova, 1965; Glamazda, 1971a, 1974). It was noted that the summer biomass of zooplankton began to decrease in 1955 (Kaftannikova, 1965). In the 1960s, with the massive development of the Ponto-Caspian species, the biomass decreased below 2 g/m^3, even below 1 g/m^3 in some years (Kaftannikova, 1965; Glamazda, 1971a, 1974). The trends in the zooplankton development after the 1970s (over 40 years) and the trophic relationships within the community have not been studied in fact.

The goal of the paper is to study the structure and distribution of the abundance of the summer zooplankton of the Tsimlyansk Reservoir, to assess the importance in the community of Ponto-Caspian crustaceans and invaders from other regions, and to analyze the dynamics of the abundance of zooplankton over the entire existence of the reservoir.

EXPERIMENTAL

Study region. The Tsimlyansk Reservoir is the only manmade lake on the Don River. It is situated in the middle of the river course, about 200 km from the mouth (coordinates of the center: 47°50′ N, 42°50′ E). At a normal retaining level (NRL, 36 m a.s.l. BS), its area is 2700 km^2, the average depth is 8.8 m, the maximal depth is 30 m, and the water turnover rate is 1.05 year^{-1} (Avakyan et al., 1987). The reservoir depression is formed by a basin with three widenings confined to the mouth areas of the Chir, Aksay Kurmoyarskiy, and Tsimla rivers. Four reaches are distinguished in the reservoir: the Upper, Chir, Potemkin, and Near-Dam reaches (*Gidrometeorologicheskii rezhim* ..., 1977). The reservoir is characterized by extensive shal-

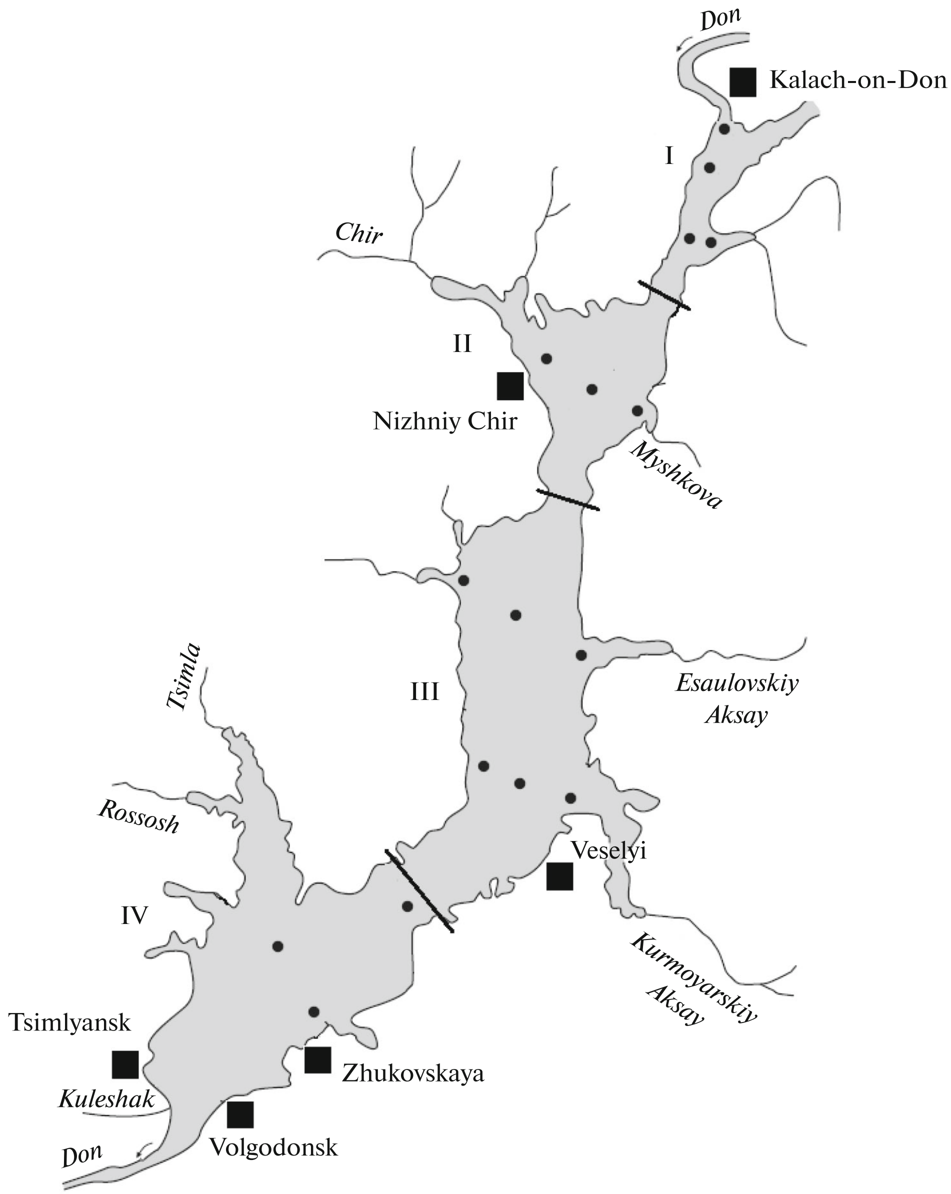

Fig. 1. Location of sampling stations in Tsimlyansk Reservoir. Reaches: I, Upper; II, Chir, III, Potemkin, IV, Near-Dam.

lows; at the NRL, areas with a depth of less than 5 m make up 29% of the area (Vekhov et al., 2014). According to the level of phytoplankton development (up to 50 mg/L), the reservoir is classified as hypertrophic (*Tsimlyanskoe vodokhranilishche* ..., 2011; Vekhov et al., 2014; Nikanorov and Horuzhaya, 2014). The materials for the present study were collected in late August to early September 2018 from the board of the expedition vessel *Akademik Topchiev* of the Papanin Institute for Biology of Inland Waters of the Russian Academy of Sciences; in the coastal areas, the samples were collected from a small boat. Sixteen sections of the reservoir were examined (Fig. 1).

Methods of sampling and data analysis. The zooplankton (Cladocera, Cyclopoida, Calanoida, and Rotifera) in all samples collected with a Juday net with an inlet diameter of 12 cm and a sieve with a mesh diagonal of 105 μm was counted. The samples were preserved with 4% formalin and examined in the laboratory under a StereoDiscovery-12 stereomicroscope (Carl Zeiss, Jena). Crustaceans and rotifers were identified with guidelines (Kutikova, 1970; Monchenko, 1974; Mordukhai-Boltovskoy and Riv'er, 1987; Borutskiy et al., 1991; *Opredelitel' zooplanktona*..., 2010; Monchenko, 2008; Sukhikh and Alekseev, 2013). The dominant species were identified based on their relative biomass (more than 10% of the total zooplankton biomass).

In the samples, the abundance and biomass of each species, their bulk values for each taxonomic group,

Table 1. Dominant species of zooplankton in different reaches of the Tsimlyansk Reservoir in August–September 2018

Taxon	Section							
	Upper		Chir		Potemkin		Near-Dam	
	B_{sp}*	$\%B_{tot}$**	B_{sp}	$\%B_{tot}$	B_{sp}	$\%B_{tot}$	B_{sp}	$\%B_{tot}$
Crustacea								
Moina micrura	1004	41	<10	<1	<10	<1	0***	0
Thermocyclops taihokuensis	809	33	563	55	99	5	<10	<1
Acanthocyclops americanus	398	16	210	20	<10	<1	30	3
Diaphanosoma orghidani	125	5	140	14	<10	<1	<10	<1
Heterocope caspia	<10	<1	21	2	1078	54	288	25
Calanipeda aquaedulcis	<10	<1	20	2	200	10	772	67
Rotifera								
Asplanchna priodonta	<10	<1	0	0	302	15	<10	<1

*B_{sp}, mean biomass of a species, mg/m^3; ** $\%B_{tot}$, contribution to total zooplankton biomass (%); *** 0, the species was absent from samples; the sections with species domination are shaded gray.

Table 2. Number and biomass of zooplankton of the Tsimlyansk Reservoir in August–September 2018

Reservoir reach	Zooplankton					*Dreissena* veligers
	Cladocera	Cyclopoida	Calanoida	Rotifera	сумма	
Number, thousand ind./m^3						
Upper	87 ± 45	238 ± 149	<1	69 ± 49	395 ± 179	<0.5
Chir	12 ± 5	161 ± 48	8 ± 4	45 ± 18	226 ± 63	1 ± 0.6
Potemkin	4 ± 2	15 ± 8	69 ± 23	134 ± 48	223 ± 64	14 ± 7
Near-Dam	3 ± 1	24 ± 10	70 ± 28	24 ± 12	121 ± 32	5 ± 1
Entire reservoir	26 ± 14	100 ± 42	41 ± 13	80 ± 24	247 ± 53	6 ± 3
Biomass, g/m^3						
Upper	1.16 ± 0.70	1.21 ± 0.69	<0.01	0.07 ± 0.05	2.44 ± 0.77	<0.01
Chir	0.16 ± 0.03	0.77 ± 0.24	0.06 ± 0.02	0.04 ± 0.01	1.03 ± 0.24	<0.01
Potemkin	0.10 ± 0.04	0.14 ± 0.01	1.33 ± 0.69	0.42 ± 0.17	1.99 ± 0.82	0.02 ± 0.01
Near-Dam	0.02 ± 0.01	0.04 ± 0.01	1.07 ± 0.64	0.02 ± 0.01	1.16 ± 0.65	0.01 ± 0.002
Entire reservoir	0.36 ± 0.19	0.51 ± 0.20	0.71 ± 0.31	0.19 ± 0.08	1.77 ± 0.38	0.01 ± 0.004

and their common values for all zooplankton were determined. The biomass was calculated with the formulas for the relationship between individual animals' body weight and length (Balushkina and Vinberg, 1979; Ruttner-Kolisko, 1977). The average values of zooplankton characteristics and their errors were calculated with the corresponding procedures of the Statistica software package for Windows, v. 10 (StatSoft, Russia).

RESULTS AND DISCUSSION

Zooplankton structure. The dominant assemblage of zooplankton in the Tsimlyansk Reservoir included eight species of mainly copepods, two to three in each of the four sites (Table 1). In the upper part of the reservoir above the mouth of the Donskaya Tsaritsa River, the main zooplankton biomass (90%) was formed by *Moina micrura* Kurz, 1874, as well as the recent invasive species *Thermocyclops taihokuensis* (Harada, 1931) and *Acanthocyclops americanus* (Marshall, 1893). In the section of this river and the Chir reach, *Thermocyclops taihokuensis* and *Acanthocyclops americanus* prevailed (75%); in the shallow Chir River Bay, *Diaphanosoma orghidani* Negrea, 1982 accounted for up to 14% of the biomass. Starting from the section of the Akseney–Aksay Esaulovskiy river, first on the Don River bed and then everywhere downstream, 65–95% of the biomass was formed by *Heterocope caspia* Sars, 1897 and *Calanipeda aquaedulcis* Kritschagin, 1873. The rotifers *Asplanchna priodonta* Gosse, 1850 were predominant (70–75% of the biomass of zooplankton)

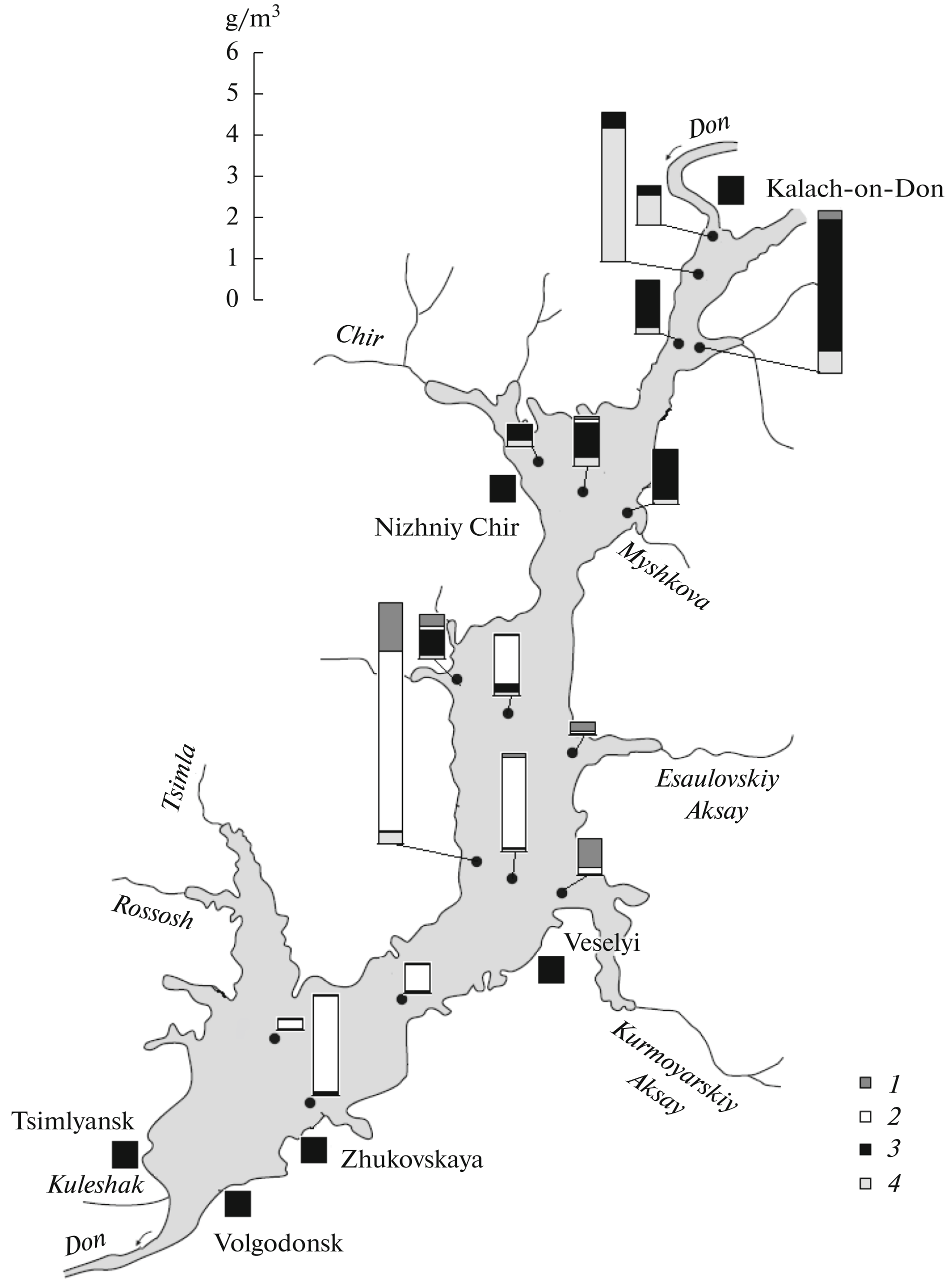

Fig. 2. Distribution of zooplankton biomass over the Tsimlyansk Reservoir area in summer 2018. Legend: (*1*) Rotifera; (*2*) Calanoida; (*3*) Cyclopoida; (*4*) Cladocera.

in the mouths of the Aksay Kurmoyarskiy, and Aksay Esaulovskiy rivers; in the Potemkin reach, their contribution to biomass reached 15% on average.

In 2018, five brackish-water, predatory, Ponto-Caspian crustaceans were found in the Tsimlyansk Reservoir and live there within their ancient range (Mordukhai-Boltovskoi, 1960): *Heterocope caspia, Eurytemora caspica* Sukhikh et Alekseev, 2013, *Cercopagis pengoi* (Ostroumov, 1891), *Cornigerius maeoticus maeoticus* (Penodone, 1879) and *Podonevadne trigona ovum* (Zernov, 1901). The most abundant were the copepods *Heterocope caspia* (up to 128000 ind./m^3) and *Eurytemora caspica* (up to 18000 ind./m^3); the rest were found in the Upper and Potemkin reaches singly (less than 100 ind./m^3). It is worth noting that *Eurytemora caspica* was previously (from the mid-1970s) identified as *Eurytemora affinis* (Poppe, 1880; Shevlyakova, 2002; Svistunova and Sayapin, 2010; Vekhov et al., 2014). In 2013, *E. caspica* was distinguished from the complex of cryptic species *E. affinis* s.l. (Sukhikh and Alekseev, 2013). The morphological and molecular analyses proved (Sukhikh et al., 2020) that *E. caspica*,

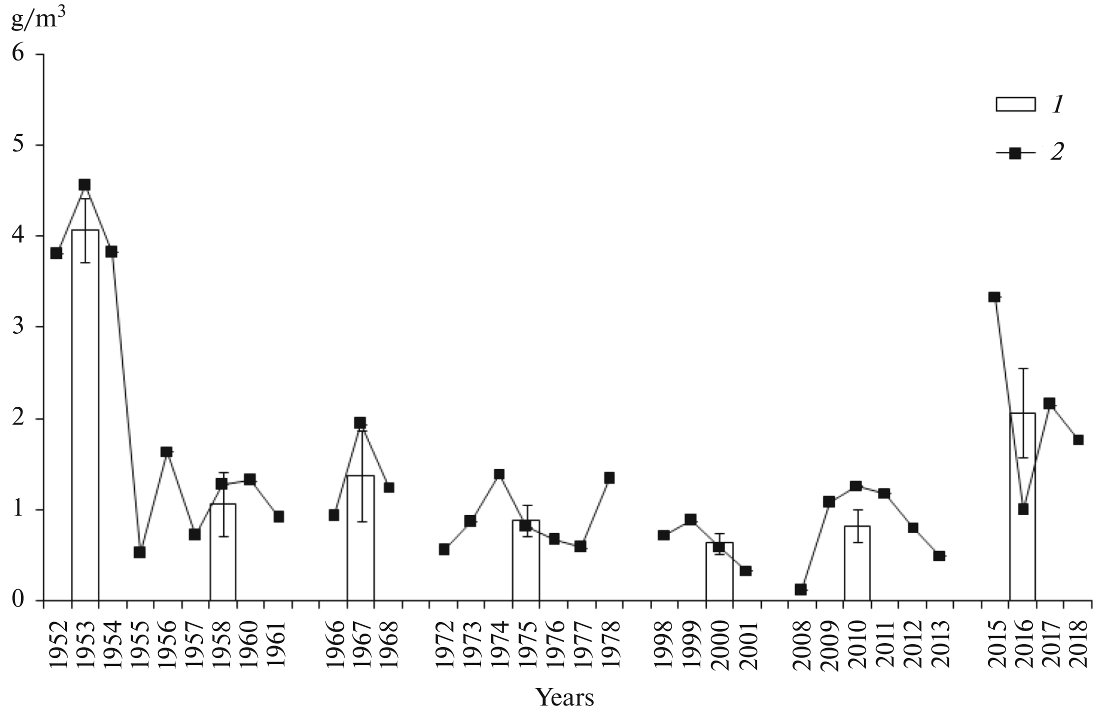

Fig. 3. Long-term (1952–2018) dynamics of summer (July–August) zooplankton biomass in the Rybinsk Reservoir. (*1*) mean values of biomass for periods of 3–7 years; (*2*) mean biomass in July–August of each year. References: 1952 (Livshits, 1954); 1953–1954 (Dzyuban, 1958); 1955–1962 (Kaftannikova, 1965; Sheinin, 1960); 1966–1978 (Glamazda, 1971a, 1974); 1998–2001 (Shevlyakova, 2002), 2008–2013 (Svistunova and Sayapin, 2010; Vekhov et al., 2014), 2015–2018 (*Predvaritel'nye materialy...*, 2018; Golokolenova et al., 2019; original data).

but not *E. affinis*, dwells in the Volga River reservoirs. In 2018, only *E. caspica* was found everywhere within the zooplankton of the Tsimlyansk Reservoir (Lazareva, 2020).

Two species of copepods are alien to the reservoir: Mediterranean *Calanipeda aquaedulcis*, which was introduced in the reservoir in the late 1950s (Glamazda, 1971a), and the East Asian *Thermocyclops taihokuensis* (sin. *T. asiaticus* (Kiefer, 1932), which appeared in 2012 (Vekhov et al., 2014) The latter species became established in the downstream Volga in the 2010s (Nechaev, 2016; Lazareva et al., 2018). It likely spread up the Tsimlyansk Reservoir from the Volga River along the Volga–Don canal. The copepod *Acanthocyclops americanus* was recorded in the reservoir for the first time in 2018. The species is common in waterbodies of the south of European Russia (Monchenko, 1974), and its spread in the reservoir is the result of its range expansion. *A. americanus* was previously found in the Don River delta (Svistunova et al., 2014); it is also widespread in the Volga and Kama reservoirs (Lazareva et al., 2018).

Distribution of zooplankton abundance. Cyclopoida and Rotifera formed the largest numbers in the Tsimlyansk Reservoir (40 and 32% of the total number of zooplankton, respectively) (32%). Cladocerans are comparatively numerous (22%) only in the Upper reach of the reservoir; Calanoid Copepoda, in the Potemkin (30%) and Near-Dam (58%) reaches. The maximal abundance (400000 ind./m^3) was observed in the Upper reach of the reservoir, and the lowest was found in Near-Dam reach (121000 ind./m^3; Table 2). Zooplankton was especially abundant in the mouth area of the Donskaya Tsaritsa River (919000 ind./m^3). The number of larvae (veligers) of *Dreissena* mollusks in most of the reservoir area did not exceed 10000 ind./m^3 (Table 2). Up to 47000 ind./m^3 were recorded only in the Potemkin reach near the right bank of the reservoir. Their contribution to the biomass of zooplankton was very small (on average, about 1%).

The bulk of the reservoir zooplankton biomass was formed by crustaceans: Calanoida (40%), Cyclopoida (29%), and Cladocera (20%). The community biomass in different parts of the reservoir varied by more than two times (1.0–2.4 g/m^3). The maximal values were recorded in the Upper (up to 4 g/m^3) and Potemkin (up to 6 g/m^3) reaches; the minimal (less than 1.5 g/m^3) was found in the Chir reach and most sampling sites near the hydroelectric power plant dam (Fig. 2). In 2018, the average level of zooplankton biomass in the reservoir (1.8 ± 0.4 g/m^3) was comparable to that observed in the eutrophic reservoirs of the upstream Volga and Kama rivers (1–2 g/m^3; Lazareva et al., 2018; Lazareva and Sokolova, 2015). However, it was significantly higher as compared to the mesotrophic reservoirs of the downstream Volga (0.2–1.2 g/m^3), which are also located in the arid zone (Malinina et al., 2016; Lazareva et al., 2018). For comparison, in the eutrophic Kremenchug Reservoir on the Dnieper River in the 2000s, the zooplankton biomass (0.1–0.9 g/m^3) was estimated as very low (Kruzhilina and Didenko, 2007).

Long-term dynamics. The zooplankton dynamics in the Tsimlyansk Reservoir was analyzed based on the summer (July–August) biomass close to the summer–autumn maximum of community development (Glamazda, 1971a). Significant variations in the amount of zooplankton were noted over the analyzed period (1952–2018). The peak biomass (3.8–4.6 g/m^3) was recorded in the first three years after the reservoir's creation (Fig. 3). At the end of the 1950s, the biomass decreased to values of less than 1.5 g/m^3; in some years in the second half of summer, values of 0.5–0.8 g/m^3 or even lower were noted (0.3 g/m^3 in 2001 and 0.1 g/m^3 in 2008). Conversely, at present (2015–2018), an increase in the summer biomass of zooplankton is noted; its average values (2.1 ± 0.5 g/m^3) are significantly higher (by 2.6 times) than those noted in 1972–2013 (0.8 ± 0.1 g/m^3) and are close to the level of the late 1950s. Presumably, this is due to the high proportion of the large (body length 1.1–1.6 mm) crustaceans *Heterocope caspia, Calanipeda aquaedulcis*, and *Acanthocyclops americanus* in the modern plankton of the reservoir.

CONCLUSIONS

It was found that Copepoda formed the bulk (60%) of the summer zooplankton in the Tsimlyansk Reservoir in 2018; they also dominate (70%) in biomass. The most abundant are the Ponto-Caspian *Heterocope caspia* and the invasive species *Calanipeda aquaedulcis, Thermocyclops taihokuensis,* and *Acanthocyclops americanus*. The zooplankton abundance decreases by half in the direction from the Upper reach of the reservoir (2.4 ± 0.8 g/m^3) to the dam of the Tsimlyansk hydroelectric power plant (1.2 ± 0.6 g/m^3). The analysis of published data for the period of 1952–2018 shows that the community biomass has more than doubled (up to 2.1 ± 0.5 g/m^3) in the last four years (2015–2018) as compared to the preceding 40-year period 2013 (0.8 ± 0.1 g/m^3). The current amount of zooplankton in the Tsimlyansk Reservoir is significantly higher than in other reservoirs in the arid zone.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflicts of interest.

Statement on the welfare of humans or animals. This article does not contain any studies involving animals performed by any of the authors.

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