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Main characteristics of the Lake Pleshcheyevo population of *Dreissena polymorpha* (Bivalvia, Dreissenidae)

Ekaterina G. Pryanichnikova*, Alexander I. Tsvetkov

Papanin Institute for Biology of Inland Waters, Russian Academy of Sciences, Borok 109, Nekouz District, Yaroslavl Region, 152742 Russia

**pryanichnikova_e@mail.ru*

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The main characteristics of the population of *Dreissena polymorpha* (Pallas, 1771) in Lake Pleshcheyevo in 2014–2016 are discussed, and two different sampling methods for *D. polymorpha* are compared. The lack of mass reproduction of *D. polymorpha* in 2015 is possibly related, among other causes, to climate change and alterations in the temperature regime of the lake. *Dreissena* is shown to be one of the main benthic suspension feeders in Lake Pleshcheyevo.

Keywords: zebra mussels, abundance, yearlings, suspension feeders, sublittoral.

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Introduction

Adult freshwater mussels *Dreissena polymorpha* (Pallas, 1771) were first recorded in Lake Pleshcheyevo (N 56°43′–56°48′, E 38°43′–38°50′) in 1984, and veligers – since 1987 (Stolbunova, 2006; Zhgareva, 1992); since then *Dreissena polymorpha* has been repeatedly studied in this lake (Bakanov, 1983; Butorin and Sklyarenko, 1989; Shcherbina, 2008; etc.). Colonies of *Dreissena* change the habitats of hydrobionts by forming a convenient substrate, capable of accommodating many macro-invertebrates, affect current rates and illumination, and improve oxygenation. Also *Dreissena* druses provide good substrates for yearling settlement.

Dreissena precipitates much of the suspension from the water, which is concentrated as agglutinants and feces and serves as food for detritivores. Direct trophic connections depend on the accumulation of feces and agglutinants of populations of *Dreissena* (Protasov, 2008). In addition, dead and living individuals of *Dreissena* can served as food for bottom feeding fish. For instance, in the Ucha Reservoir, after invasion of *D. polymorpha*, the growth rate and fecundity of European roach *Rutilus rutilus* (Cyprinidae) increased, and became similar to those of *Rutilus caspicus* (Vinberg, 1980). In Lake Pleshcheyevo, after one generation following the invasion of *D. polymorpha,* a rapidly growing *Dreissena*-feeding form of the European roach had developed (Kasyanov and Izyumov, 1995).

The direct influence of *Dreissena* on bacterial plankton is by filtering out forms suitable for feeding, and the indirect influence can be either positive or negative for the development of bacteria (Kurbatova and Lapteva, 2008). *Dreissena* negatively influences phytoplankton by reducing the amount of algae with size smaller than 40 μm, whereas a reduction in the proportion of zooplankton feeders occurs when the competition for all kinds of food resources intensifies. Changes in the zooplankton structure, in particular, a 1.5–2-fold decrease in the abundance of rotifers, is a result of competition with *Dreissena* for seston resources (Lazareva and Zhdanova, 2008). *D. polymorpha* also affects the circulation of biogenic systems in basins. In the ecosystem of Lake Mikolaiskoe the content of phosphorus in *Dreissena* (0.47 t) is comparable with the content of this element in macrophytes (0.70 t) and fish (0.80 t). Feces of freshwater mussels contain 0.1% phosphorus and 3.5% nitrogen, calculated on a dried basis, which is 0.06–0.1 and 0.14–0.33 the respective concentrations of these elements in the seston consumed by the mussels.

Biogenic elements accumulated by *Dreissena polymorpha* are taken out of circulation for 4–6 years, and if the period of shell decomposition is taken into account – almost 20 years (Stanczykowska, 1984).

Judging from the above, *D. polymorpha* is an important component of basin ecosystems. Recording the dynamics of the main characteristics of the populations, and studying the role of *D. polymorpha* as a major suspension feeder, may be important for the analysis of the ecosystem function of Lake Pleshcheyevo.

Materials and methods

The mussels were selected from samples of macrobenthos collected during the 2014–2015 growing season, and also in autumn 2016. The following classification of the basin zones was accepted (Butorin and Sklyarenko, 1989): the lower boundary of the littoral was drawn at the 3 m depth,

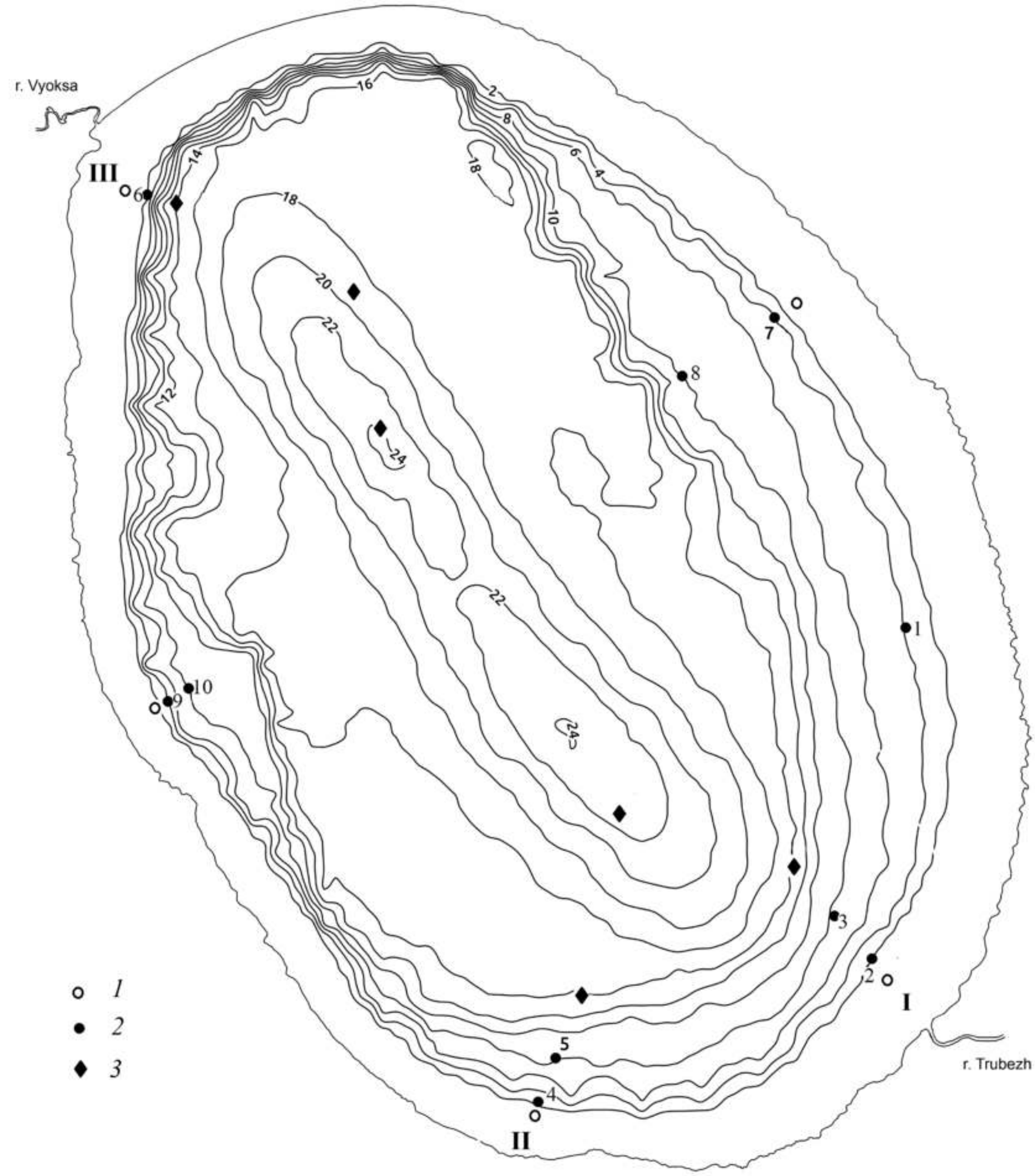

Fig. 1. Location of main sampling stations in Lake Pleshcheyevo. Sampling sites: 1 – littoral, 2 – sublittoral, 3 – profundal. Numbers (1–10) show main collecting stations of *D. polymorpha* in the sublittoral. I – area section directed away from the mouth of the Trubezh River; II – area section directed away from the "Boat of Peter the Great" Museum; III – area section directed away from the source of the Veksa River.

Station no.	2014			2015			2016
	Spring	Summer	Autumn	Spring	Summer	Autumn	Autumn
1	5.3 / 246.0	10.3 / 3150.0	4.3 / 582.5	3.2 / 1360.0	3.7 / 808.5	1.0 / 173.4	0.5 / 197.0
2	0.2 / 9.0	0 / 0	0 / 0	6.6 / 1500.0	6.9 / 5464.8	0 / 0	0.1 / 3.5
3	3.2 / 380	0.2 / 10.0	5.4 / 2394.5	0.3 / 1062.5	3.0 / 2015.0	0.3 / 87.9	0.2 / 0.5
4	10.8 / 2977.0	23.7 / 21145.0	0.7 / 136.0	11.1 / 3640.6	10.7 / 4322.5	14.0 / 5301.9	–
5	0.4 / 465.5	1.6 / 1500.0	0.8 / 500.5	3.5 / 1741.0	3.5 / 3365.2	2.4 / 2351.0	–
6	0.1 / 0.1	3.2 / 4930.0	0.4 / 85.0	0.3 / 4.0	0.2 / 4.8	3.8 / 1370.9	1.5 / 27.5
7	–	–	–	0.1 / 331.5	0.2 / 120.1	0 / 0	–
8	–	–	–	2.7 / 2265.5	2.7 / 4856.6	2.4 / 2014.2	–
9	–	–	–	2.5 / 1200.0	2.8 / 2582.0	0 / 0	–
10	–	–	–	2.1 / 313.5	2.8 / 3031.0	1.5 / 2126.7	–

Table 1. Abundance and biomass dynamics of *D. polymorpha i*n the sublittoral of Lake Pleshcheyevo.
Note: above the line (N, thous. ind./m^2), below the line biomass (B, g/m^2), "0" – live *Dreissena* were absent, only the thanatocoenosis (coquinae) was found, "–" no data.

and the base of the sublittoral is drawn at 15 m, at the boundary of the change in the slope angle. Areas below that mark were treated as the profundal zone. The samples of macrobenthos were collected using a modified DAK-100 bottom sampler (catchment area 0.01 m^2), in two replicates at each station. In 2014 and 2015, benthos was examined at Stations 16 and 22, respectively, including in the sublittoral and Stations 6 and 10, respectively (Fig. 1, Table. 1). In autumn 2016, it was examined at 14 stations, four of which were in the sublittoral. The depth of the macrobenthos sampling was 1.5 to 23 m.

We selected live specimens of *D. polymorpha* from substrate washed in a mesh bag (cells 220 µm in size), identified the raw mass and measured the length of the shell of each mussel with a precision up to 0.5 mm. The density (N, thousands of individuals/m^2), biomass (B, g/m^2) and frequency (P, %) of *Dreissena* in the lake were calculated. In addition, the mean length of an individual of zebra mussels (mm) and the proportion of yearlings (up to 5 mm inclusive, %).

In the lake, *D. polymorpha* occurs in highly aggregated colonies, as follows from visual observations and published data (Bakanov, 1983). Therefore, for the refinement of the abundance of *Dreissena* we collected additional samples of mussels in some areas by underwater filming with a frame 0.5×0.5 m.

To evaluate reproduction, we studied veligers of *Dreissena* in zooplankton samples (Zhdanova, 2018).

To study the effect of climate change on the temperature regimes of the lake, HOBO Pendant (UA-002-64) and HOBO Pro v2 (U22-001) temperature data loggers were installed from May to October at various depths in the deep part of the lake. The loggers were installed at the following depths: surface, 1.5, 5, 8, 13, 15, 17 and 21 m.

To estimate the role of mussels in filtering the water in basins we used established correlations of the rate of water filtration by *Dreissena* with their size and the concentration of suspension in water (Alimov, 1981; Mikheev, 1967; Pryanichnikova, 2012; Pryanichnikova and Shcherbina, 2005). The suspension settled by *Dreissena polymorpha* was also approximately calculated using data from Lvova et al. (2005).

Results

In the littoral of Lake Pleshcheyevo, *D. polymorpha* was only found in 2014 at one station in the soutwestern part of the lake, where the population of mussels entirely consisted of young mussels and yearlings. The total abundance of *Dreissena polymorpha* for the entire season was on average 0.3±0.2 thous. ind./m^2, biomass – 5.3±4.2 g/m^2 and they constituted 20–30% of the littoral macrobenthos. Visually, thanks to the very clear water, it was noted that in this zone of the lake, *Dreissena* druses are arranged in patches, at a considerable distance from one another, so a quantitative estimation of distribution using available sampling methods (bottom dredge) is difficult. It is possible that this was the reason why in 2015 and even in the autumn of 2016 *D. polymorpha* was not recorded even at an expanded network of stations. *Dreissena* was not recorded in the macrobenthos of the profundal zone throughout the entire study period.

In 2014, *D. polymorpha* was recorded at 6, and in 2015 at 10 stations in the sublittoral of the lake (Fig. 1, Table 1). In autumn 2016, *Dreissena* was recorded at four stations in the sublittoral. A high density of *Dreissena* was recorded at stations with a considerable quantity of empty shells in the substrate. Accumulation of coquinae supports the long-term and consistent presence of the *Dreissena* populations in the studied zones of the lake. All this is characteristic of the southern and southeastern zones of the lake (stations 1–5). In 2014–2015, the mean density of *Dreissena* at these locations was 4.6±1.0 thous. ind./m^2. In autumn 2016, the quantity of *Dreissena* in the southeastern zone of the lake was 0.2±0.1 thous. ind./m^2.

During the study period, despite the expansion of the network of stations in 2015, the recorded abundance of *D. polymorpha* in the benthos of the lake remained almost unchanged and was on average 41±3% (Table 2).

In 2014, apart from sampling *D. polymorpha* populations using a bottom sampler, we determined the density of mussel populations at some stations using a frame. Comparison of the results showed that mussel abundance estimated using a frame at two stations was considerably lower than that determined by means of the bottom sampler (Table 3).

In 2015, the mean length of a *D. polymorpha* individual at some zones of the sublittoral was relatively high (up to 19–21 mm) and was on average 13.1±1.2 mm. This is because the sampling contained almost no yearlings (up to 5 mm in size), which dominated *Dreissena* colonies at these stations in 2014, when the average length was 10.2±2.5 mm.

Both in spring and summer 2014–2015, *D. polymorpha* was present at most (80–100%) studied stations in the sublittoral (Table 1). In summer 2015, at some stations the abundance of *Dreissena* was lower than in 2014, yearlings were almost completely absent and the proportion of mussels <5 mm was even lower than in spring (Table 1, 2). In addition, a consistent decrease in the average length of a mussel due to the appearance of young specimens, was not recorded (Table 2).

In autumns of 2014 and 2015, *D. polymorpha*

Parameter	Spring 2014	Summer 2014	Autumn 2014
N, ind./m^2	2829±1525	7770±3537	2017±823
B, g/m^2	668.3±407.5	6147.0±3134.0	618.2±335.7
Mussel length, mm	8.6±2.4	11.3±3.2	10.8±1.9
Proportion of yearlings (<5 mm), %	57.8±14.9	30.9±11.8	50.4±16.2
P in the lake benthos, %	47	31	38
	Spring 2015	Summer 2015	Autumn 2015
N, ind./m^2	3490±1085	3630±1040	2525±1411
B, g/m^2	1341.8±356.4	2657.0±642.6	1342.6±567.7
Mussel length, mm	11.9±1.2	13.6±1.2	13.7±1.1
Proportion of yearlings (<5 mm), %	28.4±10.5	17.8±9.9	15.4±6.4
P in the lake benthos, %	48	45	36
		Autumn 2016	
N, ind./m^2		525±319	
B, g/m^2		57.2±47.0	
P in the lake benthos, %		40	

Table 2. Main characteristics of *D. polymorpha* populations in the sublittoral of Lake Pleshcheyevo.

Station no.	DAK-100	Frame
1	10.3	2.4
2	0.2	0.2
4	23.7	2.6
5	1.6	1.8
6	3.2	2.7

Table 3. Density (N, thous. ind./m^2) of *D. polymorpha* when different methods of sampling are used.

was not recorded at all stations of the sublittoral (70–83%) (Table 1). The average abundance of *Dreissena* was not different (Table 2), but in autumn 2015, an increase in the biomass was recorded. The proportion of yearlings of *D. polymorpha* in the autumn 2015 relative to the equivalent period of the previous year was low and comparable with the summer figures (Table 2). In autumn 2016, the density and biomass of *Dreissena polymorpha* were very low and were 0.5±0.3 thous. ind./m^2 and 57.2±47.0 g/m^2 respectively.

Based on the analysis of the long-term dynamics, minimal values for the density of veligers were noted in 2015 (Zhdanova, 2018).

Using the data obtained on the mean biomass of *D. polymorpha* in 1 m^2 in Lake Pleshcheyevo, and also the areas of the sublittoral and data on the biomass of phytoplankton it was calculated that *D. polymorpha* can filter daily up to 1/30 of the total of the volume of water in the lake. Hence, in a season of active filtration (approximately 137 days), mussels can filter the entire volume of water in the lake up to 4–5 times. It has also been calculated that in a season of active filtration, *D. polymorpha* in Lake Pleshcheyevo can settle up to several thousand tons of suspended material as feces and agglutinants.

Discussion

A high degree of aggregation of the *D. polymorpha* colonies in the lake was confirmed both by visual observations during sampling the lake by divers using a frame in 2014, and published data (Bakanov, 1983). Differences between the densities of *Dreissena polymorpha* received by various methods, were recorded only in some places (Table 3): at station 1, where at the time of sampling there were many yearlings (57%), and also at station 4, where it was visually recorded that *Dreissena* forms heterogeneous, highly aggregated colonies on dead shells and compact substrate. Such differences in the density of *Dreissena* are received in places where it forms colonies of “stains” and “brushes” (Protasov, 2008). In general, in places where *D. polymorpha* forms dense colonies, differences between the numbers of mussels obtained by two different types of sampling are minimal (Table 3). Therefore, the use of a bottom sampler to estimate the abundance of *Dreissena polymorpha* in places of its mass occurrence is acceptable.

Abundant permanent colonies of *D. polymorpha* have been recorded at depths of 4–9 m, in the sublittoral of Lake Pleshcheyevo (Butorin and Sklyarenko, 1989). On average, in 2014, the abundance of *D. polymorpha* was estimated as 3.9±1.8 thous. ind./m^2, which corresponds to our data from 2015 (3.2±0.4 thous. ind./m^2) and those from the beginning of the 1990s, but is less than in 1996 (Shcherbina, 2008). A similar situation is recorded for long-term dynamics of the *Dreissena* biomass. In 2014, the mean biomass of *D. polymorpha* constituted 2218.8±1070.0 g/m^2, in 2015 – 1780.5±536.8 g/m^2, which is half of that recorded for 1996 (Shcherbina, 2008). The density of *Dreissena polymorpha* in autumn 2016 was considerably less than the density in the previous years (0.5±0.3 thous. ind./m^2). Apparently, this is a consequence of disruptions in the reproduction of *Dreissena* in 2015.

In 1991 and 1996, the mean length of one individual of *D. polymorpha* in Lake Pleshcheyevo decreased from spring–summer to autumn, most likely due to the replenish of the population with young organisms (Shcherbina, 2008). In our study, a similar situation was recorded for 2014, whereas in 2015, there was no difference between the summer and autumn data (Table 2). This is also indirect evidence that in 2015 the population of *Dreissena polymorpha* was not supplemented by yearlings.

Thus, in 2015 no mass reproduction of *Dreissena polymorpha* was recorded in Lake Pleshcheyevo. This is supported by several facts: low proportion of yearlings smaller than 5 mm in size, mean length in the population, isolated presence of veligers in zooplankton and the absence of the mean summer quantity of *Dreissena*.

One of the reasons for the events discussed above is climate change. According to the Hydrometeorological Center of Russia (Obzory..., 2018), the summer of 2015 was the coolest in the last five years. The weather in mid-June–beginning of July was particularly cold. At that time, minimal air temperatures were very low (up to +4 °C at night), although day temperature occasionally reached +23–25 °C. July was also colder than the norm by 2–4 °C. Other unusual characteristics of that summer included few days with warm or hot weather. During the growing season, there were 30 days with a temperature above +25 °C and no days with a temperature over +30 °C. For comparison, many more such days were recorded in 2014 (108 and 7, respectively) and in 2013 (75 and 4, respectively).

The reproduction season of *Dreissena polymorpha*, manifested by the appearance of the first planktonic larvae, should begin at a water temperature of 12–15 °C, and the mass spawning at 18–20 °C (Lvova and Makarova, 1994). At a temperature below 10 °C *Dreissena* mussels do not grow or develop (Alimov, 1974; Lvova, 1977). The total of effective temperatures (above 10 °C, which is required for gonadal development from the first stage to the beginning of spawning) in all populations of *Dreissena polymorpha* is close to 2500 degrees (Lvova and Makarova, 1994). It is possible that in 2015, the cumulative effect of temperatures was not sufficient for the gonads of *Dreissena polymorpha* to be completely formed. Low temperatures in the bottom waters of the sublittoral in May–June could have a negative effect on the reproduction of *Dreissena polymorpha*. A stable temperature of 10 °C and above that was recorded at a depth of 5 m by the end of May, and at a depth of 8 m in the first ten days of June. At the beginning of July, especially in the night, the recorded temperature at 5 m to 8 m depth showed a decrease from 19–20 °C to 14–15 °C respectively. A week later, the temperature at a depth of 8 m, was almost the same as at 5 m. This could also disrupt the reproduction of *Dreissena*.

The role of *D. polymorpha* as a suspension feeder in the studied basin is considerable. In Lake Pleshcheyevo, *Dreissena* constitutes on average more than 90% of the total abundance of macrobenthic phytodetritivore suspension feeders. These freshwater mussels in the period of their maximum profusion (May to October) are capable of filtering vast amounts of water. Judging from the data obtained, *Dreissena polymorpha* can filter the total amount of water in the lake up to 4–5 times during the period of active filtration, precipitating up to several thousand tons of suspended particles. This species can concentrate considerable amounts of heavy metals dissolved in the water or adsorbed by seston, and affect biogeochemical cycles of these elements in the lake ecosystem, transferring them from the plankton to the benthos, and therefore changing their total balance (Pavlov et al., 2008).

In other basins, e.g., in the Ucha Reservoir, *D. polymorpha* during the growing season filters an amount of water equal to twice the total volume of the reservoir (Lvova-Kachanova, 1971; Lvova-Kachanova and Izvekova, 1973). The development of a wide band of filtering mollusks in the Ucha Reservoir would have increased the rate of suspension precipitation more than threefold in the zone inhabited by *Dreissena*, which would have resulted in clearing the sediment load and improving the drinking quality during the time of its being in the reservoir (Lvova, 1977). In Lake Lukomlskoe, before the invasion of *D. polymorpha,* benthic suspension feeders filtered an amount of water equal to the volume of the lake in approximately 15 years, whereas zooplankton suspension feeders did the same in five days. After the invasion and mass development of *D. polymorpha*, the filtration ability of benthic suspension feeders increased more than 320 times (Burlakova, 1998). For various lakes of the Mazurskaya Group, the time necessary for the population of *Dreissena* to filter an amount of water equal to the volume of the epilimnion was estimated from 2 days to 5–6 years at a mean filtration rate 35 ml/h per gram of live weight of the mollusk (Stanczykowska, 1968). Mikheev (1967) showed that in Pyalovsk Reservoir *Dreissena* daily filter 1/20 of its volume.

Dreissena facilitates de-eutrophication of the pelagial of water basins, because it effectively precipitates and accumulates seston at the bottom. It redistributes the energy and matter flow from plankton to benthos, and in shallow basins enhances coupling between pelagic and benthic zones (MacIsaac et al., 1999). This process is referred to as “benthification”. In the Narochan lakes, a new trend in the succession has been recorded since 1995 (Ostapenya, 2005, 2007).

Thus*, Dreissena polymorpha* in Lake Pleshcheyevo makes a considerable contribution to the process of lake purification, whereas the recorded decrease in abundance of *Dreissena* due to the disrupted processes of reproduction can affect both isolated components and the entire lake ecosystem.

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References

Alimov, A.F., 1974. Zakonomernosti rosta presnovodnykh dvustvorchatykh mollyuskov [Patterns of the growth of freshwater bivalve molluscs]. *Zhurnal obshchey biologii [Biology Bulletin Reviews]* **35** (4), 576–589. (In Russian).

Alimov, A.F., 1981. Funktsional’naya ekologiya presnovodnykh dvustvorchatykh mollyuskov [Functional Ecology of Freshwater Bivalves]. Nauka, Leningrad, USSR, 248 p. (In Russian).

Bakanov, A.I., 1983. Bentos oz. Pleshcheyevo [Benthos of the Lake Pleshcheyevo]. In: Monakov, A.V. (ed.), *Funktsionirovaniye ozernykh ekosistem [Functioning of lake ecosystems].* Institute for Biology of Inland Waters AS USSR, Rybinsk, 70–83. (In Russian).

Burlakova, L.E., 1998. Ekologiya *Dreissena polymorpha* Pallas i yeye rol' v strukture i funktsionirovanii vodnykh ekosistem [Ecology of *Dreissena polymorpha* Pallas and its role in the structure and functioning of aquatic ecosystems]. *Avtoreferat dissertatsii na soiskaniye stepeni kandidata biologicheskikh nauk [Candidate of sciences in biology dissertation abstract].* Minsk, Belarus, 22 p. (In Russian).

Butorin, N.V., Sklyarenko, V.L. (ed.), 1989. Ekosistema ozera Pleshcheyevo [Ecosystem of Lake Pleshcheyevo]. Nauka, Leningrad, USSR, 264 p. (In Russian).

Kasyanov, A.N., Izyumov, Yu.G., 1995. K izucheniyu rosta i morfologii plotvy *Rutilus rutilus* oz. Pleshcheyevo v svyazi s vseleniyem dreysseny [To study the growth and morphology of roach *Rutilus rutilus* oz. Pleshcheyevo in connection with the introduction of Dreissena]. *Voprosy ikhtiologii [Journal of Ichtyology]* **35** (4), 546–548. (In Russian).

Kurbatova, S.A., Lapteva, N.A., 2008. Vzaimootnosheniya dreisseny s planktonnymi soobshchestvami v eksperimental'nykh usloviyakh [The relationship between Dreissena and plankton communities under experimental conditions.]. *Materialy I-oy Mezhdunarodnoy konferentsii «Dreissenidy: evolyutsiya, sistematika, ekologiya» [Materials of the 1st International Conference "Dreissenids: Evolution, Systematics, Ecology"].* Borok, Russia, 83–86. (In Russian).

Lazareva, V.I., Zhdanova, S.M., 2008. Veligery dreissen v planktone Rybinskogo vodokhranilishcha: raspredeleniye i znacheniye v soobshchestve [Veliger of zebra and quagga mussels in the plankton of the Rybinsk Reservoir: distribution and significance in the community]. *Materialy I-oy Mezhdunarodnoy konferentsii «Dreissenidy: evolyutsiya, sistematika, ekologiya» [Materials of the 1st International Conference "Dreissenids: Evolution, Systematics, Ecology"].* Borok, Russia, 86–90. (In Russian).

Lvova, A.A., 1977. Ekologiya *Dreissena polymorpha* (Pallas) Uchinskogo vodokhranilishcha [Ecology of *Dreissena polymorpha* (Pallas) of the Ucha Reservoir]. *Avtoreferat dissertatsii na soiskaniye stepeni kandidata biologicheskikh nauk [Candidate of sciences in biology dissertation abstract].* Moscow, Russia, 22 p. (In Russian).

Lvova, A.A., Izvekova, E.I., Zinchenko, T.D., 2005. Dreissena i lichinki khironomid v perifitone Uchinskogo vodokhranilishcha i vodoprovodnogo kanala [Zebra mussel and larvae of chironomids in the periphyton of the Ucha Reservoir and the water channel]. *Vestnik Tyumenskogo gosudarstvennogo Universiteta [Tyumen State University Herald]* **5**, 135–140. (In Russian).

Lvova, A.A., Makarova, G.E., 1994. Gametogenez, reproduktivnyy tsikl [Gametogenesis, reproductive cycle]. In: Starobogatov, Ya.I. (ed.), *Dreissena: Sistematika, ekologiya, prakticheskoye znacheniye [Dreissena: Systematics, ecology, practical meaning].* Nauka, Moscow, Russia, 149−155. (In Russian).

Lvova-Kachanova, A.A., 1971. O roli dreisseny (*Dreissena polymorpha* (Pall.)) v protsessakh samoochishcheniya vody Uchinskogo vodokhranilishcha [About the role of Dreissena (*Dreissena polymorpha* (Pall.)) in the processes of self-purification of the water of the Ucha Reservoir]. In: Bykov, V.D. et al. (eds.), *Kompleksnyye issledovaniya vodokhranilishch [Integrated research of reservoirs]. V. 1.* Moscow State University, Moscow, USSR, 196–203. (In Russian).

Lvova-Kachanova, A.A., Izvekova, E.I., 1973. Osazhdeniye dreissenoy vzvesi i ispol'zovaniye yeye lichinkami khironomid [Precipitation of the Dreissena suspended matter and its use by chironomid larvae]. In: Bykov, V.D. et al. (eds.), *Kompleksnyye issledovaniya vodokhranilishch [Integrated research of reservoirs]. V. 2.* Moscow State University, Moscow, USSR, 130–135. (In Russian).

MacIsaac, H.J., Johannsson, O.E., Ye, J., Sprules, W.G., Leach, J.H., McCorquodale, J.A., Grigorovich, I.A., 1999. Filtering impacts of an introduced Bivalve (*Dreissena polymorpha*) in a shallow lake: application of a hydrodynamic model. *Ecosystems* **2**, 338–350.

Mikheyev, V.P., 1967. Fil'tratsionnoye pitaniye dreisseny [Filtration nutrition of the zebra mussel]. In: *Voprosy prudovogo rybovodstva [Problems in pond fish-breeding]. Proceedings of All-Russian Scientific Research Institute of Freshwater Fisheries. T. 15*. Moscow, USSR, 117–129. (In Russian).

Obzory pogodno-klimaticheskih osobennostej, nablyudavshihsya v Severnom polusharii v 2001–2018 gg. [The review of weather and climate features of Northern hemisphere in 2001–2018]. Hydrometcenter of Russia. Web page. https://meteoinfo.ru/climat-tabl3 (accessed: 22.07.2018). (In Russian).

Ostapenya, A.P., 2005. Narochanskiye lakes from the Winberg's time up to now. *Book of abstracts of International Scientific Conference «Aquatic Ecology at the Dawn of XXI Century».* St. Petersburg, Russia, 69.

Ostapenya, A.P., 2007. Deevtrofirovaniye ili bentifikatsiya? [De-eutrophication or bentification?]. *Materialy III Mezhdunarodnoy nauchnoy konferentsii "Ozernyye ekosistemy: biologicheskiye protsessy, antropogennaya transformatsiya, kachestvo vody" [Materials of the 3rd International Scientific Conference "Lake Ecosystems: Biological Processes, anthropogenic transformation, water quality"].* Naroch', Belarus, 31–32. (In Russian).

Pavlov, D.F., Shcherbina, G.Kh., Pryanichnikova, E.G., 2008. Nakopleniye nekotorykh tyazhelykh metallov *Dreissena polymorpha* i *D. bugensis* Rybinskogo vodokhranilishcha i vopros ob ikh roli v samoochishchenii vodoyemov [Accumulation of some heavy metals of *Dreissena polymorpha* and *D. bugensis* of the Rybinsk Reservoir and the question of their role in the self-purification of reservoirs]. *Materialy I-oy Mezhdunarodnoy konferentsii «Dreissenidy: evolyutsiya, sistematika, ekologiya» [Materials of the 1st International Conference "Dreissenids: Evolution, Systematics, Ecology"]*. Borok, Russia, 105–110. (In Russian).

Protasov, A.A., 2008. Iz opyta issledovaniy populyatsiy i soobshchestv dreisseny [From the experience of studies of populations and communities of Dreissena]. *Materialy I-oy Mezhdunarodnoy konferentsii «Dreissenidy: evolyutsiya, sistematika, ekologiya» [Materials of the 1st International Conference "Dreissenids: Evolution, Systematics, Ecology"]*. Borok, Russia, 9–22. (In Russian).

Pryanichnikova, E.G., 2012. Strukturno-funktsional'nyye kharakteristiki dreissenid Rybinskogo vodokhranilishcha [Structural and functional characteristics of the Dreissenids of the Rybinsk Reservoir]. *Dissertatsiya na soiskaniye kandidata biologicheskikh nauk [Candidate of sciences in biology dissertation].* Borok, Russia, 179 p. (In Russian).

Pryanichnikova, E.G., Shcherbina, G.Kh., 2005. Sravneniye skorostey fil'tratsii mollyuskov *Dreissena polymorpha* (Pall.) i *D. bugensis* (Andr.) [Comparison of filtration rates of mollusks *Dreissena polymorpha* (Pall.) and *D. bugensis* (Andr.)]. In: Riv'yer, I.K. et al. (eds.), *Biologicheskiye resursy presnykh vod: bespozvonochnyye [Biological resources of fresh water: invertebrates].* Rybinsk Publishing House, Rybinsk, Russia, 278–290. (In Russian).

Shcherbina, G.Kh., 2008. Struktura biotsenoza *Dreissena polymorpha* (Pallas) i rol' mollyuska v pitanii plotvy *Rutilus rutilus* (Linnaeus) [Structure of *Dreissena polymorpha* (Pallas) Biocenosis and Role of Mollusk in Roach (*Rutilus rutilus* (Linnaeus)) feeding in Pleshcheyevo Lake]. *Biologiya vnutrennikh vod [Inland Water Biology]* **4**, 72–80. (In Russian).

Stanczykowska, A., 1968. The filtration capacity of populations of *Dreissena polymorpha* Pall. in different lakes as a factor affecting circulation of matter in the lake. *Ekologia Polska* **14**, 265–270.

Stanczykowska, A., 1984. Role of bivalves in the phosphorus and nitrogen budget in lakes. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen* **22** (2), 982–985.

Stolbunova, V.N., 2006. Zooplankton ozera Pleshcheyevo [Zooplankton of Lake Pleshcheyevo]. Nauka, Moscow, Russia, 152 p. (In Russian).

Vinberg, G.G. (ed.), 1980. Bentos Uchinskogo vodokhranilishcha [Benthos of the Ucha Reservoir]. Nauka, Moscow, USSR, 251 p. (In Russian).

Zhgareva, N.N., 1992. Sostav i raspredeleniye fauny zarosley ozera Pleshcheyevo [Composition and distribution of phytophilic fauna of Lake Pleshcheyevo]. In: Semernoy, V.P. et al. (eds.), *Faktory i protsessy evtrofikatsii oz. Pleshcheyevo [Factors and processes of eutrophication of the lake Pleshcheyevo]*. Yaroslavl State University, Yaroslavl, Russia, 95–105. (In Russian).

Zhdanova, S.M., 2018. Veliger larvae of Dreissena (Bivalvia, Dreissenidae) in the zooplankton of Lake Pleshcheyevo (Yaroslavl Oblast). *Ecosystem Transformation* **1** (2), 19-29. https://doi.org/10.23859/estr-180723b.