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Invasive species *Dreissena polymorpha* in the Northern Dvina River estuary

Natalia Mikhailovna Makhnovich[1*], Inga Mikhailovna Zashikhina[2], Dmitry Sergeevich Moseev[1]

[1]*Petr Petrovich Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovsky Prosp. 36, 117997 Moscow, Russia*
[2]*Department of Philosophy and Sociology, Northern (Arctic) Federal University named after M.V. Lomonosov, Smolny Buyan, 1, 163002 Arkhangelsk, Russia*

Abstract

The features of distribution of *Dreissena polymorpha* (Pallas, 1771) in the northeastern part of the range and in the estuary part of the Northern Dvina River are described. Based on the earlier studies of different authors, it was suggested that the population of this mollusk is independent and self-replicating. To prove that, our study provides some population characteristics of *D. polymorpha* settlements. Mollusk samples were taken in the summer in 2018-2021. The research was conducted in the upper delta and in the lower part of the estuary section in order to evaluate the agglomeration. In total, 1538 individuals were selected from three sites of collection. A set of morphometric measurements was performed. Intra-population diversity was studied, weight and length of *D. polymorpha* individuals were evaluated. Statistically significant differences were found between the individuals living in the upstream estuary and those living in the Northern Dvina River delta, which is explained by the differences caused by of abiotic factors such as current velocities, availability of suitable substrates, amount of nutrients. There were no significant differences in the presented parameters between the second and third sampling site, due to the relative proximity of the sampling stations. The importance of further study of the biology and ecology of this mollusk in the North Dvina River basin is shown.

Key words: zoobenthos, *Dreissena polymorpha*, range, test object, biomonitoring

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Introduction

Estuaries are special ecosystems in which a variety of abiotic factors act. In these ecosystems, marine and fresh waters are mixed. Many studies are devoted to the processes taking place in such zones – hydrological, hydrochemical, geomorphological, compassionate and hydrobiological (Artemyev et al. 2017, Alimov and Bogutskaia 2004, Miskevich and Bogolitsyn 2002). A similar zone is the estuary of

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*Corresponding author: N. M. Makhnovich <nmakhnovich@yandex.ru>
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the Northern Dvina River, which forms the correct delta, the processes in which were highlighted in numerous works.

Hydrobiological research has been conducted by various organizations for a long time (Kuchina 1964, Leshchev et al. 2017, Neverova and Makhnovich 2010). To date, the main components of biocenosis, its structure, species composition of organisms, quantitative characteristics - biomass and number of different groups of animals and plants have been determined (Miskevich and Bogolitsyn 2002, Artemyev et al. 2017).

Recently, due to changing environmental conditions in the Northern Dvina river mouth (for example, warming climate), an established system can undergo some changes in structure and functioning of the community of organisms. The structure of estuary biocenosis is being rebuilt. Many works have been devoted to the influence of *D. polymorpha* on native biocenoses. The influence of *D. polymorpha* on planktonic communities (Kurbatova and Lapteva 2008, Lazareva and Zhdanova 2008), benthic communities (Peterson et al. 2023, Protasov 2008, Vinberg 1980) and fish populations (Kasyanov and Iziumov 1995) has been studied. No such studies, however, have been conducted in the Northern Dvina River delta. Another species, *D. bugensis*, is often introduced into water bodies together with *D. polymorpha*. In case this happens, the species enter into competitive relations. However, *D. bugensis* has not yet been observed in the Northern Dvina River estuary. The emergence of new organisms in the community has both positive and negative consequences for the national economy. Emerging new species are called invasive species. Such species expand their habitat through the development of a new environment (Alimov and Bogutskaia 2004).

D. polymorpha is one of the classical invasive species. This species significantly expands its original range (Mordukhai-Boltovskaya 1965). For example, in North America in the last decades of the 20th century, *D. polymorpha* penetrated the Great Lakes and settled south to the Gulf of Mexico (Hebert et al. 1989, Strayer et al. 2004, Minchin et al. 2002). Less than 40 years after its first discovery in North America, *D. polymorpha* was present in 31 US states. Recreational boating is the main vector for the spread of *D. polymorpha* between regions and water bodies in the USA (Dölle and Kurzmann 2020). In Canada, the ecological risk of *D. polymorpha* introductions to freshwater ecosystems was assessed in the provinces of Ontario and Quebec. The risk assessment considered habitat suitability as well as ecological impacts associated with the species. The ecological risk associated with *D. polymorpha* invasion in the western provinces and watersheds immediately adjacent to the Great Lakes and St. Lawrence River was considered high. In contrast, risk was considered small for most of eastern Ontario and Quebec, where calcium concentrations were found to be too low to support clam populations (Therriault et al. 2013). Of particular concern is the possible invasion of *D. polymorpha* into Alaskan freshwater ecosystems where the clam has not been documented to date. At present many rivers and lakes have suitable conditions for the development of populations of this species, and tourism development makes the threat of *D. polymorpha* invasion and its impact on real-world salmon fisheries a real concern (Schwoerer et al. 2021, 2023). On the Eurasian continent *D. polymorpha* is also currently found far beyond its historic range. After the beginning of regular commercial shipping, *D. polymorpha* spread rapidly throughout Eastern and Western Europe. In the 1960s, *D. polymorpha* was recorded in high mountain lakes where it was introduced by pleasure boats. This led to the colonization of Lake Geneva, Lake Zurich and Lake Constance in Switzerland, further colonizing Italy, Yugoslavia, Spain, Ireland and Portugal. The distribution range also expanded in Turkey and by 2021, *D. polymorpha* was present in 31 European countries. The reasons for the invasive success of *D. polymorpha* are varied. For example, high fecundity (300,000 to 1,000,000 eggs), sufficiently wide temperature limits in which the mollusks can exist and reproduce (from 0 to 32ºC), the upper limit of salinity at which mollusk settlements can be found is up to 12‰. *D. polymorpha* is also less vulnerable to predators due to its robust shell and attachment by byssus, and effectively colonizes substrates suspended in the water column (macrophytes, navigation buoys and boat hulls).

D. polymorpha more often inhabits mesotrophic lakes, but in the lower reaches of rivers mollusk settlements are also found, as current velocities decrease here and suitable soils appear due to remobilization of sediments. The main ways of spreading *D. polymorpha* outside the original range are associated with the construction of shipping channels, reservoirs, the development of trade and tourism. Due to its strong attachment to ship hulls by byssus, *D. polymorpha* has traveled landward distances between isolated water bodies, including being found even in highland lakes (Lake Geneva, Lake Constance, *etc*.) (Gelembiuk et al. 2006, Karataev and Burlakova 2022).

D. polymorpha plays an important role in freshwater ecosystems. First, it is of interest to basic and applied science as an invasive species. As a rule, the impact of invasive species affects various aspects of the functioning of ecosystems. Depending on the local conditions, the same species can cause different changes in the environments differing in their ecological factors, which determines the multilateralism and unpredictability of the impact. Invasive species can affect individual species populations and native fauna and flora communities, often resulting in irreversible ecosystem changes (Alimov and Bogutskaia 2004). Settling in a reservoir, *D. polymorpha* quickly increases its number, changes and subsequently determines the structure of hydrobiocenosis. In the reservoirs of the Arkhangelsk region, *D. polymorpha* as a foreign species appeared in the process of self-dispersal. To date, the share of this bivalve mollusk is increasing in the Northern Dvina River. Thus, competition increases in the group of filtrators. Therefore, the risk that the species will occupy a dominant position in the benthos community of the river might be high.

Secondly, this hydrobiont has a versatile economic significance. The role of *D. polymorpha* in the reservoirs is twofold. On the one hand, mollusk fouling of hydraulic structures, fish protection grates and water pipelines is a source of various kinds of biological interference. On the other hand, the species brightens water, removes a huge amount of mineral and organic suspensions from it, cleaning it and reducing the rate of eutrophy. Many benthic organisms (oligochaetes, polychaetes, crustaceans) use the waste products of the dreissena as food and building material. This mollusk plays a large role as a feeding object for many birds and bentophage fish.

Thirdly, being sensitive to lack of oxygen and pollution, *D. polymorpha* can serve as a convenient monitoring species in the studies focused on the effects of heavy metals and organic pollutants on freshwater mollusks. In 2009–2012, the bottom fauna was studied for the presence of heavy metals in living tissues in the estuary region of the Northern Dvina River. Three species of bivalves (*D. polymorpha, Unio pictorum, Pisidium* sp.), one species of larvae Chironomidae and one species Oligochaeta served as the object of the study. During the study, it was shown that to the maximum extent, *D. polymorpha* mollusks accumulate iron, manganese, zinc and cadmium. Thus, iron concentrations in mollusk tissues ranged from 30.9 to 395.2 mg/kg, manganese from 12.3 to

450.0 mg/kg, zinc from 6.9 to 29.0 mg/kg, and cadmium from 0.03 to 4.42 mg/kg wet weight (Neverova et al. 2014).

Recently, *D. polymorpha* spreaded in northern Russia. The promotion of the species occured through a dense hydrographic network and channels connecting the basins of the White, Baltic and Caspian Seas (Slynko 2002). It was revealed that the northern border of the species range runs along the 59° N. However, settlements of this mollusk are constantly found in the Northern Dvina River, the Kubenskoe and the Siverskoe lakes and other water bodies (Voroshilova and Artamonova 2008).

Analysis of mitochondrial DNA showed that *D. polymorpha* inhabiting the Northern Dvina River estuary is not introduced here randomly but forms stable independent and self-reproducing settlements (Voroshilova and Artamonova 2008). This population is unique in phenotypic structure and genetic features (Voroshilova 2008). This can be explained by the long-term isolation of the population and its origin from the Volga River (Voroshilova and Artamonova 2008).

At present, *D. polymorpha* is the most studied of all freshwater invertebrates. There are more than 4000 articles in 19 languages devoted to various issues of biology, distribution, fouling of hydraulic structures and control measures against it, parasitofauna, *etc*. (Limanova 1964, Apaydin Yağci and Yildirim 2022). At the same time, there are very few works on the study of *D. polymorpha* biology and ecology in the Northern Dvina River.

Currently available works on the ecology and distribution of *D. polymorpha* in the estuary of the Northern Dvina River are fragmented, reflect individual aspects of ecosystem processes and do not cover the entire delta. The issue of mollusk research in the river basin and in its estuary is important, as it will make it possible to assess the degree of ecosystem changes under the influence of the new invasive species.

This paper analyzes the structural organization of communities of the estuarine ecosystem of the North Dvina River. Particular attention is given to main features and patterns of the dimensional, spatial structure in the settlements of the *D. polymorpha* mollusk.

Material and Methods

Dreissena (*D. polymorpha*) settlements in the section of the Northern Dvina River of about 25 km from the mouth and within the boundaries of the Arkhangelsk-Severodvinsk-Novodvinsk agglomeration were studied in the summer months of 2018–2021. The studied area was the upper part of the river delta and the lower part of its near-mouth section. Sampling sites (denoted as stations in the following text) were three (*see* Fig. 1). Station 1 was located 25 km from the estuary, where the influence of agglomeration was not observed, stations 2 and 3 were located in the delta part. Samples were taken at depths from 0.5 to 7 m. During the study period, 1538 specimens were collected from different parts of the mouth area of the Northern Dvina River. A large number of juveniles were found in the samples (15-36%). The sizes of the studied specimens ranged from 0.2 to 3.2 cm.

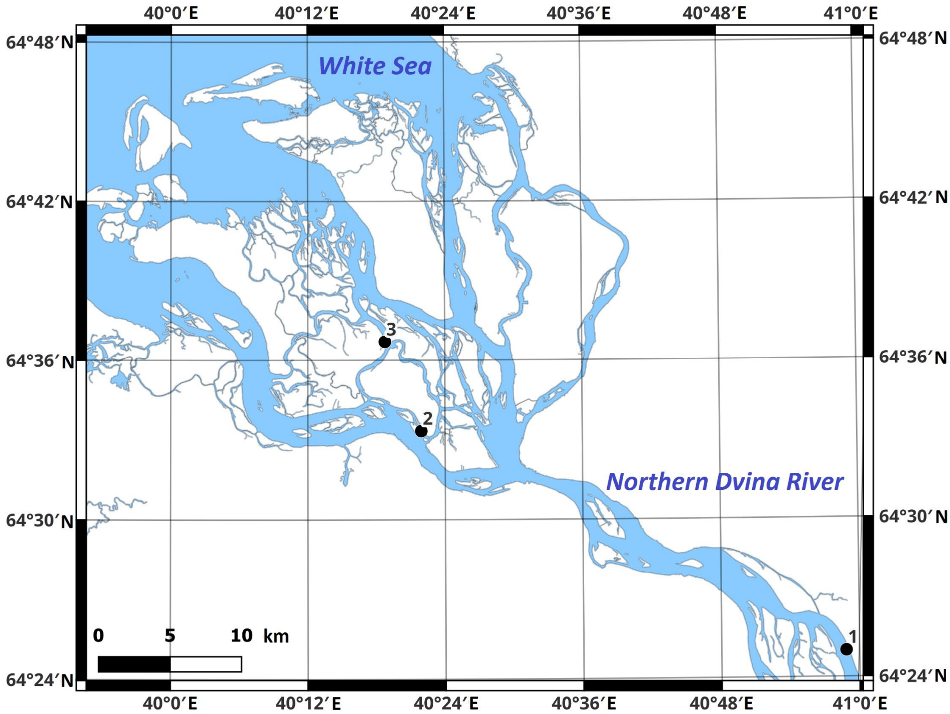

Fig. 1. Sampling scheme of *D. polymorpha* in the wellhead area of North Dvina River. Numbers (1, 2, and 3) refer to the sampling stations.

Mollusks were collected manually from submerged snags, rocks, derelict and used nets or using special equipment (net). Clams were fixed with 96 % ethyl-alcohol. Subsequently, a morphometric analysis of shells was performed. The shells were measured with a caliper with an accuracy of 0.1 mm according to three standard measurements: length (L), the distance along the longitudinal axis of the shell between the most distant points of anterior and posterior margins; height (H), the distance perpendicular to the longitudinal axis of the shell between the most distant points of ventral and dorsal margins; convexity or width (B), the distance perpendicular to the commissural plane between the most distant points of the flaps. The degree of convexity (convexity index) was determined as the B/H ratio (flat, convex, strongly convex, *etc*.). The H/L ratio was used to determine the overall shape of the shell (elongate-oval, oval, or ovoid). The individuals were weighed on Adventurer Ohaus RV 214 (Ohaus, USA) analytical scales with a precision of 0.0001 g. The biometrical data on *D. polymorpha* were compared using the weight and shell length as variables measured by the statistical method used in earlier study (Makhnovich 2018). We employed analysis of variance (single-factor ANOVA for independent groups) to compare mollusks from three different groups on the variables (weight and length). The Mann-Whitney U test was used for pairwise comparison of samples on the two variables.

Results and Discussion

The predominant soils at the river bottom at the sampling sites were sandy and loamy. *D. polymorpha* was found here in various conditions, both as part of the benthos and as part of the periphyton in considerable numbers and at various depths from 0.5 to 7 m. Live shells of *Unio* sp. were a peculiar substrate for settlements of this mollusk. In general, benthic dreissena communities were predominant. Two main chorological types of *D. polymorpha* settlements were found in this study area (Protasov 2008). Firstly, the so-called "brushes" formed on logs in shallow water. The number of individuals on such substrates numbered in hundreds (more than 300). The mollusks were arranged in one tier, less often in two tiers. The brushes were characterized by high density, abundance of *D. polymorpha*, and attachment of individuals not only to the main substrate, but also to each other. Such settlements are found in rather young communities. Another type of settlements was a druse – compact formations in which individuals are attached to each other by a bissus. The formation of druses in benthos is of a local nature.

Different size classes (Table 1) and the ratio between the length and weight (Table 2) of the animals were evaluated. A total of 1538 animals were collected and measured at the three stations: at Station 1 – 268 specimens, at Station 2 – 856 specimens, at Station 3 – 414 specimens.

Dimension classes, mm	**0-5**	**5.1-10**	**10.1-15**	**15.1-20**	**20.1-25**	**25.1-30**	**In total**
Sampling site, Station 1							
Number of instances	6	91	38	24	69	40	268
% of the total number	2.24	33.95	14.18	8.96	25.74	14.93	100
Sampling site, Station 2							
Number of instances	9	125	91	156	267	208	856
% of the total number	1.05	14.60	10.63	18.22	31.20	24.30	100
Sampling site, Station 3							
Number of instances	13	87	51	72	149	42	414
% of the total number	3.15	21.01	12.32	17.39	35.99	10.14	100

Table 1. Quantitative and percentage ratio of dimension classes of *D. polymorpha* in the wellhead part of Northern Dvina River.

The size and weight structure differed insignificantly both by station and by a biotope (for periphyton and benthos) (Table 2). Two size classes also dominated the settlement at Station 1 – small individuals between 5.1 and 10 mm in length (33.95 %) and fairly large clams between 20.1 and 25 mm in length (25.74 %). The proportion of small individuals less than 5 mm in length was insignificant. The size classes 10.1-15 mm, 15.1-20 mm, and 20.1-25 mm were represented by a small number of individuals. The average weight of individuals was 0.8168 g.

At Station 2, *D. polymorpha* was found both in the periphyton on the littoral and at depths up to 10 m. Two size classes dominated here – medium-sized specimens from 20.1 to 25 mm (31.20 %) and large specimens from 25.1 to 30 mm long (24.30 %). Smaller numbers of clams were represented by classes with sizes 5.1-10 mm, 10.1-15, and 15.1-20 mm. The average weight of dreissena tens was 0.6343 g.

The size-age structure of settlements at Station 3 differed slightly from that at Station 2. The proportion of small individuals up to 5 mm was also negligible. The dominant classes were 5.1-10 mm (21.01%) and 20.1-25 mm (35.99%). Larger individuals with shell lengths ranging between 25.1 and 30.0 mm accounted for more than 10% of the specific weight. The average weight of *D. polymorpha* was 0.6872 g.

Characteristics **Average** / **Min - Max**	**Sampling site Station 1**	**Sampling site Station 2**	**Sampling site Station 3**
Weight, g	$\frac{0.8168}{0.0345-2.2551}$	$\frac{0.6343}{0.0321-2.2674}$	$\frac{0.6872}{0.0318-2.2402}$
Length (L), mm	$\frac{19.14}{5-29}$	$\frac{17.26}{5-30}$	$\frac{17.11}{5-29}$
Height (H), mm	$\frac{9.51}{2-14}$	$\frac{8.74}{2-13}$	$\frac{8.72}{2-15}$
Bulge (B), mm	$\frac{9.73}{2-16}$	$\frac{8.80}{2-15}$	$\frac{8.81}{2-16}$
H/L	$\frac{0.48}{0.4-0.66}$	$\frac{0.50}{0.4-0.67}$	$\frac{0.50}{0.4-0.65}$
B/H (bulge index)	$\frac{0.99}{0.7-1.55}$	$\frac{0.98}{0.7-1.56}$	$\frac{0.98}{0.7-1.55}$

Table 2. Morphometric characteristics of the *D. polymorpha* population at different stations. The values presented above the line - averages, below the line – limits (Min, Max).

The size/age structure of *D. polymorpha* settlements is characterized by absence of juvenile groups less than 5 mm in length (settling juvenile mollusks). The proportion of such individuals was 2.24% at Station 1, it reached 1.05% at Station 2, and 3.15% at Station 3. At Station 1, individuals of large size classes dominated, while at Stations 2 and 3 the dominant size classes were represented by both small and large individuals. The dominance of the 5.1-10 mm size class at Stations 2 and 3 indicates mass reproduction of clams and the fact that larvae survived winter conditions in the previous year and continued their development in the spring (Lvova and Makarova 1990). The highest average weight of clams was recorded at Station 1 (0.8168 g). All of the studied groups can be classified as type IV settlements, in which several subdominant size classes are represented. In addition, a peculiarity of the size structure was the complete absence of individuals over 30 mm in length.

At all three stations, the shapes of *D. polymorpha* shells were strongly convex, with convexity indices of 0.7 and higher. According to the H/L index, two groups of individuals were distinguished at all stations. The first group was rather small. It included mollusks with H/L index $\leq$ 0.45, the shape of shells of such individuals can be called elongate-oval. The share of this group at Station 1 was 13.3% of the total number of individuals, and less than 11% (Stations 2 and 3). The remaining clams belonged to the second group with H/L index ranging from 0.5 to 0.6 (Station 1 – 86.7%, Station 2 – 89.3%, Station 3 – 89.7%). The shape of the mollusk shells of this group was oval. Analysis of variance (single-factor ANOVA for independent groups) was used to compare mollusks on the variables "H/L" and "B/H" from three different groups (P=0.071 -0.978). There were no significant differences in the proportions of shells at the three stations, which is associated with similar biotopic habitat conditions.

In terms of shell shape and size, *D. polymorpha* from the Northern Dvina River estuary does not differ from mollusks from other water bodies in Russia. Morphometric analysis of *D. polymorpha* shells from the Gorky and the Rybinsk reservoirs, as well as from the Lake Plescheyevo and the Moskva River, showed that the average values of shell length and height, as well as H/L and B/H indices, are close to those of *D. polymorpha* from the Northern Dvina River estuary (Pavlova 2007, 2010; Pavlova and Izyumov 2013). The Mann-Whitney U test was used for pairwise comparison of samples on the two variables (Tables 3 and 4).

Grouping variable: Sample 1-2		**Grouping variable: Sample 1-3**		**Grouping variable: Sample 2-3**	
Weight, g		Weight, g		Weight, g	
Statistics U Manna-Whitney	826.000	Statistics U Manna-Whitney	695.500	Statistics U Manna-Whitney	1114.000
W Wilcoxon Statistics	2101.000	W Wilcoxon Statistics	1920.500	W Wilcoxon S Statistics	2339.000
Z	-2.793	Z	-3.589	Z	-0.777
Asymptotic sign.	0.005	Asymptotic sign.	0.000	Asymptotic sign.	0.437

Table 3. Mann-Whitney U test statistics for pairwise comparison of three samples of molluscs by the variable "Weight".

There were no statistically significant differences between the samples collected at the second and third station according to the two variables ("Weight", "Length"). This could be explained by the proximity of the second and third sampling stations (Makhnovich 2016). Differences in weight and length between mollusks in the first and second, as well as in the first and third samples are noted, as habitat conditions and the influence of abiotic and anthropogenic factors are somewhat different.

Grouping variable: Sample 1-2		**Grouping variable: Sample 1-3**		**Grouping variable: Sample 2-3**	
Length, mm		Length, mm		Length, mm	
Statistics U Manna-Whitney	678.000	Statistics U Manna-Whitney	616.500	Statistics U Manna-Whitney	1173.000
W Wilcoxon Statistics	1953.000	W Wilcoxon Statistics	1891.000	W Wilcoxon S Statistics	2448.000
Z	-3.600	Z	-4.052	Z	-0.533
Asymptotic sign.	0.000	Asymptotic sign.	0.000	Asymptotic sign.	0.594

Table 4. Mann-Whitney U test statistics for pairwise comparison of three mollusk samples by the variable "Length".

Conclusions

In the estuary of the Northern Dvina River, we found one species of the genus – *D. polymorpha*. Here it forms structurally diverse communities both benthic and in the periphyton. Two main chorological types of dreissena settlements (brushes and druses) were found. Such settlements are found in young communities. The detected clusters of mollusks were distributed unevenly across the water area, which was attributed to the heterogeneity of the environment (availability of suitable substrates, current velocities, salinization, changes in dissolved oxygen concentration, pollutants) (Karataev and Burlakova 2022). Mollusks reached their greatest development at Station 1, where the largest specimens were found. However, the role of these mollusks in the functioning of existing and formation of new communities remains unclear. The proportion of this bivalve mollusk is increasing in the estuary area of the Northern Dvina River. Size structure of *D. polymorpha* population indicates the process of its growth. In spite of the fact that a number of ecological factors may influence the population unfavorably (change of salinity, absence of suitable ground, tidal and storm surge currents), the state of *D. polymorpha* at the studied sites can be considered as favorable. Industrial pollution of the delta waters is a limiting factor for the distribution of *D. polymorpha*, but studies show that in these conditions the mollusks are actively developing, utilizing organic suspended matter, including that containing toxic substances (Pavlovskaya 2008, Solovykh et al. 2009). This indicates the ability of mollusks to live not only in conditions of periodic salinization of waters, but also under a certain type of pollution of estuarine waters (Lebedeva et al. 2022). Further study of the ecology of this mollusk in the estuary of the Northern Dvina River is required, as it plays an important role in the integral assessment of the degree of anthropogenic transformation of the water area.

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