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CURRENT STATE OF THE POPULATION AND FEATURES OF THE DISTRIBUTION OF THE SOFT-SHELL CLAMS *MYA ARENARIA* LINNAEUS, 1758 IN THE KOLA BAY OF THE BARENTS SEA

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The soft-shell clam *Mya arenaria* Linnaeus, 1758 is a boreal bivalve. The range of this species covers coastal waters of the Atlantic Ocean, the northeastern Pacific Ocean, and seas of the Arctic Ocean (the Barents and White seas). *M. arenaria* settlements can occupy vast areas along the coasts, where the molluscs form large aggregations and prevail in biomass among representatives of littoral macrozoobenthos. This species can withstand fluctuations in environmental factors and affect detritus formation and sedimentation. The mollusc juveniles inhabiting upper layers of the sediment are an important food object for seabirds and commercial fish species. High tolerance allows considering *M. arenaria* as an indicator of the effect of climate change on the Arctic ecosystem. Obtaining new data on peculiarities of the species biology is necessary to identify general patterns of development of benthic organisms under varying conditions of the marine environment, to understand adaptive characteristics of certain long-lived high-tolerant molluscs, and to assess the effect of environmental factors on them. The investigation of *M. arenaria* biology may be of practical significance as well: this species may become one of promising objects of mariculture in the Arctic region. The paper provides the results of a study of the current state of the soft-shell clam population and features of its distribution in the Kola Bay of the Barents Sea. Material was sampled during MMBI RAS coastal expedition in 2021. Quantitative characteristics and size and age structure of the mollusc settlements were analyzed. *M. arenaria* aggregations were recorded in the intertidal zone of the western and eastern shores of the middle and southern bay areas. The mollusc settlements in the intertidal zone off the Elovyi Cape (the Tuloma River mouth) were found for the first time during the entire period of research in the Kola Bay (1921–2021). The highest abundance was registered in the Khlebnaya Bay (67.1 ind.·m^{-2}), and the lowest one was noted in the Belokamennaya Bay (5.0 ind.·m^{-2}). There were no abundant aggregations in the intertidal zone off the cape Abram-mys and in the Vayenga Bay. Settlements in the Kola Bay are represented by the soft-shell clams aged 4 to 14 years, with the size varying 17.5 to 91.2 mm. Apparently, *M. arenaria* distribution and quantitative and morphometric characters of its settlements are related to hydrological features of the bay (the intensity of movement of water masses in small bights and cyclonic movement of water masses in the southern bay area). An increase in the mollusc abundance and an expansion of its range may be interpreted as a response to climate change in the Arctic region and an indicator of reduction of anthropogenic load on coastal communities throughout the Kola Bay.

Keywords: *Mya arenaria*, distribution, state of the population, density, biomass, size and age structure, intertidal zone, Kola Bay

Mya arenaria Linnaeus, 1758 is a bivalve of boreal origin that digs into surrounding sediment to a depth of 40 cm [Pfitzenmeyer, Drobeck, 1963, 1967; Sveshnikov, 1963]. Its range covers coastal temperate waters of the northern Atlantic Ocean and northeastern Pacific Ocean, as well as the Barents and White seas of the Arctic Ocean. The species is reported for the Atlantic and Pacific coasts of North America and for the Baltic, Black, and Mediterranean seas of the Eastern Atlantic [Carlton, 1992; Fedyakov, 1986; Golikov et al., 1985; Strasser, 1999; Wheaton et al., 2008; Zhang et al., 2018]. *M. arenaria* settlements can occupy vast areas along the coasts, where the molluscs form large aggregations and prevail in biomass among representatives of littoral macrozoobenthos. The soft-shell clams are able to withstand fluctuations in environmental factors in wide ranges [Fedyakov, 1986]. This species is resistant to salinity within 1–30‰ [Berger, 1986; Khlebovich, Stankyavichyus, 1979], and its favorable temperature is within +4…+16 °C [GISD, 2023]. *M. arenaria* are pretty resistant to hydrogen sulfide content in water and oxygen deficiency [Sveshnikov, 1963; Thumdrup, 1935]. High tolerance allows considering the soft-shell clams as indicators of the effect of long-term climate change on the Arctic ecosystem.

M. arenaria is a key component of coastal communities. Its aggregations affect the processes of detritus formation and sedimentation, and this determines the role of the mollusc as an ecosystem engineer. The soft-shell clam juveniles inhabiting upper layers of silty sediment are an important food object for seabirds and commercial fish species [Marshall, Elliott, 1997; Piersma et al., 1998; Sutherland et al., 2000]. *M. arenaria* filter suspended organic matter of the water column thus improving water quality [Forster, Zettler, 2004]. Like other filter-feeding bivalves, these molluscs can serve as indicators of the aquatic environment conditions. By filtering water, the soft-shell clams are capable of accumulating various toxins, oxidizing organic matter, and even regulating the trophic state of water bodies to some extent [Loo, Rosenberg, 1996].

Obtaining new data on *M. arenaria* biology is necessary to identify general patterns of development of benthic organisms under dynamic conditions of the marine environment, to understand adaptive characteristics of certain long-lived high-tolerant molluscs, and to assess the effect of environmental factors on them. Studying the biology of soft-shell clams may have practical significance. In North America, it is an important commercial species [Beal, 2002; Brousseau, 1979; Connell et al., 2007; Newcombe, 1935, 1936]. Interestingly, in Europe, there is practically no commercial exploitation. Nevertheless, there are publications investigating *M. arenaria* growth characteristics. Thus, a Danish researcher considered the possibility of using it as a commercial object [Munch-Petersen, 1973]. The mollusc may become one of promising objects of mariculture in the Arctic region.

In Russia, studies on this species are concentrated mainly in the White and Baltic seas [Cardoso et al., 2009; Gerasimova et al., 2016; Maksimovich, 1978]. Also, there are investigations of *M. arenaria* from the Sea of Azov–Black Sea Basin [Savchuk, 1970; Savikin, 2020; Zolotnitskiy, Sytnik, 2020] – the area for which this mollusc is an invader. In the Far Eastern seas, comprehensive taxonomic analysis of *Mya japonica* Jay, 1857 is carried out – a species closely related to *M. arenaria* [Zhang et al., 2018]. The research is focused on clarifying the taxonomic status and geographic range of the soft-shell clams. It shows that *M. arenaria* range covers the northeastern Pacific Ocean, while the closely related *M. japonica* is distributed in its northern part.

Information on the biology and distribution patterns of the soft-shell clams from the Kola Bay is patchy. For the first time, the molluscs of the Kola Bay shallows were described by K. Deryugin [1915]. In 1921–1925, the staff of the Murmansk Biological Station studied several coastal areas;

according to the results obtained, *M. arenaria* was recorded from the Olenya Bay in the northern bay area to the Lavna River mouth in the southern one [Gur'yanova et al., 1929]. In the following 40 years, there were no regular investigations of the bay bottom communities. The monitoring was resumed only in the 1970s. In 1984, the staff of the Polar Research Institute of Marine Fisheries and Oceanography studied the central bay. In 1989, the staff of MMBI repeated this survey. These investigations were carried out from a vessel with a Van Veen grab and covered bottom communities of the deep-water bay area. In 1991–1993, there was a benthic survey of the littoral zone of the Tuloma River mouth, and the molluscs were not noted [Gudimov, Frolov, 1997]. In 2005–2007, during coastal expeditions of MMBI, *M. arenaria* was registered in the upper sublittoral of the Kola Bay from the village of Retinskoye to cape Abram-mys at depths of 4 to 12 m [Frolov, 2009]; in the littoral zone, the soft-shell clams were not found [Lyubina et al., 2009].

The Kola Bay is the largest bay in the Russian part of the Barents Sea. It is a typical fjord of tectonic, erosional, and glacial origin [Berega, 1991]. The depth of the bay gradually decreases from the entrance in the northern area to the head in the southern one. There are many bights jutting into the bay coast, and the Tuloma and Kola rivers flow into the bay head. The length along the alignment lines is 58.7 km; the straight line distance from the entrance to the head is 51 km. The total area of the bay is about 180 km^2. Its hydrological regime is affected by the warm Murmansk Coastal Current. In the apex, meteorological conditions of the adjacent land and freshwater runoff have the most significant effect.

Since the second half of the XX century, the mean global air temperature rises [Zhilina, 2021]. The Arctic is one of the most vulnerable regions of the Earth in terms of climate change: there, warming occurs faster than on the planet as a whole [Ponomarev et al., 2005; Zhilina, 2021]. To date, the Arctic seas are characterized by a tense environmental situation, with the main problems being pollution, effect of consequences of ongoing global climate change, decrease in biodiversity, and reduction of marine biological resources [Nersesov, Rimsky-Korsakov, 2021; Stishov et al., 2013; Yakimenko, Ivanenko, 2021]. Over the past 30 years, temperature has risen in all areas of the northern polar region. In general for 30 years, a linear increase in the mean annual temperature is about 2.43 °C (http://www.aari.ru). For the Arctic seas in 1936–2019, the trend sign is positive everywhere. During the last 30-year period, the Barents Sea water has warmed by about 2.2 °C. Since the 1990s, the consequences of climate change have been repeatedly recorded in the water area and coastal zone of the Kola Bay [Antsiferova, Davydov, 2009; Davydov, 2001; Dzhenyuk et al., 1997]. Climate change affects the state of ecosystems, and boreal species are especially sensitive to warming; those respond to rising temperature by expanding their range and increasing abundance [Matishov et al., 2014]. Investigations on the biology and life conditions of hydrobionts are extremely important for monitoring changes in the coastal zone.

The aim of this work is to study the distribution of the bivalve *Mya arenaria* in the Kola Bay of the Barents Sea, to assess the current state of its population, to describe and analyze morphometric indicators, and to identify factors of the key effect on the mollusc distribution in the bay.

MATERIAL AND METHODS

Data on *M. arenaria* distribution in the Kola Bay were obtained during a comprehensive coastal expedition of MMBI RAS in 2021. The survey was carried out in the littoral zone of the middle and southern bay areas, from the Retinskaya Bay to Cape Usov in the Tuloma River mouth on the western shore of the bay and from the Vayenga Bay to Fadeev Stream on the eastern shore. In the southern bay area (from the Cape Usov to cape Abram-mys), sampling was carried out in June – after the complete melting of the ice cover and fast ice that form there in winter. In spots of the littoral zone of the middle bay area (the Belokamennaya, Retinskaya, Khlebnaya, and Vayenga bays) which are accessible all year round, sampling was carried out in March. A total of 234 specimens were sampled during the research period.

The quantitative recording of the soft-shell clams was carried out in the littoral zone at low tide with a 0.1-m^2 frame. The sediment was removed to a 30–40-cm depth and washed through a sieve with a 0.5-mm mesh. In each area, 10 samples were taken. Water salinity and temperature were measured simultaneously with the sampling using a portable refractometer and thermometer with an accuracy of 1‰ and 1 °C, respectively. During the morphometric analysis, the shell length (L, mm), height (H, mm), and convexity (D, mm) were determined for each mollusc with a caliper with an accuracy of 0.01 mm (Fig. 1). The total weight of the soft-shell clam (W, g), the weight of the shell (W_r, g), and the weight of soft tissues (W_m, g) were measured. The weight of mantle water (W_w, g) was calculated as the difference between the total weight of *M. arenaria* and the weight of the shell and soft tissues. For this purpose, before weighing, the molluscs were kept in containers with seawater. Weighing was carried out on electronic scales with an accuracy of 0.01 g. The weight of soft tissues was determined after their drying on filter paper. The proportions of the shell weight and soft tissue weight in the total weight of the soft-shell clams were estimated (W_r/W and W_m/W, respectively). When describing size and weight characteristics, for each study area, mean value (*M*, mm) and standard deviation (±*SD*) were calculated. *M. arenaria* age was determined by counting the annual rings on the shell; those are formed during the winter growth cessation and are thickened growth lines [Haskin, 1954; Metody, 1990].

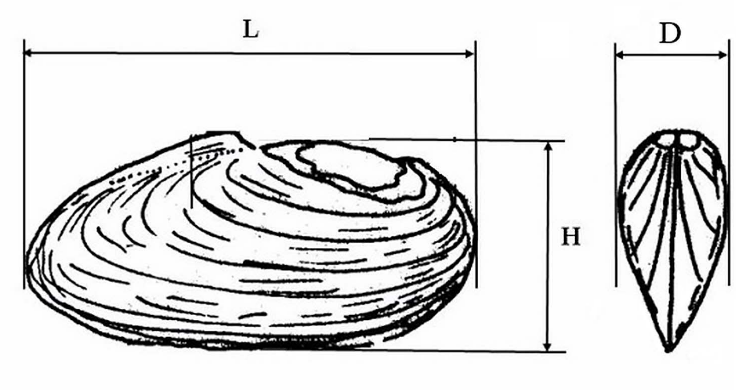

Fig. 1. Scheme of measurements of a bivalve shell [Naumov, 2006]: L, length; H, height; D, convexity

The distribution pattern of quantitative and dimensional characters of the soft-shell clams was assessed by the Kolmogorov–Smirnov test. The significance of differences was determined by the Wilcoxon–Mann–Whitney test. Differences were considered insignificant at $p \geq 0.05$. Mathematical calculations and data classification were performed using the STATISTICA 10.0 software package and MS Office Excel 2010. The relationships within the entire set of morphometric characters of the molluscs were estimated by cluster analysis. Multivariate analysis was carried out using the values of morphometric characters (body size and weight). As the main procedures, two methods were selected – hierarchical analysis and *k*-means clustering. Distances between groups of characters were assessed by the Ward's method with Euclidean distances indicated. The significance of differences between means in groups was tested using variance analysis at a significance level of $p \geq 0.05$.

RESULTS

In the Kola Bay, *M. arenaria* settlements were registered in the littoral zone in the Retinskaya, Belokamennaya, and Khlebnaya bays and in the littoral zone off the Elovyi Cape (Fig. 2). In the areas indicated, the bivalve forms aggregations chiefly in the middle horizon of the littoral zone. The occurrence in samples was of 70–100%.

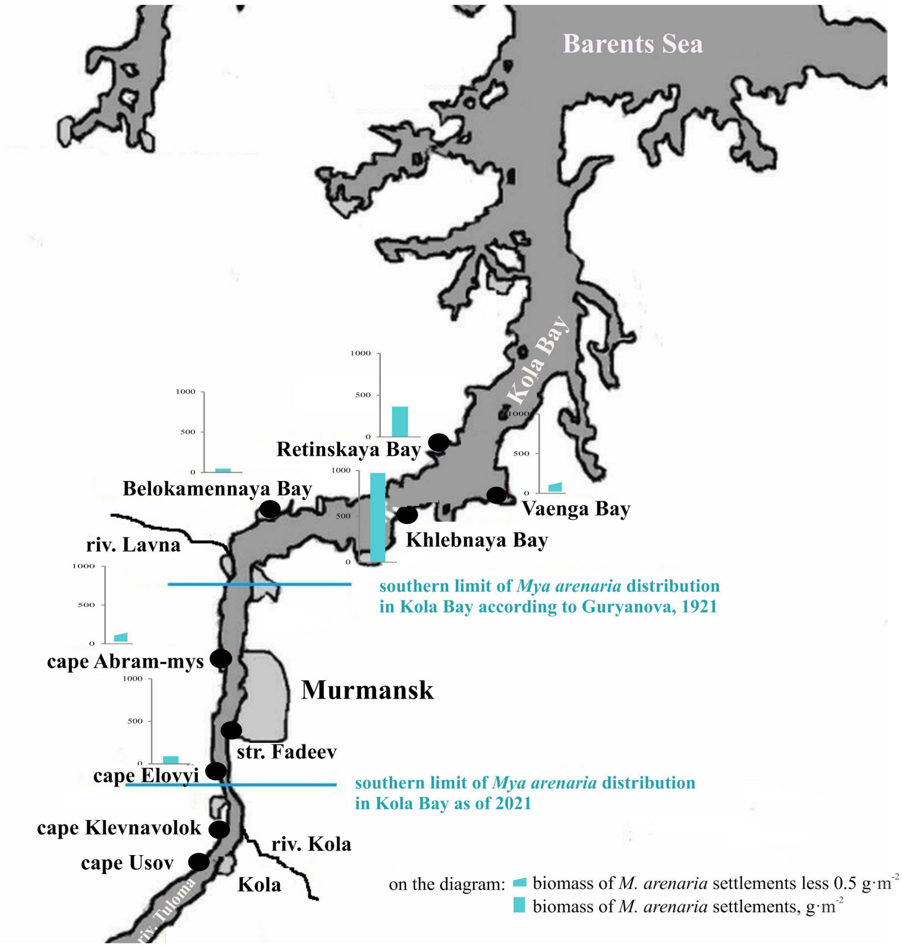

Fig. 2. Distribution and quantitative characteristics of the bivalve *Mya arenaria* settlements in the Kola Bay of the Barents Sea

M. arenaria was also recorded in the littoral zone off the cape Abram-mys and in the Vayenga Bay, but the molluscs do not form dense aggregations in these biotopes. The occurrence of the soft-shell clams there was 10–30%. The bivalves were not noted southward of the Elovyi Cape (the Klevnavolok and Usov capes). The northernmost spot covered by the research was the Retinskaya Bay. In the studied areas, *M. arenaria* mean size varied from (32.8 ± 5.11) mm in the littoral zone of the Vayenga Bay to (55.6 ± 13.4) mm in the Retinskaya Bay, with the mean body weight of (7.0 ± 1.5) g and (18.2 ± 9.6) g, respectively. The molluscs sampled in the Khlebnaya and Retinskaya bays and off the Elovyi Cape were characterized by the highest values of these characters, while the hydrobionts from the Vayenga Bay and the littoral zone off the cape Abram-mys were characterized by the lowest ones. The maximum sizes were 91.2 × 51.5 × 36.8 mm, and the body weight was 36.8 g (this mollusc was found in the littoral zone of the Khlebnaya Bay).

Individual settlements differ significantly in the size and age structure. The largest aggregation is confined to the eastern shore of the middle bay area, to the biotope of silted fine sand of the Khlebnaya Bay. This settlement occupies the southeastern bay area near the stream and is represented by the molluscs aged 4 to 14 years, with a shell length of 30.0 to 91.2 mm. The soft-shell clams inhabit mostly the middle and lower horizons of the littoral zone. The density of the settlement is 67.1 ind.·m^{-2}, and the biomass is 974 g·m^{-2}. In the settlement, the molluscs aged 7–8 years prevail (40%), with a shell length of 50.0–59.9 mm (Fig. 3). The littoral zone of the Khlebnaya Bay is flat and is represented by different sediment types. Water salinity in the bay near the waterline is 16–31‰, and water temperature varies from +1 °C in March to +16 °C in August.

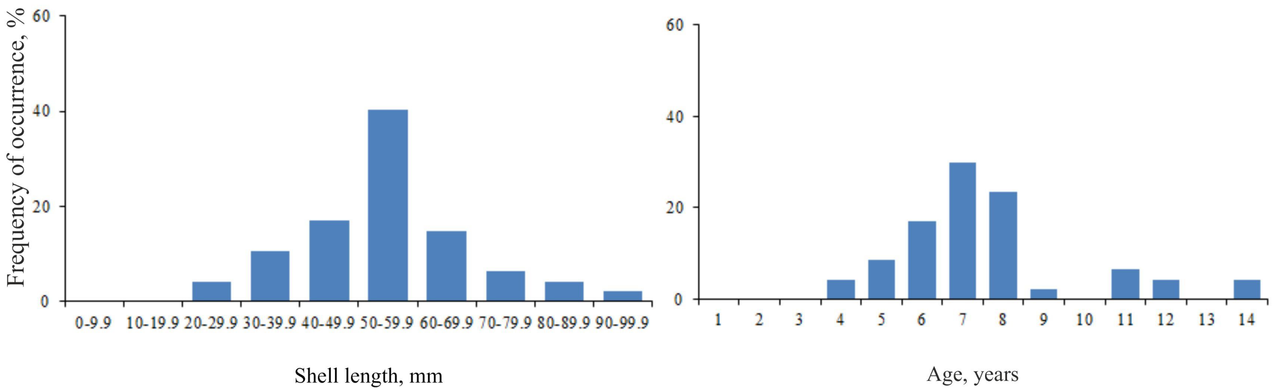

Fig. 3. Frequency distribution of the size and age structure of the molluscs *Mya arenaria* in the Khlebnaya Bay

The southern boundary of *M. arenaria* distribution in the Kola Bay is a small littoral zone of the southern area off the Elovyi Cape (the Tuloma River mouth). The density of the mollusc settlement there is 8.2 ind.·m^{-2}, and the biomass is 92.3 g·m^{-2} (Fig. 2). The sizes vary 23.4 to 68.2 mm. The age structure covers individuals 4 to 11 years. The soft-shell clams aged 6–7 years prevail (56%); their shell length ranges 40.0 to 70.0 mm (Fig. 4). The proportion of hydrobionts of older age groups (9–10 years) in the settlement is 17.4%. The bivalves of 4 and 11 years are encountered singly. Based on the sampling data, it can be concluded as follows: 2015 was the most favorable year for replenishment of this settlement with juveniles. The biotope of the littoral zone of the Tuloma River mouth is distinguished by the occurrence of numerous littoral baths. Those are separated from each other by ridges of stones and sand. The largest littoral baths have drains. The littoral zone off the Elovyi Cape is 150 m long and is represented by silty-sandy sediment with boulder fractions with fucoids. The biotope is characterized by a high degree of desalination. The salinity at the water's edge at low tide can be only 7‰; water temperature in the littoral puddles in June is +7 °C.

In the Retinskaya Bay, *M. arenaria* settlement is located at the estuary of the inflowing stream. It is represented by the soft-shell clams aged 5 to 10 years, with a shell length of 30.5 to 80.0 mm. The settlement density is 35.0 ind.·m^{-2}, and the biomass is 364.0 g·m^{-2}. The molluscs aged 6, 7, and 8 years prevail (> 60%), with a shell length of 50 mm or more. Water salinity in the bay throughout the year is 10–25‰, with the value dropping to 3‰ in May at the estuary of the stream. The width of the littoral zone is 30–50 m. The sediment is chiefly silty sand.

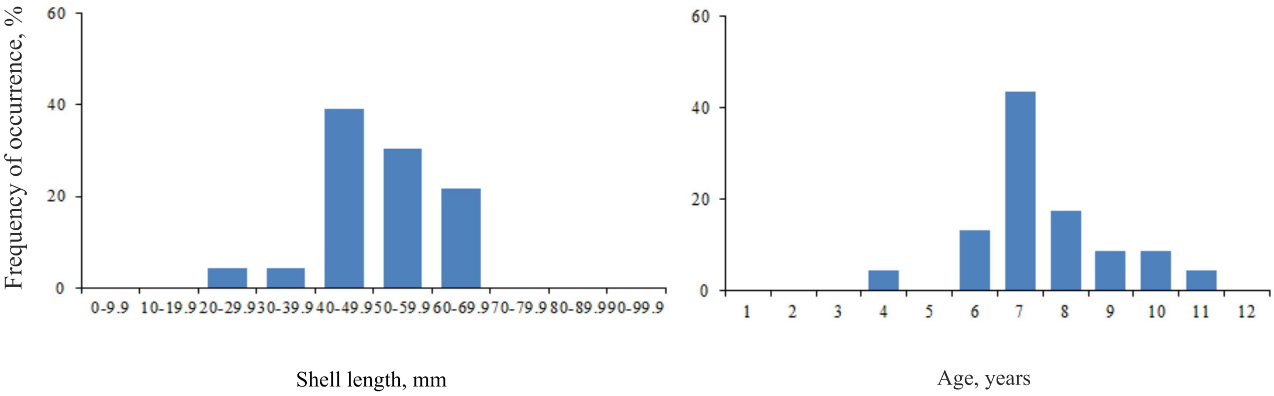

Fig. 4. Frequency distribution of the size and age structure of the molluscs *Mya arenaria* off the Elovyi Cape

In the Belokamennaya Bay, the aggregation is situated near the stream flowing out into the littoral zone. *M. arenaria* settlement in the littoral zone of this bay is in a depressed state. There, the lowest values of density and biomass are recorded: 5 ind.·m^{-2} and 48 g·m^{-2}, respectively (Fig. 2). The size distribution is characterized by the occurrence of two groups of the soft-shell clams – 3 to 5 years, with a shell length of 10–30 mm (39%), and 6 to 8 years, with a shell length of more than 50 mm (47.7%). The mean size of the hydrobionts is (43.4 ± 15.2) mm, and the body weight is (10.0 ± 8.9) g. The Belokamennaya Bay is not sharply separated from the Kola Bay; it is a small bight on its western shore located to the north of the Belokamenny Cape. The littoral zone is wide (the length from the shore to the water's edge at low tide is 130 m), with numerous boulder fractions and a belt of brown algae in the lower horizon. Water salinity at low tide near the water's edge varies 14 to 22‰.

In the Vayenga Bay, *M. arenaria* are found singly. The density does not exceed (0.3 ± 0.04) ind.·m^{-2}, and the biomass is 0.13 g·m^{-2} (Fig. 2). This bight is situated on the eastern shore of the Kola Bay and forms a wide open bay. The Vayenga River, a large one, flows into the bay apex desalinating the studied area to 16‰. The sediment in the Vayenga Bay is represented mainly by rocky placers only occasionally replaced by small spots of silt. Their fauna is extremely poor [Gur'yanova et al., 1929]. In the littoral zone off the cape Abram-mys, the soft-shell clams are encountered singly. The distribution density does not exceed (0.1 ± 0.03) ind.·m^{-2}, and the biomass is 0.47 g·m^{-2}. The biotope is characterized by intensive water movement and significant fluctuations in salinity due to the runoff of large rivers – Kola and Tuloma. At high tide, salinity is 34‰, while at low tide, the value is 10‰ [Malavenda, Malavenda, 2012]. The width of the intertidal zone is about 100 m, and the slope of the littoral zone does not exceed 5° [Kol'skii zaliv, 2009]. The size and weight indicators of *M. arenaria* found in the littoral zone of the Vayenga Bay and cape Abram-mys are provided in Table 1.

Table 1. Size and weight indicators of the molluscs *Mya arenaria* inhabiting the intertidal zone of the Vayenga Bay and cape Abram-mys

Studied area	L, mm	H, mm	D, mm	W, g	W_r, g	W_m, g	W_w, g
Vayenga Bay (N = 6)	32.8 ± 5.1	24.9 ± 4.5	15.0 ± 4.2	7.0 ± 1.5	2.7 ± 1.0	3.9 ± 0.9	1.5 ± 0.03
Cape Abram-mys (N = 3)	34.3 ± 10.5	16.3 ± 1.8	8.4 ± 1.3	12.1 ± 0.2	4.6 ± 0.1	3.8 ± 0.2	1.2 ± 0.03

Note: *N*, the number of molluscs. The abbreviations used are explained in "Material and Methods" section.

In the studied areas, the relative shell weight varies 38 to 61% of the total body weight of the hydrobionts (Fig. 5). The highest values were revealed for the Khlebnaya Bay, and the lowest ones, for the Belokamennaya Bay. The proportion of *M. arenaria* shell weight (W_r/W) in the Retinskaya Bay and off the cape Abram-mys was 55%; in the littoral zone of the Elovyi Cape, 48%; and in the Vayenga Bay, 39%. The relative weight of soft tissues is the highest for the molluscs of the Vayenga Bay (56%) and the lowest for the soft-shell clams of the Belokamennaya Bay (33%). The mean amount of mantle water was 6.5%, with fluctuations within 2% (the Khlebnaya Bay) to 29% (the Belokamennaya Bay). The ratio of the shell weight and soft tissue weight in *M. arenaria* from the littoral zone off the cape Abram-mys and Elovyi Cape was almost 1 : 1, and the proportion of mantle water did not exceed 0.5%.

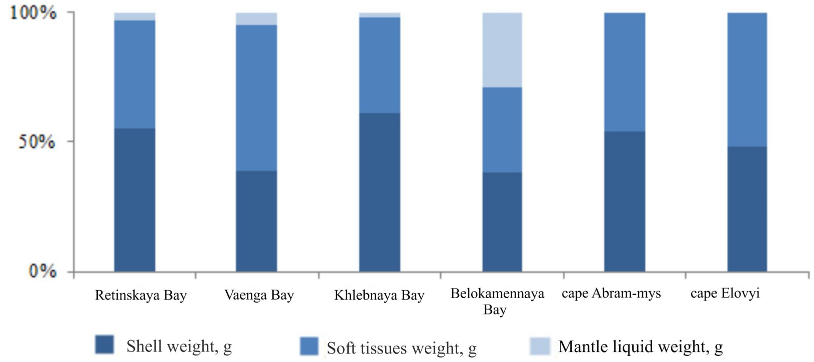

Fig. 5. The ratio between weight parameters of the molluscs *Mya arenaria* in the studied areas of the Kola Bay

No changes were revealed in the body size and weight depending on the latitudinal location of the studied areas. Therefore, to determine relationships within the entire set of morphological characters for *M. arenaria* sampled in the littoral zone of the Kola Bay, cluster analysis was applied (Fig. 6).

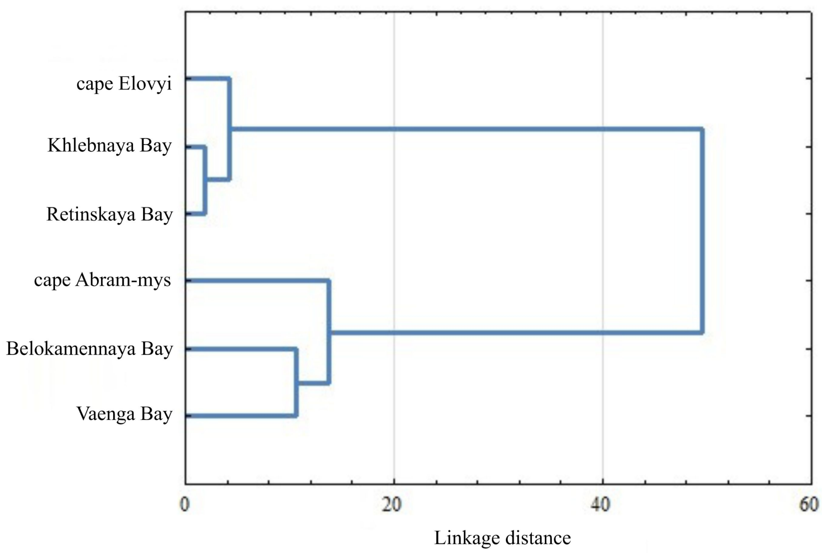

Fig. 6. Dendrogram of similarity of morphometric characters for settlements of the molluscs *Mya arenaria* in the intertidal zone in the studied areas of the Kola Bay

The analyzed set was divided into two clusters. Cluster 1 consisted of the molluscs inhabiting the biotopes of the Retinskaya and Khlebnaya bays and the Elovyi Cape. These settlements had the highest density and biomass, and the molluscs were characterized by the maximum mean values of the shell length, height, and convexity. Cluster 2 consisted of the soft-shell clams from the Vayenga and Belokamennaya bays and the cape Abram-mys vicinity. In these biotopes, the settlements had the lowest density and biomass, and the hydrobionts were characterized by lower values of morphometric characters compared to those of cluster 1 (Table 2).

Table 2. Classification of morphometric characters of the molluscs *Mya arenaria* (*k*-means clustering) and assessment of the significance of differences (*F*-test)

Character	Cluster 1, $M \pm SD$	Cluster 2, $M \pm SD$	Analysis of variance	
			F	significance level (p)
Shell length (L, mm)	54.0 ± 1.83	36.8 ± 5.74	24.37953	0.007830
Shell height (H, mm)	32.6 ± 0.87	22.3 ± 5.18	11.61329	0.027081
Shell convexity (D, mm)	20.3 ± 1.03	13.1 ± 4.13	8.43078	0.043960

Note: *M*, the mean value; *SD*, the standard deviation.

The data obtained were supplemented by the results of *k*-means clustering. The dispersion analysis showed noticeable differences between two clusters ($p < 0.05$). In cluster 1, the highest similarity of size characteristics was recorded for the molluscs of the Khlebnaya and Retinskaya bays (Euclidean distance 0.82), and in cluster 2, it was registered for the soft-shell clams of the Vayenga and Belokamennaya bays (Euclidean distance 1.58).

DISCUSSION

M. arenaria distribution and quantitative and morphometric characters of settlements in different areas of the Kola Bay are very diverse. The highest settlement density was determined for the Khlebnaya Bay. Relatively high abundance values were obtained for the Retinskaya Bay. The lowest density was noted in the littoral zone of the Belokamennaya Bay. In shallow areas off the cape Abram-mys and in the Vayenga Bay, the molluscs do not form dense aggregations. The abundance values of the hydrobionts are comparable with quantitative characteristics of the individuals from other areas. Similar abundance values were determined for the White Sea [Smolkova, 2021] and for the Kerch Strait of the Black Sea [Ivanov, Sinegub, 2007]. The quantitative characters of the soft-shell clam settlement of the Khlebnaya Bay which belongs to moderately polluted areas of the Kola Bay [Informatsionnyi byulleten', 2012] are close to abundance values of *M. arenaria* in the southeastern Onega Bay of the White Sea [Smolkova, 2021] and exceed the indicators of settlements in shallow and cleaner areas of the Eastern Murmansk [Smolkova, Meshcheryakov, 2023]. The size and age composition of the studied settlements of the Kola Bay covers individuals of 30.0 to 91.2 mm and 4 to 14 years, with a prevalence of middle-aged hydrobionts, 6 to 8 years (frequency of occurrence is 47 to 69%). In the samples, there were no molluscs aged 1 and 2 years and no yearling; it is quite natural for settlements of this species and was described earlier [Maksimovich, 2004]. The heterogeneity of the size and age characteristics of the settlements arises due to differences in the patterns of replenishment with juveniles, intraspecific and interspecific competition, and *M. arenaria* death at early stages of its development.

Apparently, the key factors affecting the soft-shell clam distribution in the bay and quantitative characters of settlements are hydrological processes (water dynamics, currents, and water exchange). The total water transport in the bay consists of tidal, runoff, and wind currents. The most significant role is played by tidal currents caused by the Barents Sea tidal wave. There, tidal currents are regular semi-diurnal; those vary depending on the cross-sectional area of the bay. The current velocity decreases from the surface horizon to the bottom; at the horizon of less than 10 m, it does not exceed 5–10 $cm \cdot s^{-1}$ in the middle bay area and 5 $cm \cdot s^{-1}$ in the northern one. The highest current velocity is characteristic of the southern bay area: there, the values reach 100 $cm \cdot s^{-1}$ [Kol'skii zaliv, 1997]. Tidal currents in the Kola Bay cover almost the entire water mass in bays and bights and serve as the main source of organic matter and oxygen necessary for the vital activity of the molluscs. However, with intensive movement of water masses, young individuals that just settled may be subject to postlarval passive transfer in the water column [Roegner et al., 1995].

As shown for the southeastern North Sea, with intensive movement of water masses together with bottom sediments, the transfer of *M. arenaria* juveniles in large numbers, with a shell length up to 15 mm, is possible [Emerson, Grant, 1991]. In the Baltic Sea, passive transfer in the water column was recorded for individuals with a shell length up to 25 mm [Kube, 1996]. Coastal areas off the Elovyi and Abram-mys capes are characterized by the highest dynamics of water mass movement; therefore, juveniles inhabiting surface layers of the sediment can be transferred by a current into more closed water areas of the bay, with a less dynamic hydrological regime. The apex spots of the Retinskaya and Khlebnaya bays are closed from the main bay area; those have a flat littoral and are characterized by weak tidal currents. The streams flowing into the apex spots of these bays have a moderate desalinating effect and provide the removal of organic matter suitable for mollusc feeding. There, the conditions are quite favorable for *M. arenaria*, and it is reflected in relatively high density and biomass of its settlements.

In addition to hydrological conditions, the distribution of the soft-shell clams in the Kola Bay can be affected by climate change and associated processes of primary production and suspended matter transfer. Because of a rise in the mean annual water and air temperature, coastal waters of the bay became more susceptible to desalination due to intensive snow melting in spring. A gain in freshwater runoff in the bay apex determines an increase in the intensity of water movement [Kravets, 2012]. In the zone of seawater and freshwater mixing, the content of suspended matter is high [Mityaev, Gerasimova, 2009]. There, intensive formation of primary production occurs due to the production activity of phytoplankton [Makarevich et al., 2004]. The distribution of suspended matter is associated with the cyclonic movement of water masses in the bay. From the south, desalinated water masses spread along the eastern shore of the southern bay area. In the zone of conjugation of the southern and middle bay areas, those collide with seawater moving from the north and, turning around, return along the western shore of the southern bay area. The eastern shore of the southern bay area is a zone of transit of suspended matter, and the western one is a zone of its concentration and, apparently, accumulation [Mityaev, Gerasimova, 2009].

Suspended matter is very important in the vital activity of inhabitants of the littoral zone. *M. arenaria* are sedentary seston feeders and filter feeders [Beskupskaya, 1963; Metody, 1990]. The soft-shell clams need a constant influx of suspended matter for their feeding: these hydrobionts filter the bottom water and pick up nutrient particles from it. The main food components are suspended detritus, diatoms of the genus *Coscinodiscus*, and particles of a macrophyte *Ascophyllum nodosum* [Beskupskaya, 1963]. Moreover, a sedentary lifestyle reduces the ability of these molluscs to compete for favorable areas of the littoral zone with more mobile invertebrates inhabiting spots with similar conditions (other Bivalvia species, Polychaeta representatives, *etc.*) [Sveshnikov, 1963]. Accordingly, *M. arenaria* have adapted to inhabit biotopes inaccessible to many other species (highly desalinated apex areas of bays and gulfs, with salinity of 10‰); there, food resources are sufficient for the soft-shell clams, and the costs of competition are reduced [Smolkova, 2012].

In the early XX century, the southern boundary of *M. arenaria* distribution in the Kola Bay was the pre-estuarine area of the Lavna River on the western shore [Gur'yanova et al., 1929]. When moving southward along the Tuloma River mouth to the Nemetsky Island, the molluscs were not encountered. Starting from the Nemetsky Island, researchers registered a gradual transition from marine fauna to freshwater one. According to our survey in 2021, the southern boundary of *M. arenaria* distribution in the bay is the littoral zone off the Elovyi Cape which is 15 km south of the Lavna River. The littoral zone off the Elovyi Cape where we have recorded *M. arenaria* (for the first time during the entire period of investigation in the littoral zone of the Kola Bay) is located on the western shore of the southern bay area, in the spot of suspended matter concentration and accumulation.

Differences in the quantitative characters of the mollusc settlements in the bay may also be associated with the effect of anthropogenic factors on the habitat. Even with a high threshold of resistance to fluctuations in environmental factors, *M. arenaria* is in a depressed state in silted eutrophic areas of the littoral zone – in biotopes subject to significant anthropogenic load. Severe siltation negatively affects the vital activity of the soft-shell clams [Winther, Gray, 1985]. Due to the occurrence of floating layers of the sediment, non-floating burrows cannot be formed, and this leads to the death of the molluscs [Sveshnikov, 1963]. Earlier, when describing *M. arenaria* aggregations in the littoral zone of the Khlebnaya Bay, a strong inverse relationship was established between the content of small silt and pelitic fractions in the sediment and the settlement density [Smolkova, Meshcheryakov, 2023]. In areas with waters subject to higher anthropogenic load and a more intensive eutrophication (the Vayenga and Belokamennaya bays and the cape Abram-mys), the settlements are in a depressed state, and the values of quantitative characters are low. In areas with lower anthropogenic load (the Retinskaya and Khlebnaya bays), aggregations have higher density and biomass. At the same time, the occurrence of the molluscs in the southern Kola Bay may be associated not only with the effect of climate change, but also with improved water quality and a decrease in anthropogenic load.

The Kola Bay is classified as a moderately polluted area of marine waters in the Murmansk coastal zone of the Barents Sea [Informatsionnyi byulleten', 2012]. The current level of background pollution of waters and especially bottom sediments of the bay is still quite high; however, a gradual decrease recorded since the 1980s undoubtedly results in an improvement in the state of the bottom fauna [Pavlova et al., 2019]. According to the annual monitoring of the State Oceanographic Institute [2021], the water quality in the water post area in the Murmansk Commercial Seaport has improved significantly in 2021. The water pollution index (WPI = 0.70) dropped to class II ("clean"). In 2018–2020, WPI was of 0.93–1.13 and was attributed to class III ("moderately polluted"). The content of phosphates decreased in 2021 by an average of 1.5 times compared to that for the previous year. The priority pollutants are still petroleum hydrocarbons, copper, and iron. In 2021, the concentration of petroleum hydrocarbons was below the maximum permissible concentration (MPC) for the first time and amounted to 0.034 $mg \cdot dm^{-3}$. The highest value, 1.3 MPC, was recorded in May. The mean concentration of copper became lower and slightly exceeded the standard (5.2 $mg \cdot dm^{-3}$). The mean annual content of iron was also lower compared to that for the last year; the value amounted to 0.46 MPC.

The concentration of oxygen in the surface water layer in the water post area (a water sampling station closest to the southern border of the mollusc distribution in the bay) dropped: the mean annual concentration was 9.3 mg $O_2 \cdot dm^{-3}$ *vs.* 11.8 mg $O_2 \cdot dm^{-3}$ in 2020.

Conclusion. New data were obtained on the distribution of the bivalve *Mya arenaria* in the littoral zone of the Kola Bay of the Barents Sea. For the first time during the research period there (1921–2021), the molluscs were registered in its mouth, in the littoral zone off the Elovyi Cape. Apparently, it is a response to climate change occurring in the Arctic region, and it indicates the formation of favorable habitat conditions in areas previously unsuitable for this. The largest settlement of the soft-shell clams is located on the southeastern shore of the middle bay area in the biotope of silted fine sand of the Khlebnaya Bay. The littoral area of the western shore off the Elovyi Cape (the Tuloma River mouth) is defined as the southern boundary of the species distribution in the Kola Bay. *M. arenaria* distribution is most likely determined by the hydrological features of the Kola Bay (the intensity of movement of water masses in bays and bights, the cyclonic movement of water masses in the southern bay area, and the degree of siltation and eutrophication of the studied areas). The obtained data on the biology and distribution of this bivalve in the Kola Bay of the Barents Sea will serve as a basis for monitoring possible changes caused by anthropogenic load or climate fluctuations.

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СОВРЕМЕННОЕ СОСТОЯНИЕ ПОПУЛЯЦИИ И ОСОБЕННОСТИ РАСПРОСТРАНЕНИЯ ДВУСТВОРЧАТЫХ МОЛЛЮСКОВ *MYA ARENARIA* LINNAEUS, 1758 В КОЛЬСКОМ ЗАЛИВЕ БАРЕНЦЕВА МОРЯ

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Mya arenaria Linnaeus, 1758 (мия) — двустворчатый моллюск бореального происхождения. Ареал вида охватывает прибрежные умеренные воды Атлантического океана и северо-восточную часть Тихого океана, а также моря Северного Ледовитого океана — Баренцево и Белое. Поселения мии могут занимать обширные пространства в прибрежной полосе, где моллюски образуют большие скопления и являются доминирующим по биомассе видом среди представителей литорального макрозообентоса. *M. arenaria* способны выдерживать флуктуации факторов среды, а также оказывать влияние на процессы детритообразования и осадконакопления. Молодь моллюсков, заселяющая верхние слои грунта, представляет собой важный кормовой объект для морских птиц и промысловых видов рыб. Высокая эврибионтность позволяет рассматривать мию в качестве индикатора для оценки влияния климатических изменений на природную среду Арктики. Получение новых данных об особенностях биологии *M. arenaria* необходимо как для выявления общих закономерностей развития бентосных организмов в динамичных условиях морской среды, так и для понимания адаптивных особенностей отдельных видов долгоживущих эврибионтных моллюсков и оценки влияния на них различных экологических факторов. Изучение биологии *M. arenaria* может иметь практическое значение: не исключено, что мия станет перспективным объектом марикультуры в Арктическом регионе. В работе представлены результаты исследования современного состояния популяции и особенностей распространения моллюсков в Кольском заливе Баренцева моря. Материал собран в ходе экспедиции ММБИ РАН в 2021 г. Изучены количественные характеристики и размерно-возрастной состав поселений мии. Скопления *M. arenaria* зафиксированы на литорали западного и восточного берегов среднего и южного колен залива. Впервые за весь период исследований Кольского залива (1921–2021 гг.) моллюски обнаружены в эстуарной его части — на литорали у мыса Еловый (устье реки Тулома). Наибольшие показатели обилия отмечены на восточном берегу среднего колена залива — в губе Хлебная (67,1 экз.·м$^{-2}$), наименьшие зарегистрированы на западном берегу — в губе Белокаменная (5,0 экз.·м$^{-2}$). На мелководных участках в районе Абрам-мыса и в губе Ваенга мия плотных скоплений не образует. Исследованные поселения залива представлены особями в возрасте от 4 до 14 лет с вариацией размеров от 17,5 до 91,2 мм. Распространение *M. arenaria*, а также количественные и морфометрические характеристики её поселений связаны, вероятно, с гидрологическими особенностями залива (с интенсивностью движения водных масс в губах и бухтах, а также с циклоническим перемещением водных масс в южном колене). Отмеченные увеличение численности моллюсков и расширение ареала можно, по-видимому, интерпретировать как отклик вида на климатические изменения, происходящие в Арктическом регионе, и показатель снижения антропогенной нагрузки на прибрежные сообщества залива в целом.

Ключевые слова: двустворчатый моллюск *Mya arenaria*, распространение, состояние популяции, плотность, биомасса, размерно-возрастная структура, литораль, Кольский залив