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Size-weight structure and growth of *Mytilus edulis* L. in littoral zone of the White, Barents and Norwegian Seas

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CONTENTS

Introduction

The most widespread benthic animals of foreshore of the Barents and White seas are bivalve molluscs *of Mytilus edulis* L., also called blue mussel. By the number this species could take a quite modest place, by biomass they could take about 40% in sublittoral and approximately twice more on littoral, reaching sometimes 90% and even more (Naumov, 1993). Fast growth rates provide them the high level of annual production, thus, bivalve mussels are valuable food supply for consumers of the second order. Ability of mussels to accumulate radionuclides and heavy metals in tissue allows us using them as bioindicators of seawater quality. These organisms are the integral component of system of marginal filters in estuaries. It is established that mussels are able to filter from 2 to 5 liters of water in an hour that in terms of days allows to filter tens tons of water per square meter of their natural settlements (Gudimov, 1998).One of the most important indicators of mussel settlements conditions is its dimensional age structure. It reflects replenishment of settlements with juvenile individuals, the growth rate of molluscs, their mortality and life expectancy in these ecological conditions.

The purpose of the real work - to investigate features of growth and population characteristics of the mussels living in littoral zone of the Barents, White and Norwegian Seas. According to the goal, it is necessary to solve the following *problems*:

1. To study spatial distribution and to estimate abundance of molluscs in the studied areas.
2. To study dimensional, weight and age structures of littoral settlements of mussels.
3. To carry out comparative analysis of growth equations of the mussels living on littoral in areas of research.

1. Basic background

1.1 Systematics and distribution of mussel *Mytilus edulis* L.

The blue mussel Mytilus edulis L. is one of the most widespread benthic invertebrates of the littoral zone of the Barents and White Sea. In littoral, and sometimes confidence interval. in the sublittoral zones these molluscs become a dominating or characteristic species. The availability of the mussel and easiness in collecting, good growth rate, simplicity of cultivation and taste of meat have made these mussels an object of shellfish fishing and cultivation. The mussel Mytilus edulis L. belongs to the phylum Mollusca, class Bivalvia, subclass Pteriomorphia, order Mytilida, superfamily Mytiloidea, family Mytilidae, genus Mytilus, species Mytilus edulis L. These are black bivalve molluscs, which lead the attached life.

This species is distributed along the coast of Iceland, the southern part of Greenland, Atlantic and Pacific coast of North America, Barents Sea, White Sea and Baltic Sea, southwest sites of the Kara Sea and the Far East seas. The mussel is mainly observed in the sublittoral zone in the most northern settlements. The mussel are found in high-altitude areas of the Siberian seas, at the archipelagoes of Franz Josef Land and Spitsbergen. In the littoral zone of East Murman Mytilus edulis L. settlements form a range border and on the East in Cheshskaya Bay and at Novaya Zemlya mussels move down in sublittoral zone up to the depth of 30 m (Guryanova, 1929).

1.2. Morphology: external and internal structure

Shell structure. The exoskeleton (shell) of mussels always consists of two shells. The front end of shell pointed, and the back considerably rounded. The shell have an extened form (Figure 1).

Figure 1. General view of *Mytilus edulis* L. (view from the right side).

The size of the right and left shells are usually identical. The exoskeleton is dark and olive, dark brown, but more often black (Gudimov, 1998). On the back of the animal shells are connected with a ligament. Shells consist of three layers: external (periostracum), internal (ostracum) and lower (gipostracum) - nacreous. The structure of external skeleton is determined by environmetal conditions in the living area.. The streamline shape and durability of shell provide mussel a good fitness to dwelling in coastal zone and in waters with raised hydrodynamics. It is also promoted by unique ability of mussels to quickly and reliably attach to stones, seaweed, logs, to each other and other objects with a very strong byssus threads (Figure 2.).

Figure 2. Littoral settlement of mussels in Belokamennaya Bay (Kola Bay).

Internal structure. The body of the mussel consists of a trunk and small foot and the head is reduced. The foot represents muscular outgrowth which in natural habitat does not carry out movement function, and generally serves for allocation of byssus threads (byssus gland is located in foot) (Fokina, 2010). Mouth is located on the front end of trunk and anus located on the back. The trunk of molluscs is covered with lateral folds - cmantle. Free edges of mantle folds form output siphon through which water leaves mantle cavity. Water comes to mantle cavity through the opening siphon, which is formed with fringed outgrowths of mantle (Figure 3).

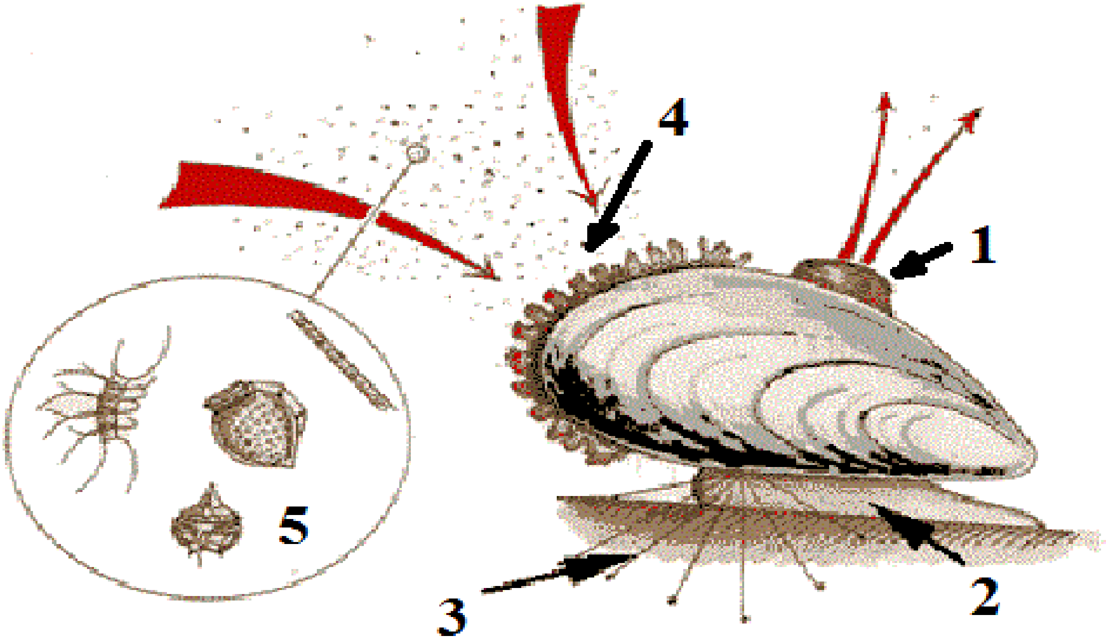

Figure 3. *Mytilus edulis L.* Look on the right side: 1 - output siphon; 2 - foot; 3 - byssus thread; 4 - opening siphon; 5 - suspended particles (Fokina et al., 2010).

The mantle cavity represents space between folds and trunk. Digestive, blood, secretory, sexual, nervous systems and gills are located there. The ciliary epithelium (located in mantle cavity) creates water currents, which wash internal organs.

The threadlike gills represent respiratory organs. An extended branchiate petals fall down in the lower part of mantle cavity, and then are bent up. At the same time, the neighboring threads are fastened with cilia forming plates (Sharova, 2002).The digestive system of bivalve molluscs differs due to the passive way of feeding (filtering). Receptor cells (organs of taste) and ciliary fillets are located on gills and oral blades in which food particles are sorted from the mineral; further with water current organic material goes to actinostome (Sharova, 2002).

The blood system consists of heart (it is located on the back part), arterial vessels, venous channels, lacunas and sine. Function of blood is carried out by hemolymph. The blood system is not closed.

Cerebral and pleural ganglia provide the nervous system and the pedal gangliya (the innervating adjacent organs) is located in the foot. Single-celled receptors are located on surface of soft body (Sharova, 2002).Sense organs are poorly developed. Sensory cells are located at edges of siphons and foot. In addition there are poorly differentiated. Adult individuals have no eyes. *Mytilus edulis L.* are sexually dimorphic animals. Usually they reach maturity stage age from 2-3 years. Mantle tissue is the main place of gonads development. In the period of the maturity, males have cream color gonads, whereas females have reddish-orange color gonads (Maksimovich, 1985).

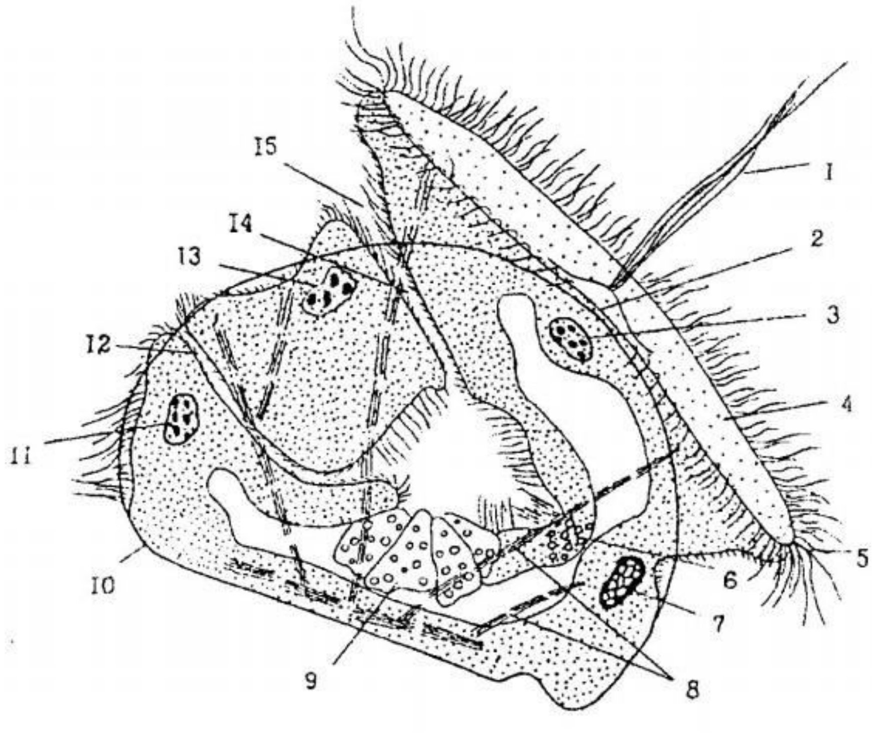

Figure 4. Mussel larva in veliger stage. 1 - apical threads; 2 - parietal plate; 3 - cerebropleural ganglion; 4 - sail; 5 – preoral sail cord; 6 - crystal pedicle gland; 7 - front adductor; 8 - sail muscles retractors; 9 -

digestive gland (liver); 10 - shell; 11 - visceral ganglion; 12 - back gut; 13 - pedal ganglion; 14 - gullet; 15 – mouth, (Kulakovsky, 2000).

A number of abiotic factors leads to the beginning of reproduction cycle; they are temperature increase, salinity change, wave activity and water draining (Newell, 1989). It is well known that a water temperature increase to 10-13 ºC stimulates tasseling of reproductive products. After the fertilization, the larvae, which represent blastula, gains an ability to active swimming. After the blastula stage the conchostoma stage follow, which have an accelerated development of shell gland. Then there is "reversing" of shell gland, –followed by the trochophore stage (Maksimovich, 1985). This stage is short and ends with formation of the veliger larvae (Figure 4).

The growth of the settled juvenile begins immediately after metamorphosis. In winter, the growth of mussels practically stops. The value of annual growth increment decreases from the first year of life (as many other slowly growing species). The curve describing size at current age has the form of a parabola (Seed, 1968; Sadykhova, 1983). There are large individual variation among individuals in the annual growth increment, showing up already from the first years of life. The growth rate of the animal for the first years largely determines the nature of its growth during later life (Sadykhova, 1983). Therefore, comparing the intensity of mussel growth during the first 2 years of life in different parts of the range can clearly indicate the potential growth of the species at a given location.

Unlike many aquatic organisms, *Mytilus edulis* L. mussel continue to grow throughout life, so the aging process is accompanied by a gradual increase in body size, as well as changes in energy distribution (Sukhotin et al., 2002; Fokina, 2010). Somatic growth decreases, although reproductive activity increases. It is known that sedentary benthic animals from the sublittoral and littoral zones, as well as from different levels of the tidal zone, are characterized by differences in some physical parameters.

In tidal zone, animals are regularly affected by hypoxia during outflow. This process largely influences the growth, since the metabolic rate is greatly reduced during hypoxia. Studies have shown that the growth rate decreases and mortality increases at the age of six years, as a result of the expected reduction in aerobic metabolism (Sukhotin et al., 2001).

In foreshore of East Murman the favorable period for mussel growth is short and usually lasts from April to September. During this productive season, energy intake from food is sufficient for intensive growth and reproduction of mussels. At this time, there is a flowering of phytoplankton, however its concentration rarely exceeds 300 million colonies/m^3 (Voznaya & Ryzhov, 1979). During a long and cold winter, concentration of phytoplankton decreases significantly, few phytoplankton cells per liter available and detritus makes the main part of the mussel diet. During this period, the stored energy reserves of the body are utilized and resorption of gonads is observed. In conditions of lack of food and low temperatures, the activity of the organism and the intensity of metabolism reach a minimum value. In addition, since the growth rate of animals are determined by the rate of metabolic processes, the growth also slows down and practically stops (Hopkins, 1930; Sadykhova, 1983).

2. Material and methods

2.1 Sampling areas

The work is based on materials collected by the author in 2011-2015. Data on the spatial distribution, individual size and weight, and age structure of the mussel settlements were obtained from the littoral sections of the gulfs of the Barents, White and Norwegian Seas (Figure 5).

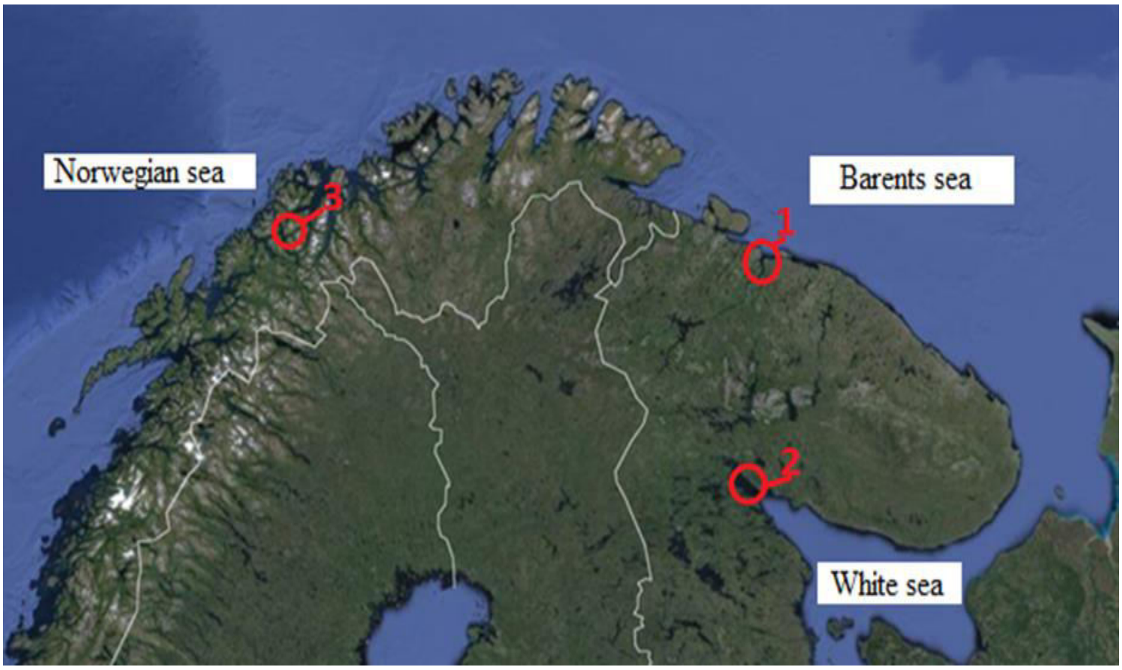

Figure 5. Areas of sampling in Barents (1), White (2) and Norwegian seas (3) in 2011-2015.

In the Barents Sea, the material was collected in the Kola Bay, where three sections (knees) are traditionally distinguished: southern (upper), central (middle) and northern (lower). Sampling was carried out in accordance with this division in the the Abram-Cape, Belokamennaya Bay and Cape Retinsky areas respectively (Figure 6).

Figure 6. Stations of *Mytilus edulis* L. sampling in Kola Bay of the Barents Sea (Abram-Cape, Belokamennaya Bay and Cape Retinsky).

Kola Bay is a fjord shaped Bay of the Barents Sea located in the northern coast of the Kola Peninsula The maximum depth reaches 170-180 m in the estuary and gradually decreases from the entrance to the edge. The topography of the bay is formed by a combination of concentric and radial faults. The shores of the bay have pronounced differences. On the eastern shore of the bay there are incongealable ports Murmansk and Severomorsk; on the western side - the port Polyarny (Figure 6). The south-eastern coast is characterized by a more incised outlines due to a large number of perpendicular faults to the coastline (Dzhenuk & Savelieva, 1997). The physical and geographical properties of the Kola Bay are in many ways similar to most of the fjords that form the coastline of the Norwegian and southeastern parts of the Barents Sea. Salt waters of Atlantic origin, which indicates an intensive water exchange on its maritime boundary, form the water mass of the bay, with the exception of a relatively small volume in its southern part. The climate of the Kola Bay is determined by the contrasts of physical conditions between the unfrozen sea and the adjacent land, although the water mass of the bay itself has a significant effect on meteorological conditions. Due to the powerful heat transfer of the Atlantic water masses, bay practically does not freeze, although in cold winters its southern part is filled with freshened waters and covered with 30-40 cm ice thick. In some years, ice is observed in February-March also in the middle part of the bay (Dzhenyuk & Savelieva, 1997).The warming of the gulf waters begins in April, proceeds slowly, and by July the surface layer temperature rises to 10 °C. At a depth of 50 m, the annual maximum temperature is reached in September-October, at a depth of 200 m in November, to 6.5-7.0 and 5.5 °C. In the spring, complete homothermia is observed, and in summer a maximum contrast is created between the temperature of the surface and deep layers.

The Barents Sea water mass plays a crucial role in the distribution of salinity throughout the Kola Bay. Starting from a depth of 100 m and deeper the salinity of the bay waters during the year is maintained at 34.0-34.5 ‰. At a depth of 50 m in the middle part of the Kola Bay, slight desalination can be observed (up to 33.8‰). In the middle and northern parts of the bay at depths of 10-25 m in the winter-spring period salinity remains close to 34 ‰, in summer it can decrease up to 32 ‰. The surface layer is affected by a significant seasonal variability of salinity in all parts of the bay. In winter, it does not fall below 30 ‰, by the summer it falls to 15-20 ‰, especially in the southern knee. A strong decrease in salinity (up to 10-15 ‰) is possible only in the surface layer in June-October. A short-period range of salinity variation is also observed and caused by tidal currents. In the southern part, the differences for the tidal cycle are about 5 ‰ (in average), in some series of observations they can reach 12 ‰ (Table 1).

Table 1. The salinity of the surface waters of the Kola Bay and the intensity of its movement in the sampling areas

Sampling area	**Intensity of water movement *10^{-3}, mg $CaSO_4$/g*hour (Malavenda, 2009)**	**Salinity, %**	
		Tide	**Low tide**
Southern knee (Abram Cape)	8	10	5
Middle knee (Belokamennaya bay)	3	24	14
Northern knee (Cape Retinsky)	10	34	30

Tides are semidiurnal up to 4 m. Tidal currents and fluctuations level of water flow largely determine the rate of renewal and purification of waters in the territory of the littoral. An important role is played by the wind regime.

In the White Sea, the stations were done in the Kandalaksha Bay near Ryazhkov Island (Northern bay, Bolshaya Peschanka bay, South bay) and in Chupa Bay (Seldyanaya, Kruglaya, and Left Bay) (Figure. 7).

Figure 7. Stations of *Mytilus edulis* L. sampling in Kandalaksha bay of the White sea in island Ryazhkov and in Chupa bay.

Chupa Bay is one of the largest clips of the Karelian coast of the White Sea (Figure 5, area 2). The length of the bay is 37 km, the width varies from 0.7 to 3.3 km, and the total area is 4,500 hectares. It is located near the junction of the Kandalaksha gulf and the Basin (see Figure 7 needed). The average depth of the water area is 21.6 m, the maximum - 67 m. The relief of the seabed is complex and represents a series of troughs and pits of various sizes and configurations.

According to its morphological characteristics, Chupa Bay is a fjord, and according to the physical conditions it could be characterized as a tidal estuary. According to its topographical characteristics, the Bay can be divided into three sections: vertex (stump), middle and mouth (Babkov, 1998). A significant variability in the velocities of tidal currents is noted in various parts of the bay. In the upper and lower parts, the velocity flow on the surface layer is relatively small - 16-18 m/s, in the middle part in the straits between the islands it reaches 30-40 m/s.

As for all the bays of the White Sea, Chupa is characterized by significant seasonal variations in water temperature on the surface layer, from −1.5 °C in winter to 19.3 °C in late summer. The salt regime of the upper 5-meter layer of water in the bay is determined by the magnitude of freshwater runoff. At maximum flow in April-May, salinity at the surface decreases to 1 ‰, and deeper than 5 m - to 12 ‰. By the middle of July salinity increases to 17-20 ‰, and in August it is more than 24-25‰. The oxygen regime is favorable, the oxygen content during the growing season (June-August) in the 0-5 m layer exceeds 100%, and only at the end of August it goes down to 90% deeper than 10 m. The freezing duration is 5-7 months, fixed ice is formed in the first decade of December, especially in areas affected by continental flow with decreased salinity.Ryazhkov Island (Figure 7) is the largest and the only one inhabited island of the Northern archipelago, located in the Kandalaksha gulf of the White Sea. The size of the island is 3.3 kilometers long and 1.5 kilometers wide. Rapid tidal currents and shallow depths characterize the water area around the island. The coves of Ryazhkov Island are usually calm with weak currents, silt is deposited at the sea bottom. Water warms up well, especially on littoral, intensive mixing of water masses is observed during the strong and stormy winds. Water temperature near the bottom can reach +15 ... +17 ° C in the summer (Ninburg et al., 1975; Bianchi et al., 1979). The littoral of Ryazhkov Island is represented by sandy and silty-sandy soils.

In the Norwegian Sea, sampling was done on a littoral site of Tromsø Island (Northern Norway) the outer border of Balsfjord (Figure. 8).

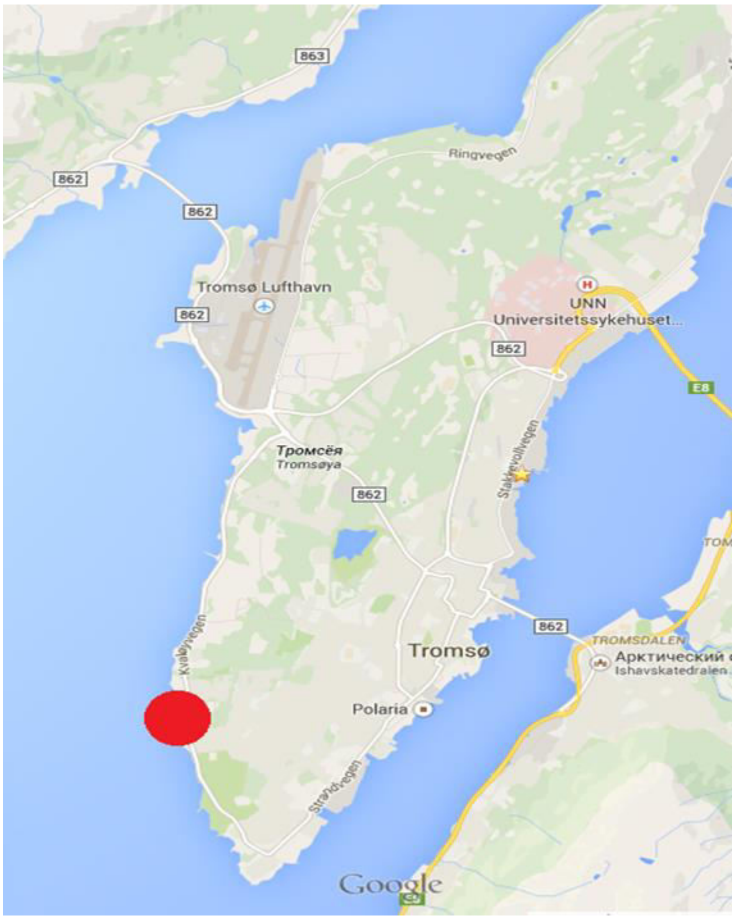

Figure 8. Station of sampling *Mytilus edulis L.* at Tromsø Island, Balsfjord (Norwegian Sea.)

Balsfjord is located on the north-western coast of Norway and cuts deep into the mainland. The structure of the waters of the Norwegian Sea is formed by two main water masses of Atlantic and Arctic origin. In the "pure form", Atlantic waters are found only in the southern part of the sea, in the surface layer at depth of 300 m. The temperature and salinity of the coastal waters does not have pronounced seasonal variations. Coastal waters of Norway interact with the Atlantic, so their temperature in summer is 8-14 °C, in winter - 4-6 °C. Salinity varies from 33.21 to 34.9. In the fjord area, from October to March, the south-western winds predominate, and in April-August - the northeast (Skjoldal et. al, 1995).

2.2 Methods of collecting and processing samples

Collection of materials on the distribution and biological characteristics of the mussel settlements at all stations was performed at low tide. Evaluation of the abundance of settlements (density and biomass indices) was applied by the trial area method using a 10 × 10 cm metal frame (Guide ..., 1980). From each horizon of the littoral, three samples were taken, which were subjected to post-processing.

In the laboratory, before processing the material, the surface of the mussel shells was cleaned of epibionts. The length (L, mm), height (H, mm) and width (B, mm) of the mussel shells were measured with a caliper (0.1 mm accuracy). Weighing (wet) was carried out on electronic scales with an accuracy of 0.01 g. The total wet weight of the whole mollusc (MM) was determined, and separately the mass of its soft tissues (STM) and the shell (SM) was registered. This was achieved by using a scalpel, the closure muscles were cut, after that the soft tissues of the animal were separated from the shell (individuals less than 1 cm in length were not opened). By the difference between the mass of the whole mollusk and the sum of the mass of the soft tissues and the shells, the weight of the liquid inside the was determined (SLM).

In total, over 2750 individuals of *Mytilus edulis* L. were examined (Table 2).

Table 2. Volume of collected material

Material collection area	**Number of stations**	**Number of samples.**	**Number of examined molluscs**
Kola Bay (Barents Sea)	3	9	> 400
Ryazhkov island (Kandalaksha Gulf, White Sea)	3	9	900
Chupa Bay (Kandalaksha Gulf, White Sea)	3	9	> 1100
Tromsø Island - Balsfjord (Norwegian Sea)	1	3	> 350
Total:	10	30	> 2750

To determine the growth and size-at-age of mussels, the "annual rings", the lines of winter growth stop on shells, were counted and measured (Figure. 9).

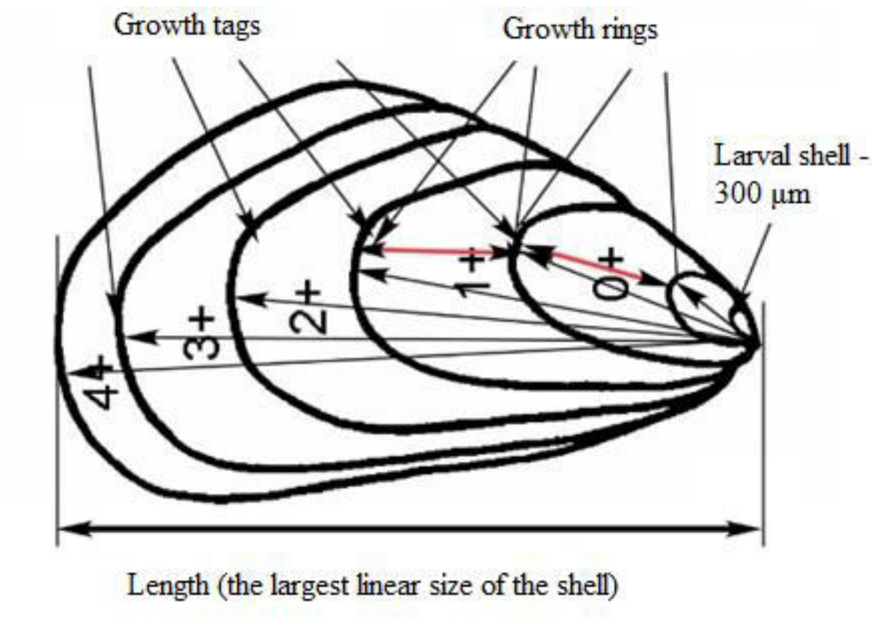

Figure 9. Age determination of *Mytilus edulis* L. mussel (Maksimovich, 2007).

The growth of mussel shells in all the investigated populations was calculated by the Bertalanffy equation, which describes an infinite type of growth (both weighted and linear).

$$L_t = L_\infty (1 - e^{-k(t-t_0)})$$

where L_t - is the length (L, mm) of the shell at the age of t;

L_∞ - the average theoretical maximum length of mollusc in the investigated population;

k - growth constant, how fast L_∞ is achieved

t_0 - constant indicating the time at which the length of the organism in the adopted growth model was zero (Maksimovich, 1989, Melnikova, 2005). In the text of the thesis, values of the arithmetic mean and confidence interval are indicated for the calculated. All calculations were carried out using the MS Excel 2013 software package and Graph Pad Prism 5.0.

3. Results

3.1 Settlement characteristics of the mussels inhabiting littoral zone in Kandalaksha Bay of the White Sea

3.1.1 Abundance indexes of settlements

In the water area of the Kandalaksha Bay within the Ryazhkov Island in littoral settlements, the density and biomass of the mussels averaged at 10.5 thousand indv./m^2 and 16.9 kg/m^2, respectively. At the same time, in the bays (Northern bay, Bolshaya Peschanka bay, South bay) of the Ryazhkov Island, these indicators varied significantly: density - from 4.5 to 17.3 thousand ind./m^2; Biomass - from 2.5 to 24.9 kg/m^2 (Figure 10).

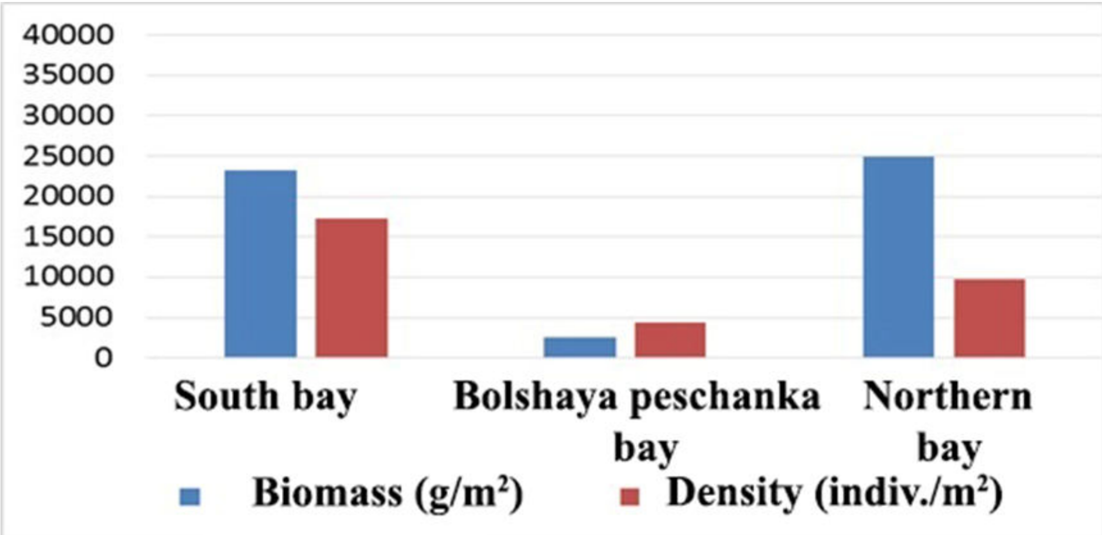

Figure 10. Biomass and density of *Mytilus edulis* L. in the littoral of Ryazhkov Island.

In the Chupa Bay, the average density and biomass of the settlements exceeded those of the Ryazhkov Island and averaged 23.1 thousand ind./m^2 and 34.6 kg / m^2, respectively. The higher abundance indexes of the mussel settlements in relation to the Ryazhkov water area are noted both in the whole Chupa Bay and in each of its separate bays. In the areas of the Chupa Bay, the density of settlements was lowest in the Seldyanaya Bay (14.1 thousand indv./m^2), while in the Kruglaya Bay and Left Bay it was quite high and relatively equal (27.6-27.7 thousand indv./m^2). At the same time, with a high number of mussel settlements in the Kruglaya Bay, the minimum biomass of mollusks is noted here (Figure. 11).

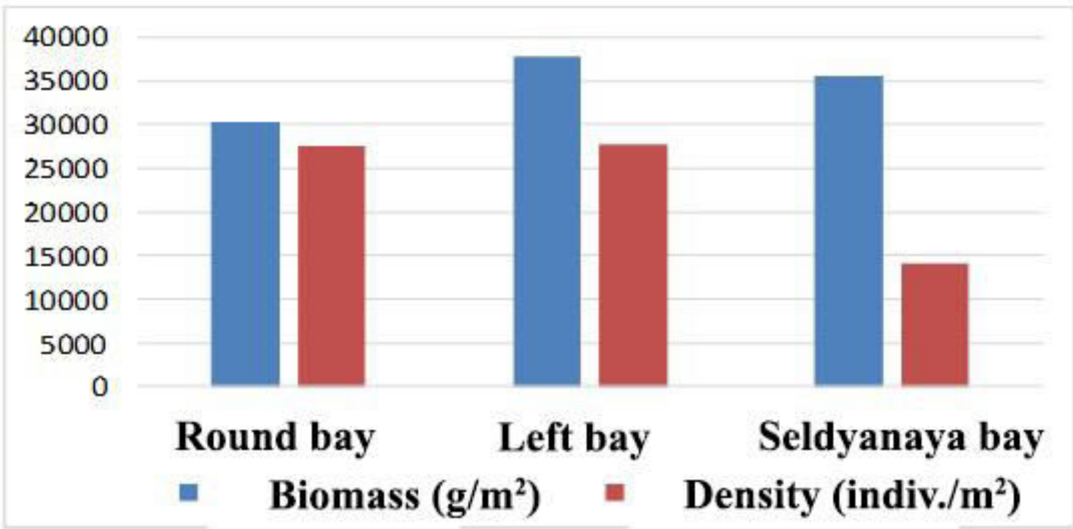

Figure 11. Biomass and density of *Mytilus edulis* L. in the littoral of Chupa Bay.

3.1.2 Size and weight distribution

In the water area of the Kandalaksha gulf around Ryazhkov Island, the average length of mussels varied from 1.56 to 2.46 cm and in the whole water area was 1.96 cm. The greatest length (2.5 cm) and mass (2.5 g) was recorded in the Northern lip, which ensured the maximum biomass of mussels in this settlement in relation to the remaining bays of Ryazhkov island, including the South bay, where the maximum density of mussels was observed. The size and weight parameters of the mussels in the settlements of the Ryazhkov Island bays and their averaged indices are shown in Table 3. For the Chupa bay, similar indices are presented in Table 4.

Table 3. Average size and weight of the *Mytilus edulis* L. settlements on the littoral of Ryazhkov Island (Kandalaksha gulf).

Parameter	South bay	Bolshaya peschanka bay	Northern bay	Average value
Length (см)	1,92±0,07	1,56±0,08	2,46±0,14	1,96±0,1
Totale weight (g)	1,35±0,16	0,58±0,08	2,53±0,36	1,49±0,2
Soft tissue weight (g)	0,34±0,04	0,16±0,02	0,76±0,1	0,42±0,05
Shell weight (g)	0,55±0,05	0,25±0,03	1,03±0,13	0,61±0,07
SLM, g	0,57±0,07	0,19±0,03	0,90±0,15	0,55±0,08

The mussel of the Chupa bay is characterized by larger sizes of shells, the average length varies from 1.94 to 2.63 cm in the bays, and an average size is 2.20 cm. It was found that the ratio of the weight of soft tissues to the mass of the shell (STM/SM) in the mussel of the Chupa bay was 0.33-0.46, on average 0.38, while in the Ryazhkov island this index for separate bays was 0,62-0,73 and on the average - 0,68. Thus, it can be concluded that in the Chupa Bay mussels, having a large length of shells, are inferior to the mussels of the Ryazhkov island in terms of body weight. In terms of the weight of soft tissues to the total mass of the mollusk (STM/MW), it can be said that the yield of the "finished product" in the Chupa bay is 20%, and at Ryazhkov Island 28%, this data must be taken into account for organizing aquaculture in Kandalaksha gulf.

Table 4. Size and weight structure of the *Mytilus edulis* L. settlements on the littoral of Chupa bay (Kandalaksha gulf).

Parameter	Seldyanaya	Left bay	Round bay	Average

	bay			value
L, см	2,63±0,25	2,04±0,03	1,94±0,14	2,20±0,14
MM, g	2,45±0,19	1,09±0,08	1,12±0,07	1,55±0,11
STM, g	0,46±0,03	0,27±0,06	0,21±0,05	0,31±0,05
SM, g	1,18±0,09	0,59±0,09	0,62±0,09	0,80±0,09
SLM, g	0,83±0,08	0,25±0,02	0,19±0,07	0,42±0,06

3.1.3. Age structure of settlements

The maximum age observed of the mussels inhabiting Ryazhkov island was: in the Bay Bolshaya Peschanka - 6 years, in the Southern Bay - 6 years, in the Northern bay - 8 years (Figure 12). Thus, the most older mussels were recorded in the Northern Bay, and individuals aged 4-5 years (44.4%) form the basis of the settlements.

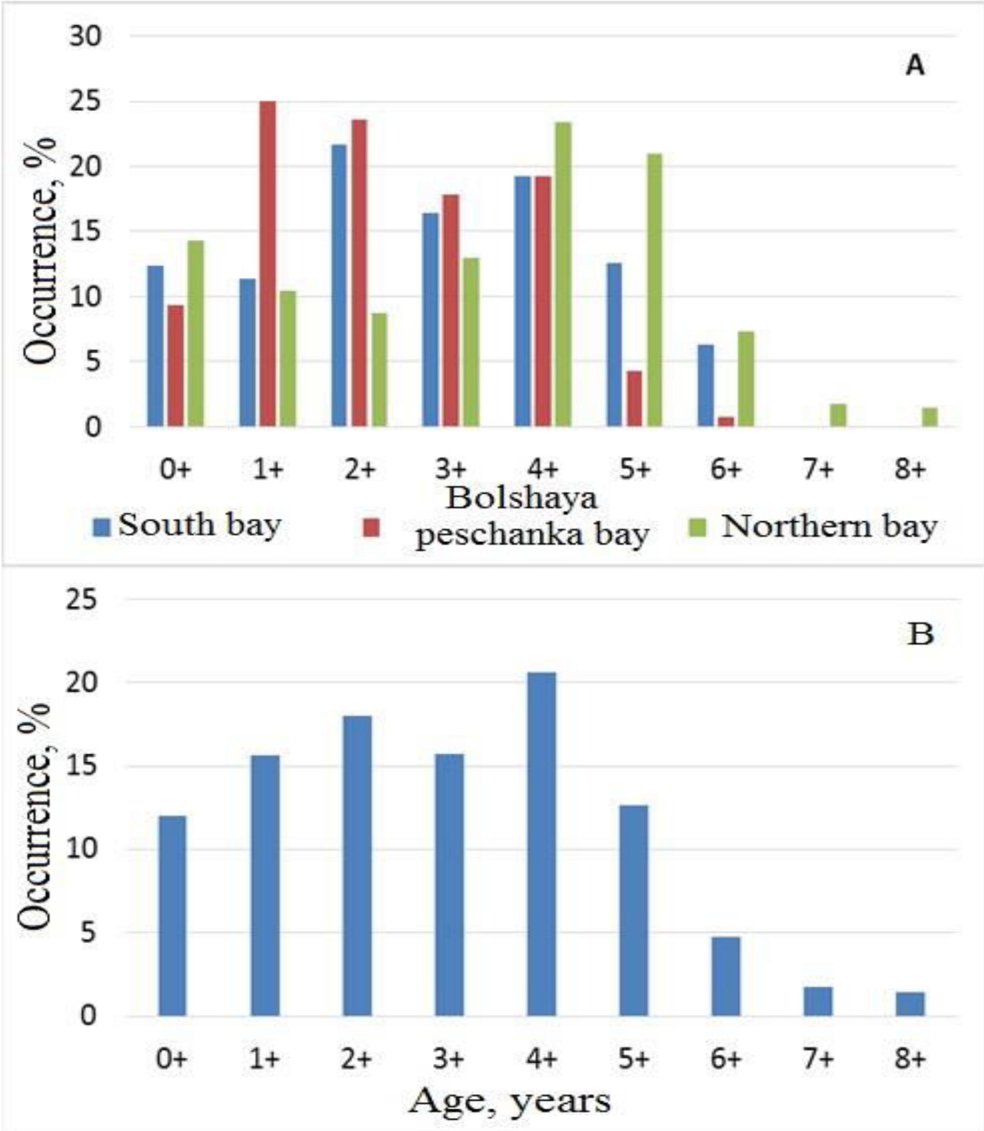

Figure 12. Age structure of the mussel of the three settlements in Ryazkhov island bays (A) and in the Ryazhkov Island, all settlement combined(B).

In general, the island's water area is characterized by a normal distribution of mussels by age groups, which indicates normal functioning and development of settlements.

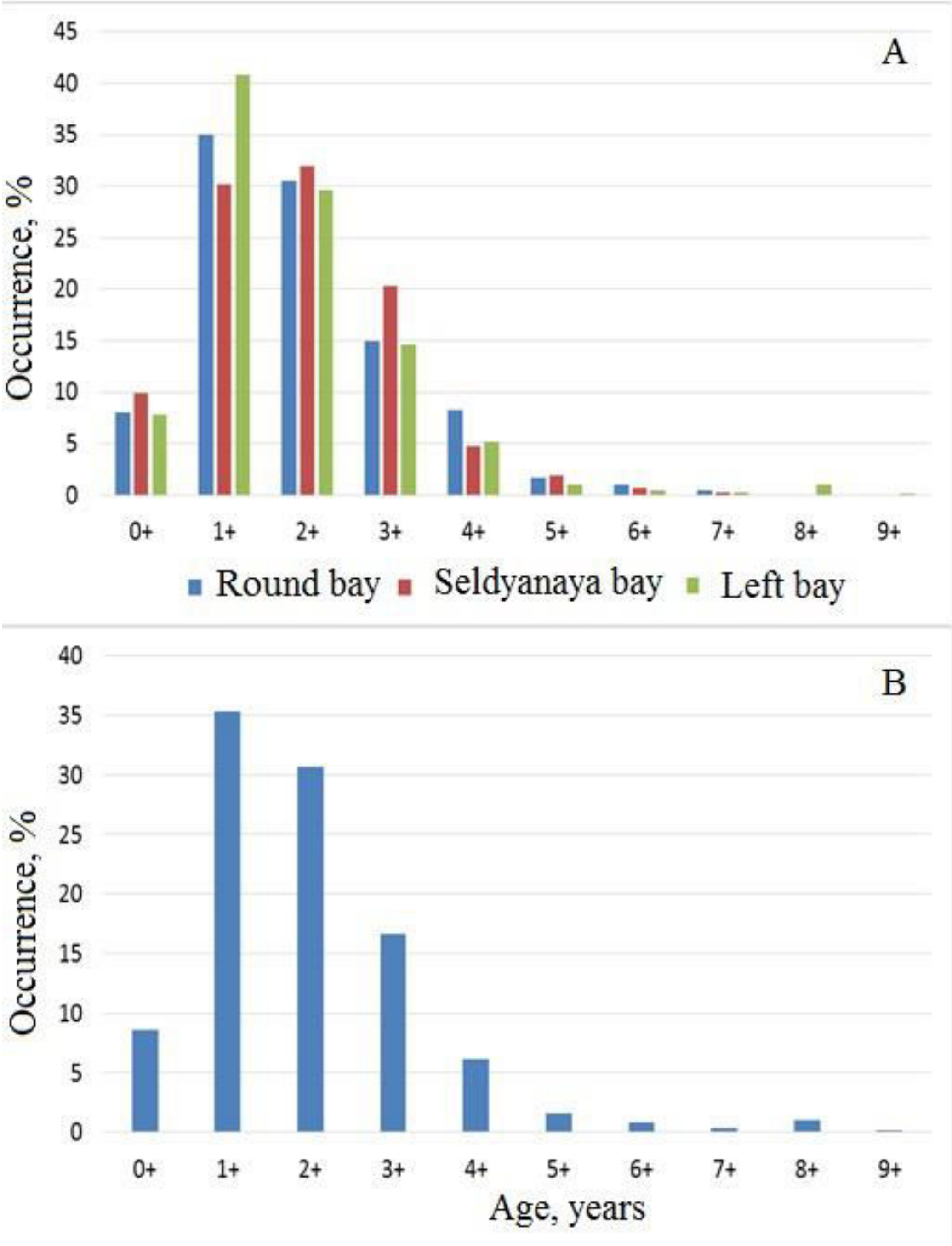

Figure 13. Age structure of the mussel settlements in Chupa's bays (A) and all settlement combined (B).

Despite the fact that in Chupa Bay the maximum observed age is 9 year, which is higher than that of Ryazhkov Island, in general, the settlements of this bay are "younger" than in the island. In all the bays of the Chupa Bay, individuals 1-3 years old dominate the settlements (Figure 13).

3.1.4. Growth of mussels on littoral of Kandalaksha Bay.

To determine the growth of mussels in the Kandalaksha Gulf of the White Sea, the parameters of the Bertalanffy growth equation were determined. (Table 5). Also graphs were plotted. This graphs reflect the growth of mussels in the settlements near the Ryazhkov island and in the Chupa bay of the Kandalaksha gulf (White Sea) (Figure 14).

Table 5. Parameters of the growth function for determining the growth of the mussels in Ryazhkov Island and Chupa bay Bay (Kandalaksha gulf, White Sea).

Research area	**Parameter**		
	k	**L_∞**	**t_0**
Ryazhkov island	0,16	4,99	-1,19
Chupa bay	0,14	4,53	0,85

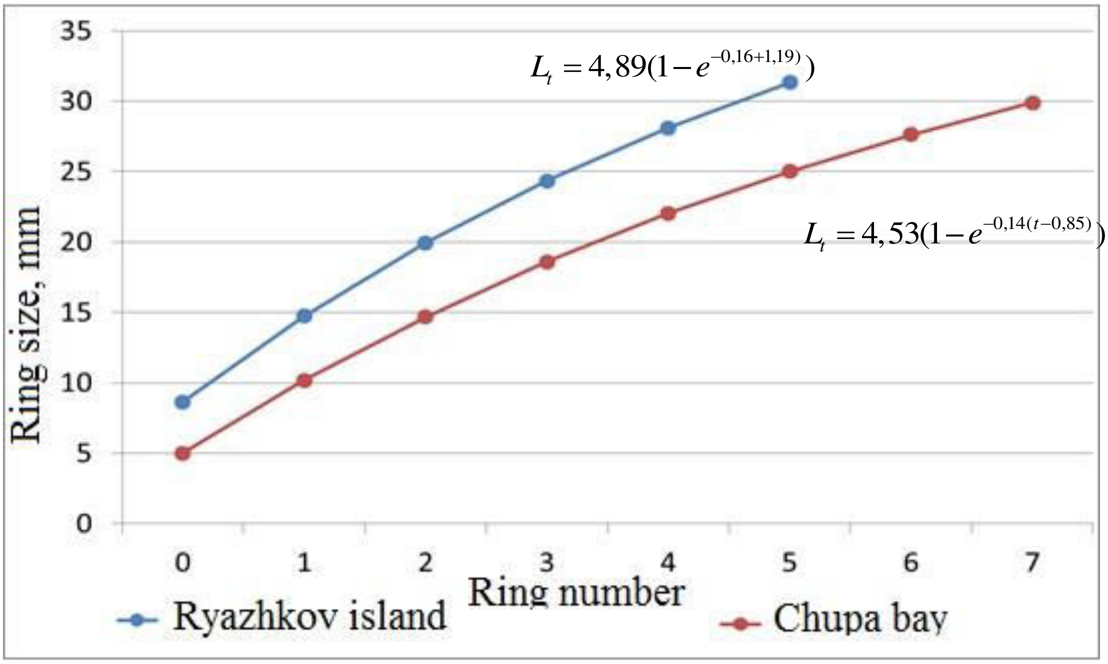

Figure 14. Mussel growth near Ryazhkov island and Chupa bay (Kandalaksha Gulf, White sea)

3.2 Settlement characteristics of the mussels inhabiting littoral zone in Kola Bay of the Barents Sea

3.2.1 Abundance indexes of settlements

In the Kola Bay, the density of mussels in the littoral settlements varies from 2133 ind./m2 to 7125 ind./m2, increasing from the south to the north (Figure. 15). The high density of the mussels at the mouth of the bay is associated with the stony type of the littoral, which causes a large surface area for attachment of mollusks, as well as intensive water exchange. The size and weight characteristics of the mussels that inhabit the littoral in the area of the Rethinsky cape surpass the mussels from the rest of the investigated areas.

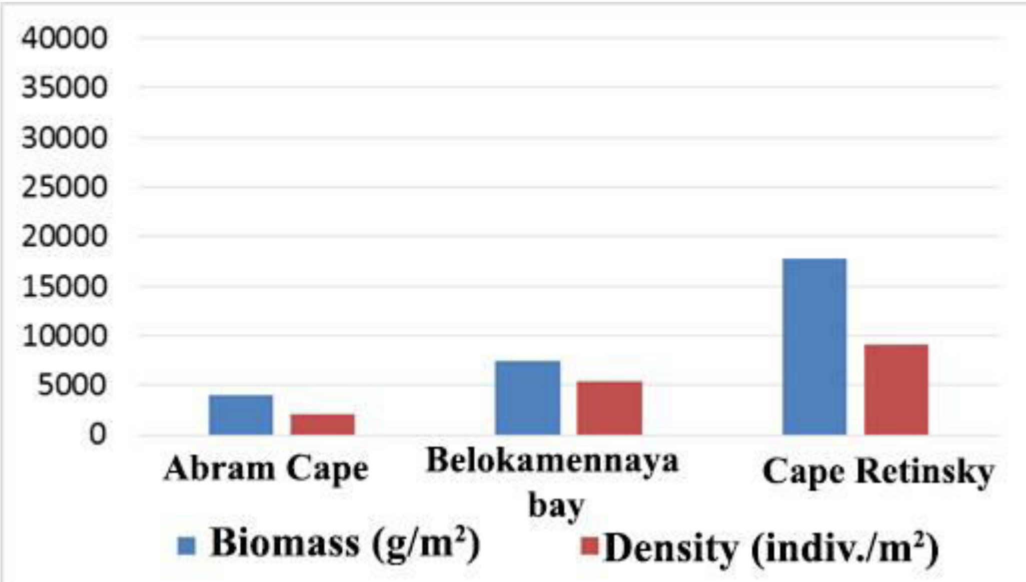

Figure 15. Indicators of the mussel settlements abundance on the littoral of the Kola Bay.

The biomass of mussels also increases towards the northern knee and varies from 4.7 kg / m2 to 17.1 kg / m2. At all sites, the values of density and biomass of mussels increase from the upper horizon to the lower horizon.

3.2.2 Size and weight distribution

According to the results of the study, it was found that mussels do not inhabit the upper horizon of the littoral. In general, the average length of the mollusc shell in the Kola Bay was 3.4 cm. But this parameter, as well as the weight of the mollusk, shell and soft tissues, do not remain constant in the water area of the bay, but increase in the direction from the southern knee to the northern one, and also Increase from the middle horizon to the lower horizon (Table 6). The largest individuals are found on the lower horizon of the littoral.

Table 6. Size and weight structure of *Mytilus edulis* L. settlements on littoral of Kola bay

Sampling area	**Horizon**	**L, см**	**MM, g**	**STM, g**	**SM, g**
Abram cape	Middle	2,3±0,2	1,22±0,41	0,57±0,17	0,32±0,1
	Low	2,5±0,1	1,46±0,12	0,63±0,06	0,39±0,03
Belokamennaya bay	Middle	2,3±0,6	1,68±0,41	0,90±0,25	0,70±0,16
	Low	3,6±0,2	2,34±0,41	0,95±0,12	0,76±0,14
Cape Retinsky	Middle	3,4±0,6	6,54±2,79	1,78±0,59	2,89±1,36
	Low	4,2±0,5	9,42±2,56	2,20±0,54	3,01±1,21
Average		3,4±0,3	4,4±1,03	1,26±0,24	1,39±0,46

Note: "±" - confidence interval.

3.2.3. Age structure of settlements

The age structure of the mussel population in the Kola Bay is heterogeneous (Figure 16). Abram-Cape region is characterized by predominance of individuals of younger age groups (up to 4 years), and the maximum noted age of individual individuals here did not exceed 5 years. Juvenile individuals also predominated in the Belokamennaya bay, but there were individuals under 6 years old, and the widest age group (up to 7 years) was recorded in the estuary of the bay. At the Cape Retinsky the basis of the mussel settlements was formed by mature individuals at the age of 5 (27%).

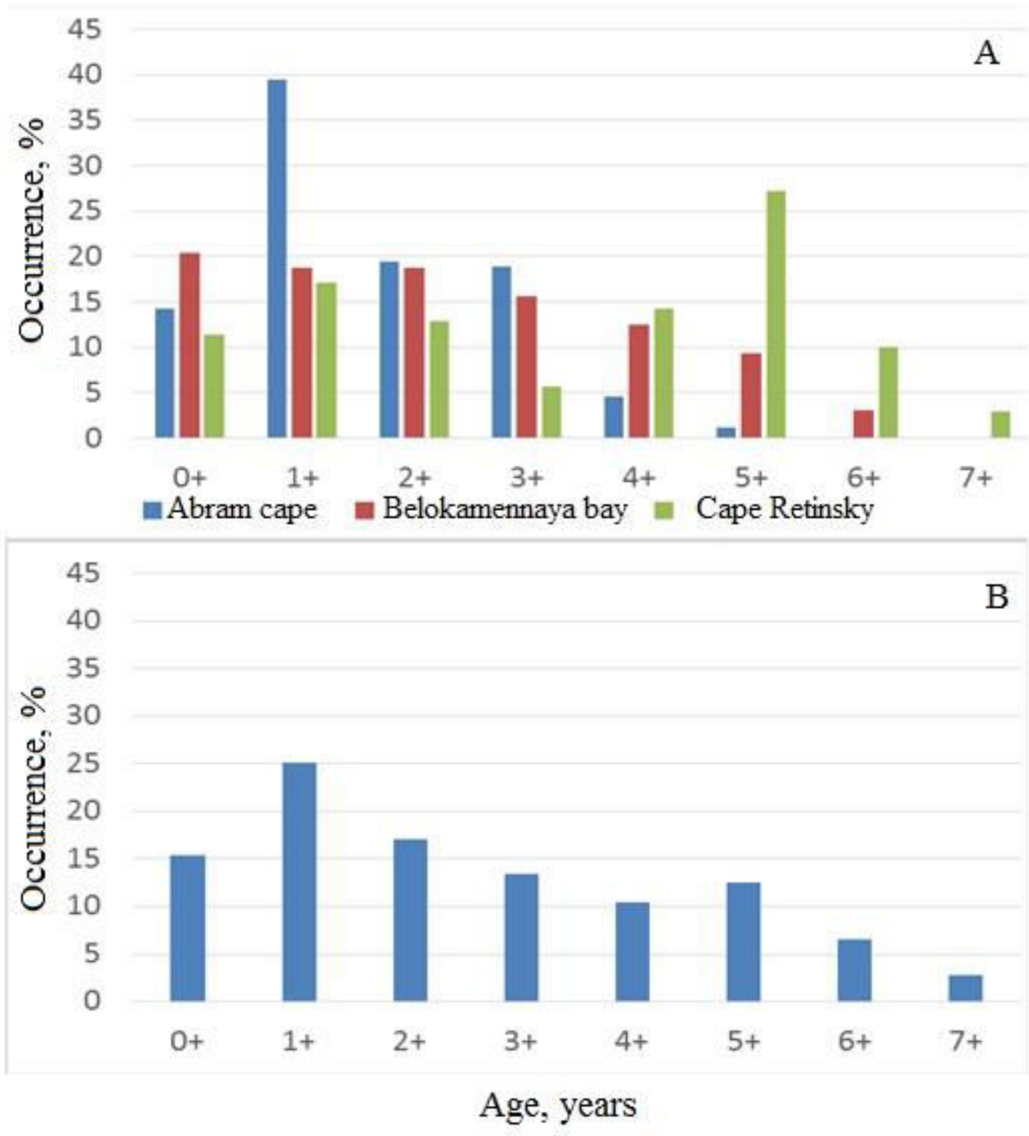

Figure 16. Age structure of mussel settlements in the studied areas (A) and all settlement combined (B).

The average age of the mussels (defined as the weighted average of the number of individuals for each age class in the settlement) in the surveyed areas of the Kola bay littoral varied from 1.6 to 3.9 years (Figure 17).

Results of the research show that the largest individuals with maximum age (the maximum age of 7 years with a length of the shell 4.5 cm) are found in the northern knee of the Kola Bay, forming the densest settlements in comparison with other parts of the gulf.

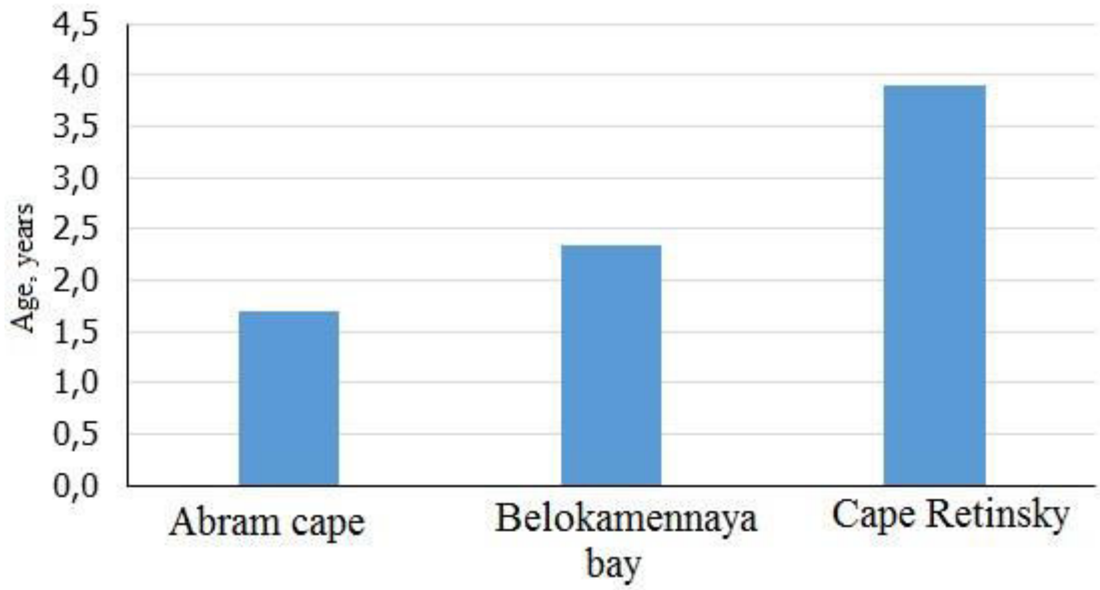

Figure 17. Average age of *Mytilus edulis* L. mussels in the studied settlements.

3.2.4 Growth of mussels on littoral of Kola Bay.

Considering the growth rate of mussels on the littoral in different parts of the Kola bay, it was noted that the maximum rate of growth is typical for molluscs living on the lower horizon of the littoral (Figure 18).

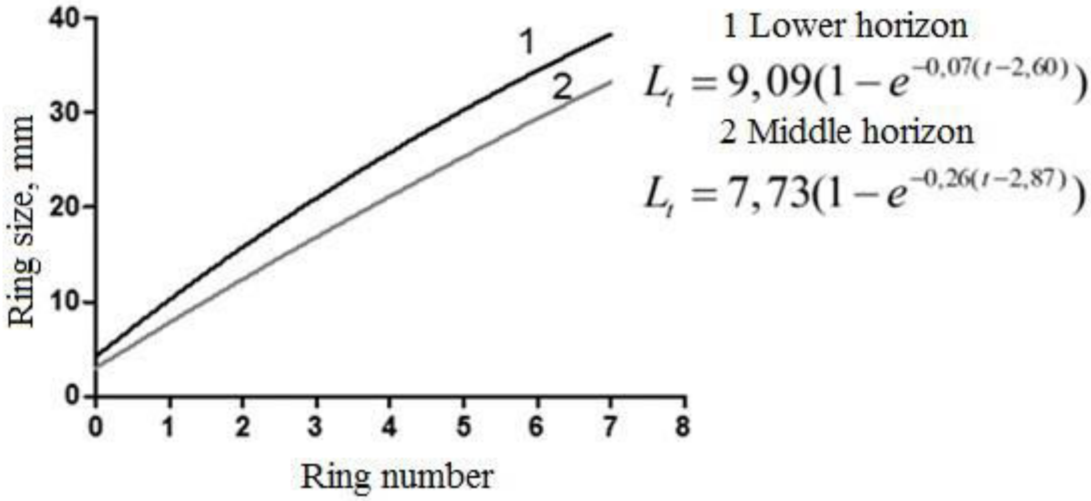

Figure 18. The growth of mussels in the area of the Abram-Cape.

This phenomenon is typical for the entire Kola Bay, since the value of the coefficient L_{max} (the average limiting length of the mollusk of the studied population) is higher in the lower horizon, compared with the average in all investigated regions. Many authors (Savilov, 1953, Briggs, 1982, Seed, 1979, Kulakovsky, 2000) noted such pattern for mussels of natural settlements. In addition, an increase of this coefficient was revealed in the toward direction to the mouth of the Kola Bay. The maximum value of L_{max} is determined for mussels that inhabit northern knee of the Kola bay - 16.05 (Figure. 19).

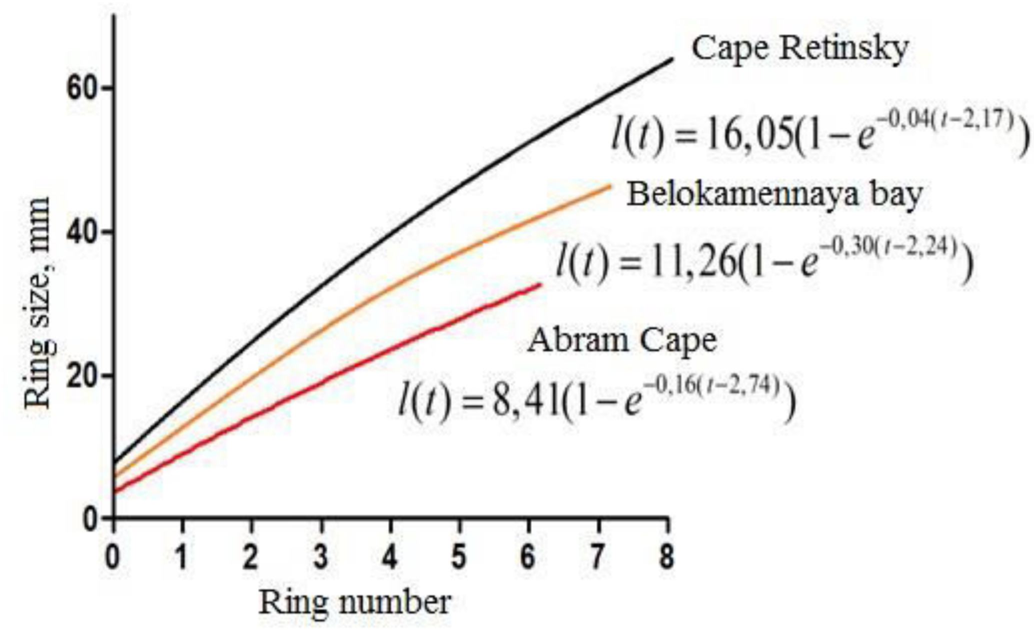

Figure 19. Dynamics of mussel growth in the investigated areas of Kola bay.

3.3 Settlement characteristics of the mussels inhabiting littoral zone of the coastal part of the Norwegian Sea

3.3.1 Abundance indexes of settlements

At a high density of settlements of mussels (23533 indv/m^2) on the littoral of the fjord Balsfjord, their biomass is relatively low (7.8 kg/m^2) (Figure 20). First of all, this is due to the size and age composition of the population.

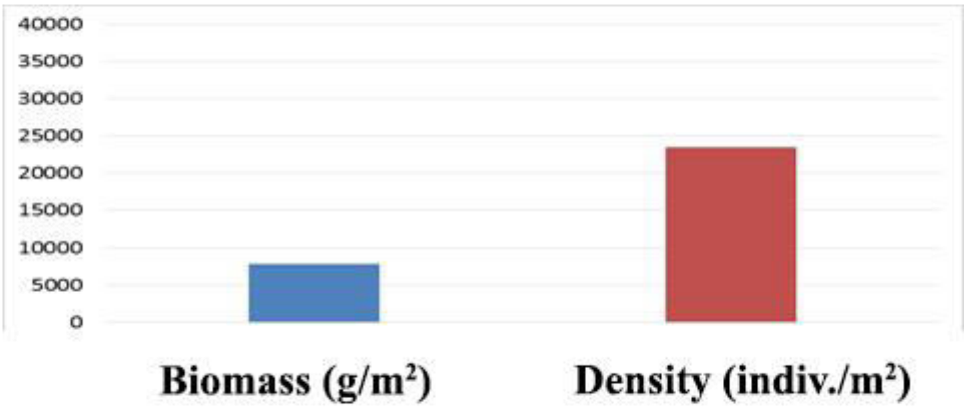

Figure 20. Abundance indicators of the mussel settlement in littoral zone of fjord Balsfjord (Norwegian sea).

3.3.2. Size and weight structure of settlements

The basis of the mussel settlements in fjord is formed by small individuals with an average length of 1.2 cm and a mass of 0.85 g (Table 7). The average ratio of the soft tissues weight to the total mass of the mollusc (Mm / M) is 0.2, and to the shell weight - 0.38.

Table 7. Size and weight structure of mussel settlements in fjord Balsfjord (Norwegian Sea).

Parameter	**Value**
L, см	1,2±0,19
MM, g	0,85±0,11
SM, g	0,44±0,07
STM, g	0,17±0,01

3.3.3. Age structure of settlements

This is a "young" settlement, the core of which consists of settled individuals and juveniles (Figure 21). The maximum age of mollusks reached 5+ years.

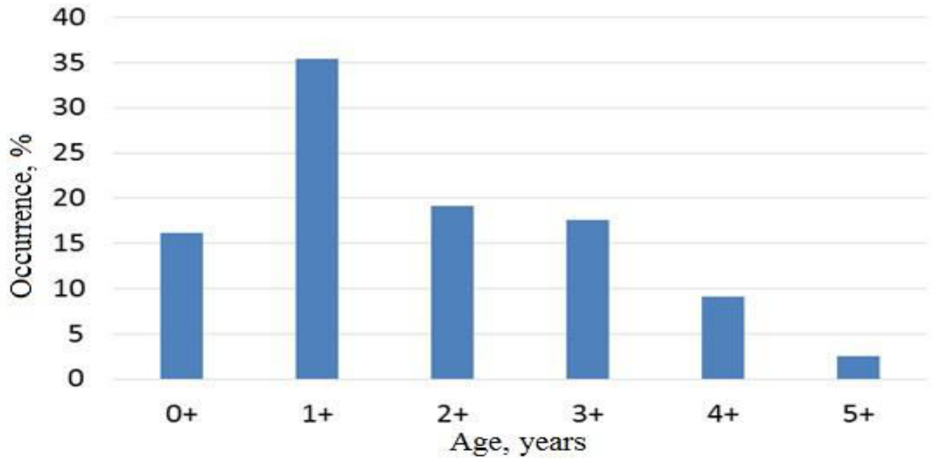

Figure 21. Age structure of mussel settlements in fjord Balsfjord (Norwegian sea).

3.3.4. Growth of mussels on littoral of fjord Balsfjord.

According to the calculated parameters of the Bertalanffy equation (k = 0.156, L_∞ = 3.58, t_0 = 0.26), the mussel growth rate curve was obtained. (Figure. 22).

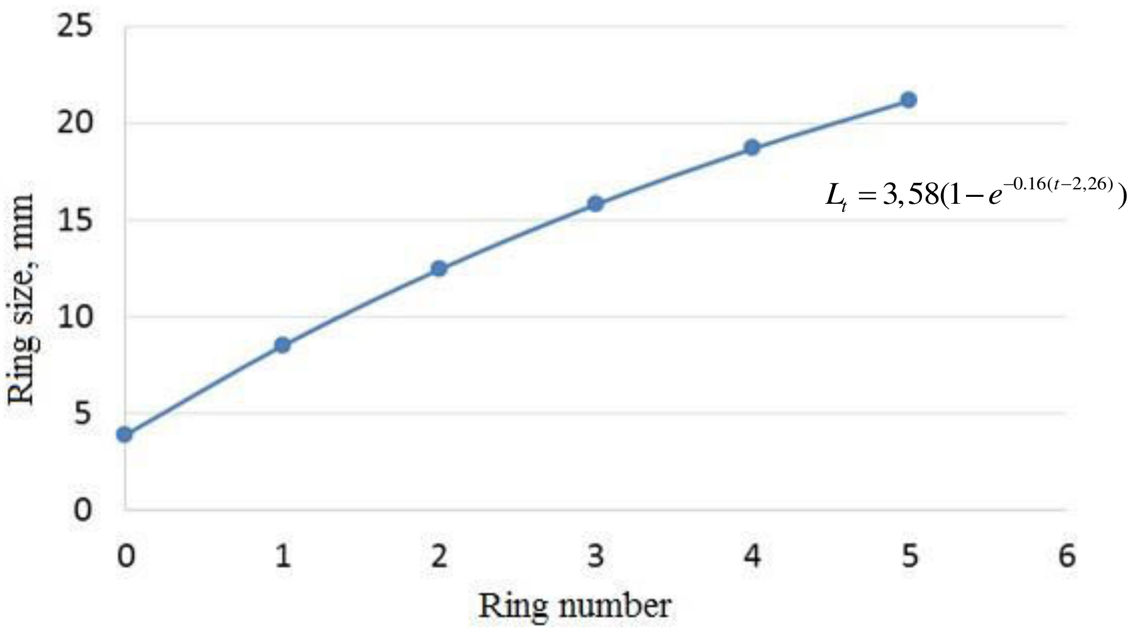

Figure 22. Growth of mussels on littoral zone of fjord Balsfjord (Norwegian Sea).

4. Discussion

4.1 Comparison of mussel settlements characteristics of the White, Barents and Norwegian seas

The highest density of mussels were observed in the southern bay of the Ryazhkov Island (Figure 10). The minimum values of the abundance and biomass of the settlements are observed in the Bolshaya Peschanka Bay, which is primarily associated with the sandy type of the littoral and the absence of stony-boulder girdle in this bay. Relatively high indices of abundance in South and Northern bays can be explained by the predominance of the rocky type of the littoral, which causes a large surface area for attachment of molluscs to the substrate. At the same time, in Southern Bay, where the maximum density of mussels is recorded, their biomass is than in Northern Bay, which is primarily due to the difference in the size and weight characteristics of molluscs in these settlements. Our studies have shown (Fig. 14) that mussels from the settlements of Ryazhkov island have higher shell growth rates than in Chupa bay.

From the foregoing it follows that the highest density and biomass indicators were recorded in the Chupa bay, the basis of the settlements is formed by individuals aged 1 to 3 years and in Ryazhkov island - 4-5 years. The highest rates of growth are typical for mollusks of the littoral of the Ryazhkov Island.

Mussels lead an attached lifestyle and prefer rocky soils, but can also settle on sandy areas of the bottom with small stones or pebbles. In addition, as a substrate, small pebbles and sand, fastened with bisus threads, can be used. Mussels on the littoral of the Kola Bay do not form a distinctly expressed belt except for a site in the area of the Rietinsky cape.

Perhaps this is due to the fact that on the lower horizon there is an increased water exchange, which provides mussel with food and promotes self-cleaning processes.

According to observations, it was found that in all the investigated settlements of the Kola Bay, a significant part is composed of settled individuals and juveniles, which is an indicator of the normal development of the settlement. Domination by the number of mussels at the age of 1-3 years is probably interlinked with the fact that each year there is an intensive settling of juveniles and relatively less elimination. However, it is known (Agarova, 1979) that the replenishment of littoral settlements with juveniles is strongly interrelated with the abiotic factors of the environment and with the total duration of drainage during the larval deposition period.

Study of the growth patterns molluscs is a considerable interest for analyzing their production capabilities, age-specific features of energy metabolism, and also energy flows through populations (Zotin, Ozernyuk, 2004). An additional interest in the study of growth is connected with the apparent differences in growth rates of mussels on artificial substrates and in natural conditions (Bayne, 1980; Kautsky, 1982; Thompson, 1984).

Considering the growth rate of mussels on the littoral in different parts of the Kola bay, it was noted that the maximum rate of growth is typical for molluscs living on the lower horizon of the littoral (Figure 18).

This phenomenon is typical for the entire Kola Bay, since the value of the coefficient Lmax (the average limiting length of the mollusk of the studied population) is higher in the lower horizon, compared with the average in all investigated regions. Many authors (Savilov, 1953, Briggs, 1982, Seed, 1979, Kulakovsky, 2000) noted such pattern for mussels of natural settlements. In addition, an increase of this coefficient was revealed in the toward direction to the mouth of the Kola Bay. The maximum value of Lmax is determined for mussels that inhabit northern knee of the Kola bay - 16.05 (Figure. 19).

During the study of mussel population in the coastal part of the Norwegian Sea, a high density of molluscs' settlements with their relatively low biomass was recorded. The basis of the settlements is composed of settled individuals and juveniles. The maximum age of molluscs is 5 years. The nature of linear growth of mussels in the Norwegian Sea is similar to mussels from the Barents and White Seas. However, the growth rate of mussels in the Norwegian Sea is lower than that of mollusks from other areas studied.

Based on the results of the studies, a summary table of the population characteristics of mussel settlements in the Barents sea (Kola bay), White sea (Kandalaksha bay) and Norwegian sea (Balsfjord) has been obtained (Table 8). Average parameters of mussel growth in these seas are presented on fig. 23.

The analysis of own observations makes it possible to establish that among the surveyed bays, the densest settlements of mussels are noted in the fjord Balsfjord, but due to the fact that this settlement is the "youngest" and the mollusks have the lowest rate of growth, their biomass per unit area is minimal comparing with Barents and White Seas. In the Kandalaksha Gulf, there is a maximum biomass of mollusks per unit area, but with a relatively equal average age of mollusks in the settlements of the White and Barents seas, in the Barents Sea, the mussels are significantly larger due to a higher growth rate, and have a greater weight. From a practical point of view, to estimate the value of possible food products, we are interested in the mass of the soft tissue of the mollusc and its relationship with the total mass and shell weight. Results of these calculations are presented in Table. 9.

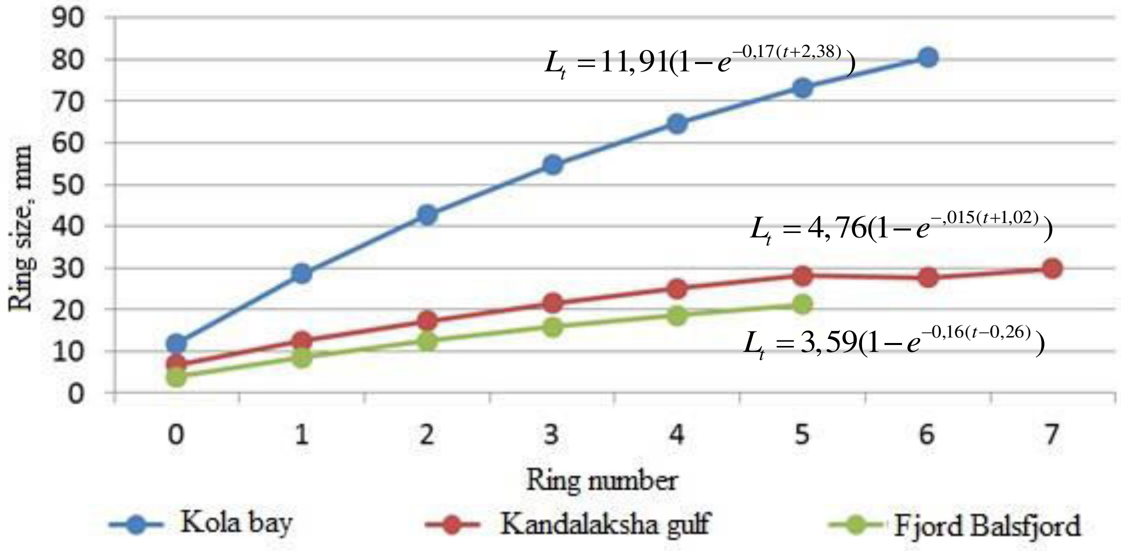

Figure 23. Growth of mussels settlements in Barents (Kola bay), White (Kandalaksha gulf) and Norwegian (fjord Balsfjord) seas.

Table 8. Population characteristics of mussel settlements in Barents (Kola bay), White (Kandalaksha bay) and Norwegian (fjord Balsfjord) seas.

Research area	**Biomass, kg/m²**	**Density, thousand indiv./m²**	**L, см**	**MM, g**	**STM, g**	**SM, г**	**Average age, years**
Kola bay	9,75	5,57	3,43	4,41	1,26	1,39	3,05
Kandalaksha gulf	25,75	16,82	2,09	1,52	0,37	0,71	2,92
Fjord Balsfjord	7,81	23,53	1,2	0,85	0,17	0,44	2,26

Table 9. Ratio of some mussels parameters from settlements in Barents (Kola bay), White (Kandalaksha gulf) and Norwegian (fjord Balsfjord) seas.

Research area	**STM/SM**	**STM/MM**	**Production output per unit area, kg/m²**
Kola bay	0,91	0,29	7,02
Kandalaksha gulf	0,52	0,24	6,14

Fjord Balsfjord	0,39	0,20	4,00

In the Kola Bay, where the mussels have the highest growth rates of the shell, the maximum relative weight of the soft tissue mass is observed. Apparently, this is due to the fact that in the mixing zones of salt and fresh water a complex system of currents is formed, contributing to the detritus settling - the main component of mussel nutrition. The body weight of the mollusk in the Kola Bay is only 9% below the weight of the shell, compared to 48% in the Kandalaksha Bay, and 61% in the fjord of the Norwegian Sea. In relation to the total weight of the mollusc, the food production output (STW) is 29% in the Kola bay, 24% in the Kandalaksha gulf and 20% in Balsfjord. If we take into account the density of settlements in these bays, it turns out that in the Kola bBay, where the density of settlements is minimal (5.57 thousand indiv./m^2) and more than 4 times inferior to this value in the Norwegian fjord (23.53 thousand indiv./m^2). Thus, the maximum growth rates of the molluck are recorded in the Kola Bay, and at the same time, based on the ratio STW/SW, a significant part of the energy is invested in increasing body weight, it can be assumed that the most favorable conditions for the mussel settlements are formed here.

Conclusion

The most dense settlements of mussels are found in the fjord of the Norwegian Sea, they have low growth rates and their biomass per unit area is minimal, in comparison with the gulfs of the Barents and White seas. In the Kandalaksha gulf, with a high density of molluscs, their maximum biomass per unit area is noted. In the Kola bay, the maximum growth rates of the molluscs are noted, and at the same time, based on the ratio STW/SW, a significant part of the energy is invested in enlargement of body weight, so it can be assumed that the most favorable conditions for the mussel settlements are formed here.

Taking into account the physical and geographical characteristics of the research areas, it can be assumed that the waters of the fjords of the Norwegian Sea are subject to the greatest influence of warm Atlantic waters. But they go deep into the continent, which probably causes the freshening and stagnation of the coastal waters due to the large number of skerries. The waters of the White Sea are characterized by a strong temperature drop and considerable cooling in winter, the water area of the sea in winter is covered with ice, and the salinity is below oceanic. The Barents Sea occupies an intermediate position. Here there is a weakened effect of warm waters of Atlantic origin, the salinity of the sea is close to the norm and there is an open water exchange in the estuary of the Kola bay. All these factors form favorable conditions for nutrition and individual growth of mussels, but the lack of a substrate affects the density of settlements. In the White Sea, apparently, on the contrary, with the availability of the substrate and high densities of settlements, more severe conditions inhibit the speed of individual development of the mussels.

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