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Linear growth and yield of bivalve mollusks *Mya Arenaria* linnaeus, 1758 in the conditions of the littoral of the barents and white seas

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Abstract. *Mya arenaria* are large bivalve mollusks burrowing into the ground. Mollusks are widespread in the northern hemisphere. The growth patterns of *M. arenaria* were studied in the arctic part of the species' geographic range. As a result of the research, it was revealed that the mollusks from the Severnaya Inlet of the Kandalaksha Bay of the White Sea have the highest growth rate. The limiting shell length is L∞=174.7 mm, and the rate of growth retardation is k=0.0518 year–1. The mollusks from the Yarnishnaya Inlet of the Barents Sea have the lowest growth rates L∞=84.27 mm, and the rate of growth retardation is k=0.0721 year-1. A positive correlation was found between the nature of the soil and the limiting shell length of mollusks (r = 0.94).

1. Introduction

The study of the patterns and characteristics of the growth of living organisms is one of the fundamental tasks of developmental biology. Growth rate is the main mechanism of adaptation of species and populations in general to different conditions of existence. Of particular relevance and significance are studies carried out in conditions of high latitudes, on the shelves of the Arctic seas. Knowledge of the patterns of growth of organisms, in addition to the fundamental role, is extremely important from a practical point of view, since this process is associated with the development of mariculture, rational use of natural resources, assessment of anthropogenic load on marine ecosystems.

To describe growth from a mathematical point of view, researchers at different times proposed different formulas and equations (Gompertz function, Bertalanffy equation, physical and chemical growth theory of S. Brody, T. Robertson, W. Ostwald, balance theory of growth by Zaik V.A., phenomenological theory of growth by Zotin A.I., Zotin R.S.). Nowadays, many studies have been carried out on the linear growth of bivalve mollusks [1-10], and *Mya arenaria* in particular [11-20]. However, this topic does not lose its relevance to this day.

In the tidal zone, the impact of natural factors on benthic invertebrates reaches maximum values both in absolute value and in duration, frequency and amplitude, which is reflected in the growth rate, feeding rate, metabolic rate, etc.

The bivalve mollusks *Mya arenaria* Linnaeus, 1758 are one of the few species that have adapted to life in the dramatically changing environmental conditions. These are large bivalve mollusks that burrow into the ground. Mollusks are widespread in the northern hemisphere. *M. arenaria* is an Atlantic boreal species distributed from the Barents and White Seas to the coast of France, Florida, and northern

America. In the Atlantic Ocean, the mollusk inhabits the littoral to the Bay of Biscay and North Carolina, in the Pacific Ocean - to California and the Sea of Japan. *M. araparia* lead a sedentary lifestyle and are able to withstand changes in environmental factors in wide ranges.

The aim of the research was to study the features of the linear growth of the bivalve mollusk *Mya arenaria* in different conditions of the Barents and White Seas, to assess the influence of abiotic factors on the growth rate of mollusks, and to calculate the yield potential.

2. Materials and methods

The growth patterns of *M. arenaria* were studied in the arctic part of the species' geographic range. The study areas were located in the littoral of the Barents Sea (Yarnyshnaya Inlet (wide bench), the Zelenetskaya Inlet (Dalny Beach)) and the White Sea (Severnaya Inlet and Dolgaya Inlet of Kandalaksha Bay, Sorokskaya Inlet and Kolezhemskaya Inlet, Onega Bay) (Fig. 1). The studies were carried out in August 2009-2010. Samples were taken according to standard hydrobiological methods in the littoral zone at low tide. Salinity and water temperature are measured simultaneously with sampling using a handheld refractometer and thermometer. The hydrological characteristics of the study areas (the amplitude of temperatures and salinity, the length of the littoral zone from the water's edge at the syzygy low tide to the line of the syzygy high tide, the type of inlets, the predominant type of soil) were studied on the basis of literature data [25-30]. The mechanical composition of the soil was determined using a set of soil sieves with a mesh size of 10, 5, 2, 1, 0.5, 0.25, <0.25 mm. The graded soil was weighed by fractions, the percentage of each fraction in the sample was determined. It is known that *M. arenaria* mollusks form dense settlements predominantly in silty-sandy soil. Therefore, we included data on the quantitative content of fine fractions with a particle size of less than 0.25 mm and combined fractions of coarse-grained sand with gravel and small stones of 0.25 mm and larger in size.

Figure 1. Map of the study areas.

The biological analysis determined the length of the shell, calculated the value of the annual increment in the length of the shell. Quantitative and dimensional indicators have a non-normal distribution (assessment by the Kolmogorov-Smirnov test) [30-35]. Therefore, data processing was carried out using nonparametric methods of statistical processing, for this, the median (Me) of length, annual increments were calculated, the error (m) and the coefficient of variation (CV,%) were determined. The significance of differences was determined using the Mann-Whitney U-test ($p<0.05$). The age was determined by counting the growth rings formed during the winter cessation of growth and representing thickened growth lines. The nature of the linear growth of mollusks in the settlements was described according to the group age series constructed from the averaged data for each point of the study. The linear growth of the bivalve mollusk *M. arenaria* in the White and Barents Seas was approximated using the Bertalanffy equation:

$$L_t = L_\infty\ (1\text{-}e^{-k\ (t\text{-}t0)}),$$

where L_t – shell length at age t, L_∞ – asymptotic (limiting) length of a mollusk shell, k – rate of age-related slowdown in mollusk growth rate, t_0 – the age that corresponds to the length of the mollusk equal to zero. Coefficients L_∞, k and t_0 were found by the method proposed by Melnikova E.B. (Melnikova, 2009) to determine the coefficients of the Bertalanffy equation in the absence of regular measurements, using the average values of the shell length of the same-aged individuals.

The variability of the maximum size of mollusks (L_{max}), the annual increase in shell length, and the maximum shell length (L_∞) depending on the percentage of fractions with a particle size of less than 0.25 mm in the soil is considered. Linear correlation is considered using Spearman's nonparametric correlation coefficient (r). The conditional assessment of the tightness of the connection between the signs was carried out according to the Chaddock scale, considering the coefficient values less than 0.3 - a sign of lack of connection, values from 0.3 to 0.5 - weak connection, from 0.5 to 0.7 - medium connection, from 0.7 to 0.9 - strong connection, and values over 0.9 - a sign of functional dependence. A statistically significant correlation between 0.5 and more was taken into account.

The yield of *M.arenaria* mollusks is calculated for a single sample:

$$P = ((N_t + N_{t-1})/2)(W_t\text{-}W_{t-1}),$$

where N_t and N_{t-1} — abundance, W_t and W_{t-1} – theoretical values of the average weight of individuals in age groups, t— age (years).

Specific yield is defined as the value of production related to the average biomass for the same period of time (P/B ratio).

Mathematical calculations were performed using the STATISTICA 10.0 software package. To determine the nature of linear growth and analyze the data obtained, a total of 106 mollusk shells were processed.

3. Results

The density of *M. arenaria* settlements in the studied areas had similar values (Table 1). The maximum density was noted in the Kolezhemskaya Inlet of the Onega Bay of the White Sea, the minimum - in the Yarnyshnaya Inlet of the Barents Sea. The mollusks in the Dolgaya Inlet of the Kandalaksha Bay of the White Sea had the highest biomass, and the mollusks of the Kolezhemskaya Inlet of the Onega Bay had the lowest biomass values at the maximum population density.

Table 1. Quantitative characteristics of *M. arenaria* settlements in the studied areas of the Barents and White Seas.

Study area	Density, ind./m^2 M±m	Biomass, g/m^2 M±m
White Sea, Kandalaksha Bay		
Dolgaya Inlet	42.8±4.2	1193.5±4.1
Severnaya Inlet	52.7±2.7	392.3±1.9
White Sea, Onega Bay		
Sorokskaya Inlet	32.5±1.6	482.3±2.3
Kolezhemskaya Inlet	66.7±3.8	214.6±5.1
Barents Sea		
Zelenetskaya Inlet	35.0 ± 0.7	258.0 ± 1.1
Yarnishnaya Inlet	31.0 ± 0.4	329.9 ± 1.0

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Size and age composition of settlements. Mollusks from 3 to 14 years old were found in the White Sea. Studies have shown that in the Kandalaksha Bay of the White Sea, mollusks were represented by ten age classes, the main share was made up of mollusks at the age of 7 years (41.7%) in Severnaya Inlet and 9 (26.7%) years in the Dolgaya Inlet, in Onega Bay - by nine age classes, with a predominance of mollusks at the age of 6 years (29.4%) in the Sorokskaya Inlet and 5 and 7 years (25% each) in the Kolezhemskaya Inlet. In the Barents Sea, the populations consisted of mollusks ranging in age from 4 to 12 years old and divided into nine age classes. The main share was made up of mollusks aged 7 years (30.4%) in the Yarnishnaya Inlet and 6 years old (37.0%) in the Zelenetskaya Inlet (Fig. 2).

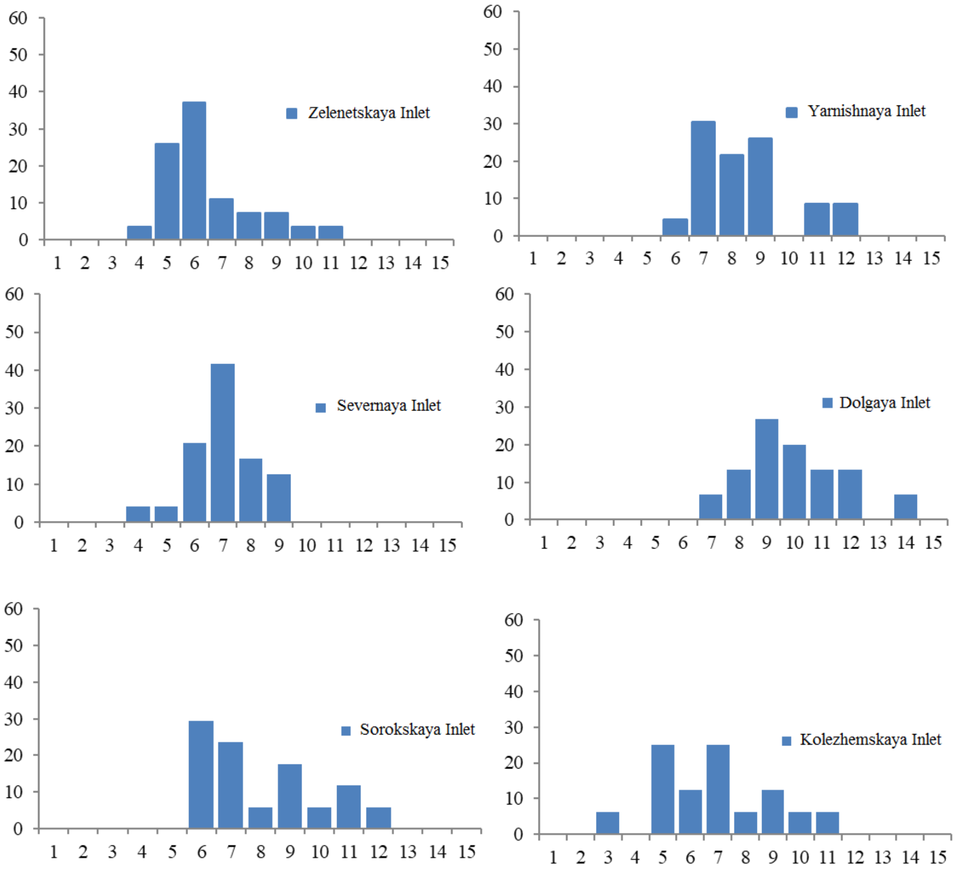

Figure 2. Age composition of the studied populations of *M. arenaria* in the Barents and White Seas (abscissa - age, years; ordinate - frequency of occurrence, %).

The shell length of *M. arenaria* mollusks varied from 26.3 to 62.5 mm in the Barents Sea and from 14.9 to 91.5 mm in the White Sea. The average increase in shell length in the Yarnyshnaya Inlet was 5.4±0.2 mm/year, in the Zelenetskaya Inlet - 4.9±0.2 mm/year, in the Severnaya Inlet and the Dolgaya Inlet of the Kandalaksha Bay, the increase was 6.4±0.2 mm/year and 6.0±0.1 mm/year, respectively. In the Onega Bay, the average increment in shell length in the Sorokskaya Inlet was 5.6±0.4 mm/year, and in the Kolezhemskaya Inlet - 4.2±0.1 mm/year (Fig. 3).

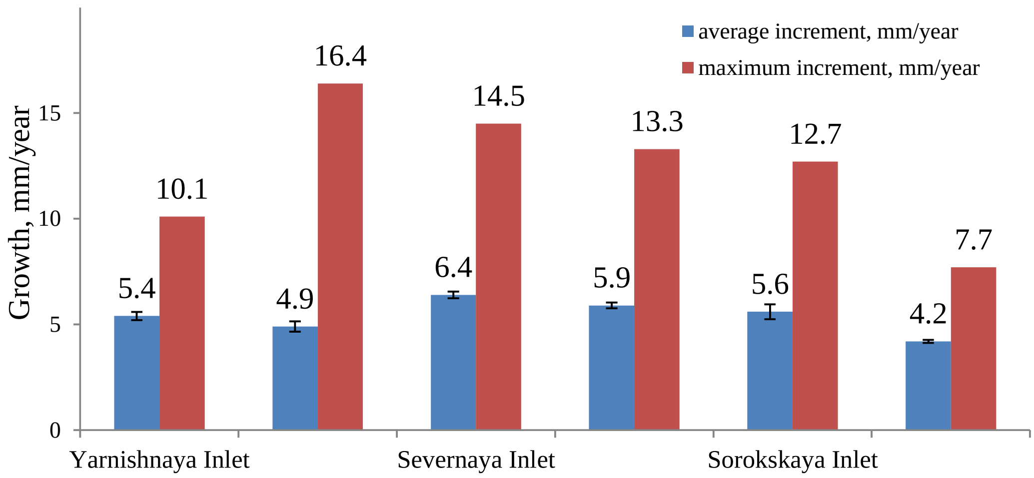

Figure 3. Average and maximum increments of *M. arenaria* mollusks in the studied areas.

The maximum increase in shell length was 16.4 mm/year and was recorded in mollusks in the Zelenetskaya Inlet of the Barents Sea. In the White Sea, the maximum increase was 14.5 mm/year in mollusks in the Severnaya Inlet of the Kandalaksha Bay (Fig. 3). The parameters of the Bertalanffy equation calculated for these mollusks were as follows: for the Zelenetskaya Inlet, the limiting (asymptotic) shell length L∞ was 118.49 mm, the index of age-related growth rate retardation was k=0.0566 year-1, for the Severnaya Inlet - 174.7 mm and 0.0721 year-1, respectively (Fig. 4).

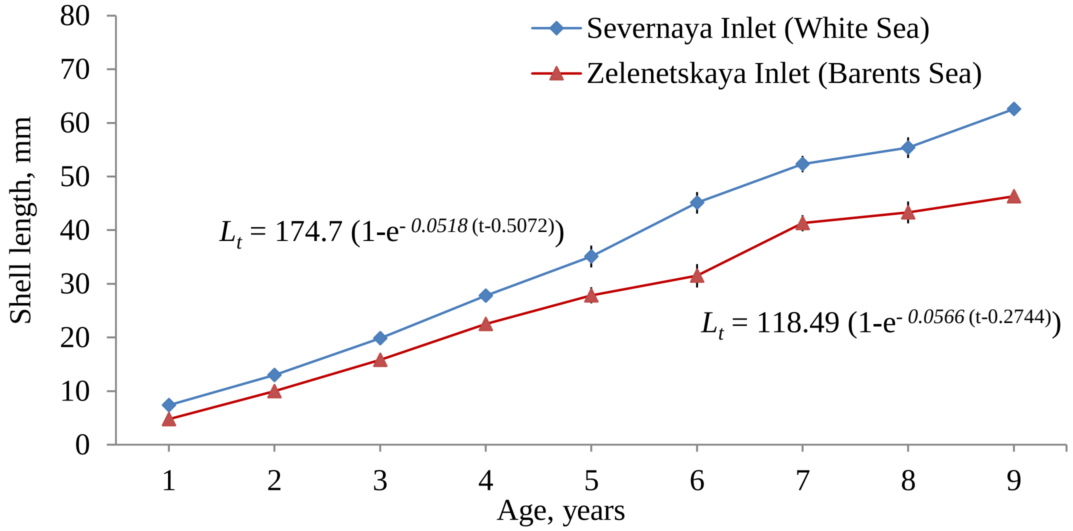

Figure 4. Age-related changes in the shell length of *M. arenaria* mollusks in the Severnaya Inlet of the White Sea and the Zelenetskaya Inlet of the Barents Sea

The analysis of the coefficients of the growth equations made it possible to determine the nature and direction of growth of *M. arenaria* mollusks depending on the study area. The largest limiting shell length (L_∞) is calculated for mollusks living in the Severnaya Inlet, Dolgaya Inlet, Sorokskaya Inlet of the White Sea, the smallest - for mollusks from the Yarnishnaya Inlet of the Barents Sea, the Kolezhemskaya Inlet of the White Sea. The growth deceleration constant (*k*) is most significant in the Yarnyshnaya Inlet of the Barents Sea, and the least in the Sorokskaya Inlet of the White Sea. The t_0 index, which characterizes the time during which the mollusks reach their maximum size, is the highest in the Severnaya Inlet. The t_0 index has similar values for the Dolgaya Inlet of the White Sea and the Yarnyshnaya Inlet of the Barents Sea (Table 2).

Table 2. Indicators of linear growth of *Mya arenaria* in the studied areas of the Barents and White Seas.

Bertalanffy equation parameters	Study area					
	Yarnyshnaya Inlet	Zelenetskaya Inlet	Severnaya Inlet	Dolgaya Inlet	Sorokskaya Inlet	Kolezhemskaya Inlet
L_∞	84.27	118.49	174.70	159.01	169.56	89.69
k	0.072	0.057	0.052	0.049	0.045	0.065
t_0	0.12	0.27	0.51	0.05	0.24	0.16
φ'	2.71	2.90	3.20	3.08	3.11	2.72

Legend: L∞ is the asymptotic (limiting) length of the mollusk shell, k is the index of age-related slowdown in the growth rate of the mollusk, t0 is the age that corresponds to the length of the mollusk, equal to zero.

As a result of determining the granulometric composition of the soil, differences in the habitats of mollusks in terms of the content of finely dispersed fractions were revealed. In the Zelenetskaya, Severnaya, Dolgaya, and Sorokskaya Inlets, the content of particles less than 0.25 mm in size in the soil varied from 49.6 to 60.3%. Here, mollusks had the largest values of the limiting shell length (L∞) (Fig. 5). In the Yarnishnaya Inlet and the Kolezhemskaya Inlet, strong siltation was observed with a prevailing content of fine fractions in the soil of 71.0 and 76.7%, respectively. The indices of linear growth of mollusks are the lowest here: in the Yarnyshnaya Inlet, the limiting (asymptotic) shell length L∞ was 84.27 mm, the growth rate deceleration was k=0.0721 year-1, for the Kolezhemskaya Inlet - 89.69 mm and 0.0650 year-1, respectively (fig. 6). Correlation analysis revealed strong positive relationships between the granulometric composition of the soil and the limiting shell length of mollusks (r=0.94).

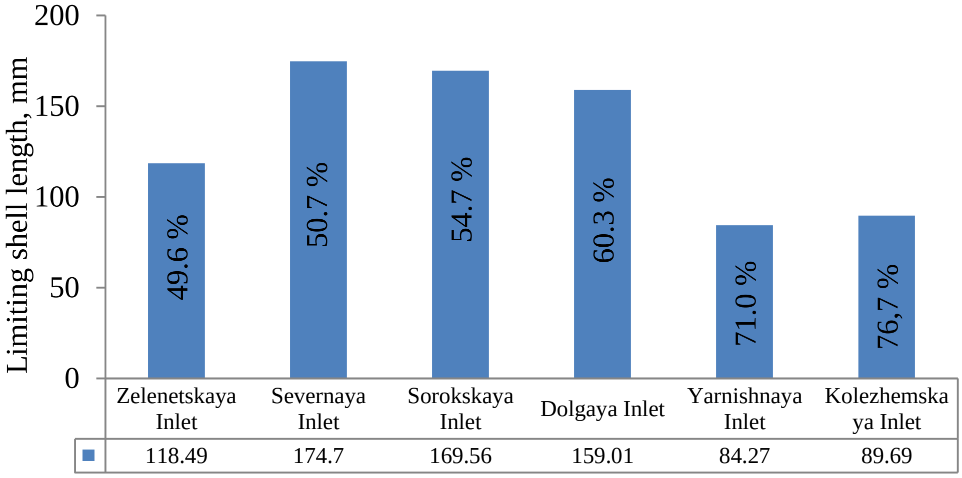

Figure 5. The limiting (asymptotic) shell length of *M. arenaria* mollusks in the studied areas (the histogram indicates the content of the fine fraction in the soil with a particle size of less than 0.25 mm).

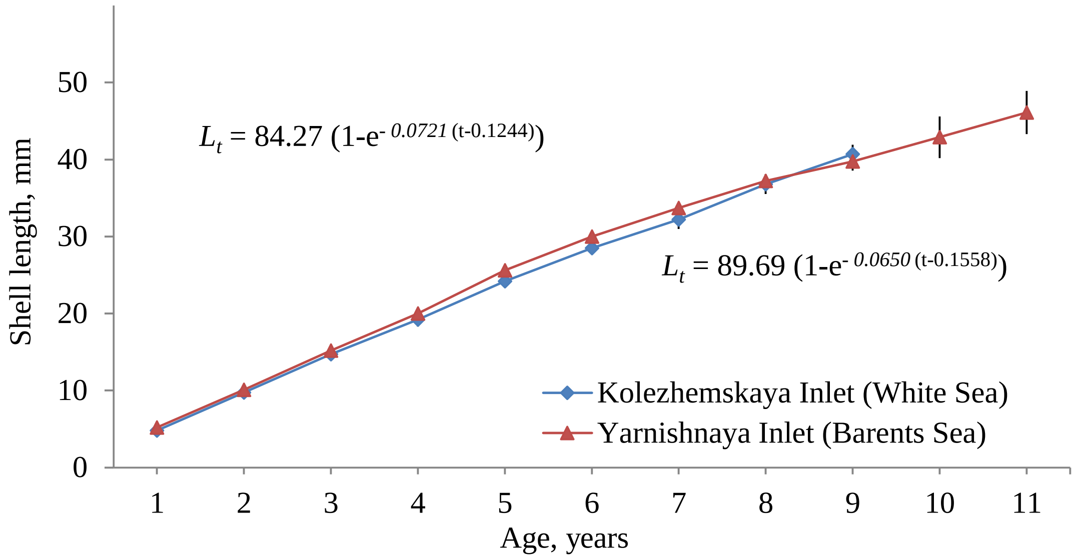

Figure 6. Age-related changes in the shell length of *M. arenaria* mollusks in the Kolezhemskaya Inlet of the White Sea and Yarnishnaya Inlet of the Barents Sea.

The annual yield in the Barents Sea in the Zelenetskaya Inlet was higher than in the Yarnyshnaya Inlet and amounted to 90.5 g/m2 and 44.8 g/m2, respectively; the P/B ratio was 0.35 in the Zelenetskaya Inlet and 0.14 in the Yarnyshnaya Inlet. In the White Sea, the maximum value of the annual yield was obtained for the Dolgaya Inlet of the Kandalaksha Bay, the minimum value - in the Kolezhemskaya Inlet of the Onega Bay and amounted to 166.0 g/m2 and 86.7 g/m2, respectively, the P/B ratio values are 0.17 and 0.40. The yield of mollusks from the Severnaya Inlet of the Kandalaksha Bay was 143.8 g/m2 (P/B ratio 0.27), Sorokskaya Inlet of the Onega Bay - 125.0 g/m2 (P/B ratio 0.20).

4. Discussion

The studied areas of the Barents and White Seas are typical biotopes characteristic of *M. arenaria* settlements. These are apex parts of various inlets with silty-sandy littoral, where the mollusk can form rather dense settlements. Our data on the abundance of *M. arenaria* are comparable with the data of other researchers. Similar indicators of abundance in the White Sea are noted by I.B. Shcherbakov (2006) in the littoral of the Dolgaya Inlet (25.4 ind./m^2) and the Severnaya Inlet (46.7 ind./m^2). In the Kerch Strait of the Black Sea, the density of settlements of this species was up to 23 ind./m^2 (Ivanov, Sinegub, 2007). V.A. Sveshnikov (1963) noted a lower density of mya settlements in the littoral zone of the White Sea (Yuzhnaya Inlet of the Kandalaksha Bay, 14 ind./m^2, the apex part of the Chupa Inlet, 7 ind./m^2). The maximum density of the settlement, noted by us, was 66.7 ind./m^2 in the littoral of the Kolezhemskaya Inlet of the White Sea, while the littoral is characterized by the greatest length (up to 2000 m), strong siltation (76.7%), and maximum freshening (20 ‰) [36].

The settlements of *M. arenaria* in the Barents and White Seas in 2009 were characterized by the prevalence of individuals of middle age groups (6-9 years) with a different frequency of distribution in the study areas. The absence of mollusks at the age of 1–2 years and underyearlings in the samples was noted. According to our sample data, it can be assumed that 2002-2006 were the most favorable years for the recruitment of *M. arenaria* settlements in the areas of the White Sea studied by us, and 2003-2005 - in the Barents Sea.

The analysis of the linear growth of mollusks showed that the most significant factors affecting the linear growth of mollusks is the granulometric composition of the soil. The nature and growth rate are also determined by the amount of fine fractions contained in the soil. For *M. arenaria*, the most favorable is silty-sandy soil with a content of fine fractions of no more than 70%.

It is obvious that for benthic organisms having a stationary lifestyle, an important factor is the nature of the soil. However, the presence of a positive correlation between the nature of the soil and the limiting length of the shell of mollusks cannot be interpreted as a direct effect. In our case, the data on the granulometric composition of the soil in the littoral zone can indirectly characterize the degree of hydrodynamics of the studied areas, which, most likely, determines the feeding conditions of mollusks. Thus, the Zelenetskaya Inlet of the Barents Sea, Dolgaya and Severnaya Inlets of the Kandalaksha Inlet and Sorokskaya Inlet of the Onega Bay, in addition to a similar granulometric composition of the soil, are characterized by the presence of fresh streams in the apex parts, which, most likely, carry out a sufficient amount of suspended organic matter necessary for active nutrition and growth of mollusks.

The linear growth rate of mollusks in the Onega Bay is almost 2 times less than in the Kandalaksha Bay. Despite the milder climatic conditions in the Onega Bay, it is one of the most freshened in the White Sea (Filatov and Terzhevik, 2007). *Mya arenaria* grows more slowly here, which is also reflected in the value of the main indicators of growth rates (L_∞ = 174.7, k = 0.052 - in the Kandalaksha Bay, L_∞ = 89.69, $_k$ = 0.065 - in the Onega Bay). A similar variability can be traced in the studied areas of the Barents Sea. Salinity (32 ‰) and growth rates of mollusks (L_∞ = 118.49, k = 0.057) in the Zelenetskaya Inlet noticeably differ from the salinity values (19 ‰) and growth rates (L_∞ = 84.27, k = 0.072) in the Yarnyshnaya Inlet. The apex part of the Yarnishnaya Inlet is a vast muddy-sandy beach, which is located far from the open sea and is characterized by significant fluctuations in salinity throughout the year. The salinity of the Dalniy beach of the Zelenetskaya Inlet decreases to 23‰ only during the snow melt in spring (Matveeva, 1948).

5. Conclusions

As a result of our research, it was revealed that the mollusks from the Severnaya Inlet of the Kandalaksha Bay of the White Sea have the highest growth rate. The limiting shell length is L_∞=174.7 mm, and the rate of growth retardation is k=0.0518 year $^{-1}$. The mollusks from the Yarnishnaya Inlet of the Barents Sea have the lowest growth rates, L_∞=84.27 mm, and the growth rate deceleration rate is k=0.0721 year^{-}.

The rate of linear growth of mollusks and the increase in biomass (yield) are influenced by the granulometric composition of the soil and different hydrological conditions of the studied areas.

A positive correlation was revealed between the nature of the soil and the limiting length of the shell of mollusks.

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