

# Density of hydrobiont populations in the coastal zone of the Barents Sea and in aquaculture

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**Abstract.** Objects for obtaining additional food sources and maintaining the quality of the environment in multicultural farms of the northern seas can be kelp (*Laminaria saccharina*), sea urchin (*Strongylocentrotus droebachiensis*), mussel (*Mytilus edulis*), which do not require significant costs during cultivation. The aim of the study was to assess the productive potential of species promising for multiculture based on the density of their populations. The work is based on the materials of expeditionary research of marine communities of the Barents Sea and on the analysis of scientific and practical developments on the cultivation of aquatic organisms in the reservoirs of the High North. Kelp and mussels are characterized by a wide range of variation density and biomass, and individual characteristics. On the Murman coast, in natural kelp beds, the average biomass is 1.4–5.4 kg/m<sup>2</sup> (up to 16 kg/m<sup>2</sup>), and the average density is 9–104 specimens/m<sup>2</sup> (up to 172 specimens/m<sup>2</sup>), significantly varying depending on the local conditions of the biotope. The largest biomass values are characteristic of the mussel population at the Kola Bay mouth (4.8–17.8 kg/m<sup>2</sup>), and the highest population density was noted in the bays of the Eastern Murman (45030–61167 specimens/m<sup>2</sup>). Mussels with the largest size and weight (from the studied areas) were found in the Pechenga Bay (shell height 4.3±0.1 cm, mussel weight 6.84±0.34 g). The population density parameters of cultivated species in marine benthic communities, which affect the growth of aquatic organisms, can be recommended for use in multicultural farms of kelp, mussels and sea urchins.

## 1 Introduction

Aquaculture in the northern regions is becoming an important economic sector of human activity. The significant increase in aquaculture production for additional food sources raises the challenge of maintaining the quality of the aquatic environment and preserving natural aquatic communities. Maintaining the quality of the aquatic environment in marine coastal waters requires the creation of multicultural farms using organisms of different trophic levels: producers and consumers – filter-feeders and phytophagous. Cultivated species for which technologies for growing in the natural environment in the northern seas have been developed and tested include kelp (*Laminaria saccharina*), green sea urchin

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(*Strongylocentrotus droebachiensis*), blue mussels (*Mytilus edulis*). These hydrobionts are of the particular interest in connection with the current trend of minimizing the use of artificial feeds when cultivating species in natural conditions. With the joint cultivation of kelp and mussels, it is possible to use the resources of the aquatic environment without adding additional feed. When growing sea urchins in the marine environment, the main food is kelp.

The main goal of aquaculture is to obtain a high biomass of organisms for use both in raw form and for the extraction of biological active substances during further processing. The biological productivity of aquaculture objects is determined by their production characteristics and depends on the morphological parameters, physiological, biochemical and reproductive properties of cultivated organisms embedded in their hereditary development program. The productive characteristics of aquaculture objects through size and weight parameters are related to the functional features of the cultivated species, since there is a relationship between the magnitude of the productive potential and the size of the organism. The biological production of organisms also depends on climatic conditions and, first of all, temperature, photosynthetic active radiation (FAR), the intensity of water movement and other abiotic factors.

The aquaculture object in each particular case is the population of the cultivated species. Population-dynamic parameters of cultivated organisms are formed as resultants of the two main factors complexes: biotic and abiotic. The realization of these parameters depends on the complex of abiotic factors of the environment in which the species is cultivated. The main factor among the biotic ones is, first of all, the population density of cultivated hydrobionts.

The main environmental factors significantly dependent on density are competition for resources and territory, parasitism, various forms of symbiotic relationships, stress, the formation of aggregations and the territorial distribution of organisms in the biotope. The maximum biological production potential, as a rule, is not fully realized in natural populations, since the population density is regulated by a system of resource and interspecific restrictions. The factors constraining the population size and limiting the possibility of realizing the productive potential include many environmental factors. In the case of aquaculture of the primary producer as kelp, the most important abiotic factors limiting population growth will be the FAR and the intensity of water movement in the cultivation area. When growing herbivorous organisms, or the first-order consumers, the most important factors are the food availability and the presence of predators in the environment.

During joint cultivation, the interaction of individual components of the polyculture and the information exchange is carried out through metabolites released by hydrobionts into water. The habitat in the polyculture conditions is formed due to the vital activity of each organism, which carries out growth in accordance with its hereditary program and is realized during ontogenetic development. At the same time, the development program of each population is influenced by a combination of biotic and abiotic factors. Thus, the environment acts as an integrator of all possible positive and negative impacts on the cultivating objects, ensuring the interconnection of all components of the polyculture and the ecosystem as a whole. Management and control of the production characteristics of cultivation objects in aquaculture must be carried out at the level of species, population, community and ecosystem.

The purpose of this work was to use population density parameters of cultivated species in natural marine communities, which affect the growth of aquatic organisms and can be applied in multicultural farms of kelp, mussel and sea urchin. The objective of the study was to assess the productive potential of species promising for aquaculture in the conditions of the northern seas, based on the density of their populations.

## 2 Materials and Methods

This work is based on the analysis of materials of scientific and practical developments on the cultivation technology of hydrobionts in marine reservoirs of the High North and on the materials of own expedition research of marine communities in the Barents Sea [1-25]. The authors analyzed publications on the cultivation biotechnology of kelp [5], mussels and sea urchins [8, 16, 23] in the conditions of the northern seas. The literature data of hydrobiological studies of natural communities on the Murman coast, in which kelp (*Laminaria saccharina*), mussels (*Mytilus edulis*) and sea urchins (*Strongylocentrotus droebachiensis*) are the dominant species, were analyzed.

The work uses the kelp growing experience in the laboratory and on a plantation. The author of the work took part in scientific works when creating a kelp plantation in the Dalnezelenetskaya bay of the Barents Sea. The article presents the authors' data on the density of kelp and mussel populations in various bays of the Murman coast. The methodology of data collection and processing was indicated in detail in our publications [12, 14, 17].

To compare the productivity of commercial hydrobionts in natural populations and in marine cultivation conditions, such an indicator as the biomass concentration in the living space ( $C_w$ ), or habitat density, was used:

$$C_w = \sum W/V,$$

where  $W$  – hydrobionts biomass,  $V$  – living space volume (the nearest living space) [13].

## 3 Results and Discussion

In the coastal waters of the Barents Sea, kelp (*L. saccharina*), mussels (*M. edulis*) and sea urchin (*S. droebachiensis*) are abundant and valuable commercial species. In multicultural farms, these hydrobionts serve as suitable objects with good edibility and technological characteristics and require insignificant costs for cultivation in marine ecosystems. They form the initial links of the trophic chain in natural benthic communities and can maintain the water quality in aquaculture plantations.

***Laminaria saccharina*** L. (the present name – *Saccharina latissima* (L.) Lane, Mayes, Druehl et Saunder) is a large brown alga with a stipe and blade attached to the substrate by rhizoids. The nutrients necessary for growth are absorbed by the whole surface of the thallus, mainly by the blade surface. This species forms widely distributed communities that occupy significant areas in the upper sublittoral zone in the bays of the northern seas, which are inhabited by mussels and sea urchins.

It is used as a food source, as well as for the processing and extraction of polysaccharides (alginates and others), a variety of biologically active substances. Kelp plantations can be used as natural bio filters to improve water quality in the cultivation of fish and invertebrates, as well as in reaction zones on the seashore. Kelps are harvested from natural beds or grown on plantations. Kelp cultivation methods have been developed using different technologies and plantation designs, depending on the purpose of a plantation and can vary significantly [1].

Kelps are grown in a suspended culture in the water column in the upper 5-10-meter layer of the sea. In natural conditions, large kelp thallus is firmly attached by rhizoids to a solid substrate – to rocks, boulders and large stones. *Laminaria* plants are also well fixed by rhizoids on a rope substrate. A common method for kelp growing is using fine ropes as substrates with weights at the end, which are tied to horizontal main ropes with floats (barrels) to hold them near sea surface.

When cultivating kelp, zoospores are used, which are obtained from mature spore-bearing plants from natural beds. String substrates are immersed in containers with a

suspension of zoospores. The seaweed's density is regulated through a certain concentration of zoospores in the seed culture. Transplantation can also be used – the young plants (about 30 cm) are collected on the seashore and woven into strings of 3–5 specimens after 10–12 cm or after 30 cm. The most important environmental factors in the kelp cultivation are light (grown in a water layer near the surface), intense water movement and the presence of biogenic elements.

During *Laminaria saccharina* cultivation on a pilot plantation on the Barents Sea (Dalnezelenetskaya Bay), a yield of 55–60 t/ha was achieved, some later – 70 t/ha. It is noted that kelp biomass on the plantation is higher than the average biomass in natural beds, but lower than the maximum biomass observed in natural communities.

As the analysis of the results obtained in the expeditions studies of benthic seaweed communities on the Murman coast shows (Table 1), the biomass and density in beds dominated by *L. saccharina* as a short-cycle species vary significantly depending on the growing habitats. The most important factors are the availability of a suitable substrate, the intensity of wave action and tidal currents, the depth, the slope of the bottom and other local features of habitats. The average biomass of this kelp species on the Murman coast is estimated to be 2–10 kg/m<sup>2</sup>, the maximum can reach 30 kg/m<sup>2</sup> or more. The density of plants in the settlements of the species also varies significantly. It is possible to observe very high densities in beds formed by young plants in places with intense water movement, but protected from direct wave action. At the same time, in relatively protected lips, on the bottom with individual stones with 100 % coverage of the bottom with kelps, densities may be low 1–5 plants in the age of one year or more per 1 m<sup>2</sup>. So, according to our observations and literature data [4] the average biomass of *L. saccharina* is about 2–10 kg/m<sup>2</sup>, the maximum can reach 30 kg/m<sup>2</sup> or even more.

The kelp density and biomass are controlled by biotic factors and depend on the characteristics of the life cycle. *L. saccharina* has a short-cycle with a heteromorphic life cycle and with a macroscopic sporophyte, which is used in cultivation. On the Murman coast, the life expectancy of *L. saccharina* is 3 years. At the same time, the perennial part is the stem, and the blade is an annual, with maximum size and weight at the end of summer. The growth and destruction of the blade are almost constant, with destruction processes prevailing in late autumn and winter, and in spring and summer, growth and production processes are predominant. The ice-free Murman coast with strong storms and low temperatures in winter (about 0°C) is characterized by significant seasonal and annual variability in the age structure of kelp beds. In the beds of the species, both all age groups or the dominance of one age group (usually at the age of 1 + years) can be present, depending on the growing conditions. There is a high elimination of 2+ years plants and older due to both biotic factors (sporulation) and abiotic – climatic and hydrological features of the Murman coast.

**Table 1.** Average biomass (*Bmean*) and density (*Nmean*) of *Laminaria saccharina* and their variations (min–max) in kelp communities on Murman coast.

Region	Depth, m	<i>Bmean</i> (min–max), kg/m <sup>2</sup>	<i>Nmean</i> (min–max) specimens/m <sup>2</sup>
<i>Western Murman (Rybachy Peninsula), weakly protected area</i>			
Ainu Islands	0–5	3.8 (2.2–6.8)	104 (64–152)
	6–10	2.9 (2.1–3.6)	64 (20–100)
The Kiysky raid	0–5	5.4 (1.8–16)	26 (6–42)
	6–10	2.7 (0.5–5.2)	12 (3–24)
Vaida Bay	9	0.5	16
Tsyp-Navolok Bay	5–10	5.4 (3.8–7)	19 (16–22)
<i>Eastern Murman, weakly protected area</i>			
Klimkovka Bay (Maliy Oleniy Island)	5–10	3.2 (0.5–5.9)	81 (70–92)
Orlovskaya Bay	5–10	1.4 (0.8–2)	21 (14–24)

(in Teriberskaya Bay)			
Zelenetskaya Bay	2–3	0.2–10.6	10–202
<i>Eastern Murman, relatively protected area</i>			
Yarnyshnaya Bay	0–5	2.4 (0.1–5.7)	28 (5–90)
	6–10	2 (0.1–5.5)	13 (5–33)
Dalnezelenetskaya Bay	0–5	5 (1–15)	24 (10–80)
Drozdovskaya Bay	5–10	6.9 (2.3–14)	9 (3–15)
Ivanovskaya Bay	5–10	2.7 (0.5–10)	8 (5–25)

Our data on the size and weight of *L. saccharina* also indicate a wide range of variation in such indicators as the length and weight of the thallus (Table 2). Commercial plants are considered to be in the second year of life, in accordance with the size and conditioning qualities of the blade. The study of the seasonal course of the growth processes of kelp in the conditions of the Murman coast showed that the blade reaches its maximum weight in July–September, then in the autumn the destruction of the blade begins and the weight decreases [19]. The blade is destroyed especially after spore release. In the conditions of the Murman coast, plants older than one year in summer usually reach a length of 2–4 m and a weight of 0.1–0.7 kg.

Thus, *L. saccharina* is characterized by a wide range of variation in both population indicators - the density and biomass, and individual characteristics – the size and weight of the thallus in natural communities. This is due both to the biological features of the species, its morphological and productive organization of the thallus and the peculiarities of the course and duration of the life cycle, and to the living conditions on the cold Murman coast and poorly protected from wave action. It can be thought that the variation of organism and population indicators provide this species to adapt to very different and severe growing conditions.

To compare the biological productivity of natural and artificial settlements of *L. saccharina*, data on the Dalnezelenetskaya inlet were used (Tables 1, 2). The biological characteristics of the kelp population in the benthic communities were studied in detail in this area of the Murmansk Marine Biological Institute marine station. There is a fairly complete hydrological and hydrochemical characteristic of the habitat. The kelp plantation was located here.

The living space of *L. saccharina* at the bottom can be represented as a parallelepiped with a base area of 1 m<sup>2</sup>, the height is equal to the length of the plant. *L. saccharina* has a rather flexible stem and, depending on waves and the direction of currents at tides, the thallus can cover a sufficiently large space. Then, with the average and maximum length of the plants, the volume of living space will be 1.46 and 2.5 m<sup>3</sup>. The calculations of biomass in living space (*C<sub>w</sub>*) were made: at an average and maximum density (24 and 80 specimens/m<sup>2</sup>), at an average and maximum length (1.46 and 2.5 m) and at an average and maximum weight of the thallus in different age groups (Tables 1, 2). The age structure was based on a population of normal type, with a predominance of young plants, which is characteristic for half-protected places from the waves in the Dalnezelenetskaya Bay. The biomass in living space (*C<sub>w</sub>*) in natural beds varied in the range of 3.21 kg/m<sup>3</sup> (1.88–36.08 kg/m<sup>3</sup>).

At plantation the living space of kelp can be represented in the form of a cylinder, the height of which is 1 m (the length of the linear meter of the rope on which kelp grows), and the radius of the base is the thallus length. The average length of plants on a plantation is 1.5–3.0 m, the average weight (raw) is 300–500 g, the density of transplanting algae is 30, 50 and 15 specimens per linear meter, plants are of the same age group of 1+ years [5]. Then, the biomass of kelp in the living space (*C<sub>w</sub>*) in artificial settlements is about 1.27 kg/m<sup>3</sup> (0.16–3.54 kg/m<sup>3</sup>).

**Table 2.** Average length (*Lmean*) and weight (*Wmean*) of *L. saccharina* thallus of different age and their variation (min-max) in natural beds on Murman coast

Region	Age, year	n, specimens	<i>Lmean</i> (min-max), cm	<i>Wmean</i> (min-max), g
<i>Western Murman (Rybachy Peninsula), weakly protected area</i>				
Ainu Islands	0+	88	74 (26–146)	22 (5–50)
	1+	7	114 (57–250)	68 (10–250)
	2+	5	165 (102–240)	217 (120–345)
The Kiysky raid	0+	35	62 (20–133)	54 (2–150)
	1+	78	129 (50–246)	159 (25–580)
	2+	53	177 (78–316)	287 (52–730)
Vaida Bay	1+	16	73 (37–148)	34 (15–110)
Tsyp-Navolok Bay	1+	10	132 (56–150)	235 (20–400)
	2+	13	170 (107–257)	344 (160–660)
	3+	2	120–157	185–410
<i>Western Murman, protected area</i>				
Kyslaya Bay (in the Ara Bay)	0+	3	37 (34–39)	8 (7–10)
	1+	4	92 (84–101)	94 (73–115)
	2+	3	180 (160–204)	322 (268–375)
<i>Eastern Murman, weakly protected area</i>				
Klimkovka Bay, (Maliy Oleniy Island)	0+	10	33 (16–46)	5 (1–10)
	1+	48	99 (33–147)	45 (8–120)
	2+	14	108 (61–141)	72 (20–100)
Orlovskaya Bay (in the Teriberskaya Bay)	0+	16	53 (31–74)	18 (7–35)
	1+	19	91 (61–121)	71 (20–240)
	2+	5	115 (90–137)	130 (100–170)
Zelenetskaya Bay	0+	25	18 (14–26)	6 (3–13)
	1+	146	137 (83–213)	61 (10–255)
	2+	5	114 (75–101)	133 (66–289)
<i>Eastern Murman, ravelly protected area</i>				
Dalnezelenetskaya Bay	0+	66	55 (21–104)	22 (0,2–246)
	1+	47	145 (52–250)	342 (13–1004)
	2+	17	146 (99–227)	429 (128–1348)
Drosdovskaya Bay	0+	11	95 (53–129)	136 (50–210)
	1+	29	152 (73–244)	236 (25–594)
	2+	15	235 (161–338)	1340 (90–2250)
	3+	9	250 (219–294)	1700 (200–3030)
Ivanovskaya Bay	0+	8	90 (43–156)	92 (17–279)
	1+	19	209 (125–302)	573 (172–1499)
	2+	12	224 (100–299)	747 (30–1238)
	3+	3	313 (215–363)	1070 (611–1320)

An important factor for kelp habitat with a large thallus is the intensity of water movement. The water exchange in the canopy of algae on the plantation in Dalnezelenetskaya Bay, according to approximate calculations, was  $2.4 \cdot 10^3 \text{ year}^{-1}$ . It is believed that this value indicates a good water exchange, and thus a good provision of kelp plantation with biogenic elements [25].

Thus, during plantation cultivation of kelp, *C<sub>w</sub>* values are lower than in natural beds of the species at the bottom. Therefore, it is possible to improve the structure of kelp placement in suspended culture.

***Strongylocentrotus droebachiensis*** O.F.Müller, the sea urchin, is a widely distributed species of echinoderm living in the zone of kelp communities and deeper. It leads a sedentary life. It usually lives on the bottom and on kelp, feeds on algae, and also scrapes detritus and small invertebrates from the surface of the substrate.

Sea urchins are an extremely valuable object of harvesting and cultivation. It used the gonads of sea urchins as a delicacy food and a source of biologically active substances. In the conditions of the Murman coast, the gonads of sea urchins are reached their maximum development in winter and early spring. It is extremely difficult to organize the collection of sea urchins at this time of year due to weather conditions. Therefore, it is proposed to collect sea urchins at a convenient time of the year, and then grow (ranking) in special cages. The biotechnics of sea urchins cultivating in cages in the conditions of the Murman coast was developed in PINRO (Polar branch of the FSBSI “Russian Federal Research Institute Of Fisheries and Oceanography”) [23]. In nature, *S. droebachiensis* feeds on kelp and all invertebrates living on kelp. In aquariums, it willingly eat artificial feeds, the basis of which is fish processing waste. The main factors in sea urchin keeping in cages are the temperature and intensity of water movement.

In the coastal Murman waters, sea urchins (*S. droebachiensis*) form dense clusters in the upper sublittoral in the kelp belt and deeper at depths up to 30 m, on crusty red *Lithotamnion* algae. The densest settlements of sea urchins are characteristic of the lower border of brown algae beds. They carry out the seasonal migrations: in summer and autumn the population density is a maximum at depths of 3–5 m, and in winter – at 10–15 m. The sea urchin distribution on the bottom is aggregated. The average density of sea urchins in congregations is estimated from 2–15 to 12–30 specimens/m<sup>2</sup>. The maximum density can be up to 40–70 and even 100–200 specimens/m<sup>2</sup>. Congregations of sea urchins usually occupy 20–50, rarely 70 % of the bottom. The biomass in sea urchin settlements averages 300–1600 g/m<sup>2</sup>, the maximum is 3–6 kg/m<sup>2</sup> [3, 6, 18, 24].

It is believed that on Murman coast, *S. droebachiensis* enter sexual maturity at the age of 3,5–4,5 years with a shell diameter of 28.5–30.5 mm; the average shell diameter of adults reaches 78–98 mm. Commercial congregations with a density above 10 specimens/m<sup>2</sup> are noted in areas with high hydrodynamics. The commercial size is considered to be the diameter of the shells more than 50 mm and a weight of 75–125 g. The largest diameter of the shell and the weight of the sea urchins is in January–June – 45–80 mm with a weight of 60–170 g [18, 24].

When calculating the biomass of sea urchin population in the living space ( $C_w$ ) in benthic communities the following averages were used. Sea urchins are sedentary organisms, nevertheless they easily climb kelp stems, the average length of which is about 40 cm. The living space is represented in the form of a parallelepiped with a base of 1 m<sup>2</sup> and a height of 0.4 m. The average density is 15–30 specimens/m<sup>2</sup>, the weight of an adult sea urchin with a commercial diameter is about 75 g.

The sea urchin cultivation is carried out in cages. Recommended size of cages is 0.5\*1.0\*2.0 = 1 m<sup>3</sup>, and the recommended density is 40–50 specimens per 1 m<sup>2</sup> of the cage bottom; according to some data – up to 100 specimens per m<sup>3</sup>. The weight of an adult sea urchin is about 75 g. Thus, the  $C_w$  in natural sea urchin settlements varies about 2.81–5.6 kg/m<sup>3</sup>; in cages: 3–7.5 kg/m<sup>3</sup>, the values are closed. The density conditions in cages and the volume of cages during the cultivation of the sea urchin correspond to the natural habitat conditions of the species.

***Mytilus edulis*** L., the edible mussel, is a widespread species of bivalve mollusks in the coastal waters of the northern seas. Mussels are tightly attached by their byssus to a solid substrate or benthic algae, and are also capable of active and passive movement in space. They are characterized by a filtration nutrition type.

*M. edulis* cultivation technology, adapted to the conditions of the White and Barents Seas, has been worked out during the experimental and industrial mussel plantations [7, 8, 9, 11]. In the conditions of the northern seas, mussel cultivation is carried out by a suspended method on artificial substrates, which are placed in the upper three-meter layer of water near natural mussel settlements. Mussel larvae from the aquatic environment settle on substrates. Settled mollusks feed on plankton by filtering water. The growth rate of mussels in the water column under suspended culture conditions is significantly higher than that of mussels living at the bottom of the reservoir in natural settlements on the littoral and sublittoral [11].

It is known that natural mussel settlements significantly change the environment characteristics in their habitats. Mussels secrete various metabolites into the water, including biologically active substances, as carbohydrates, proteins, nucleic components, vitamins, urea and other compounds. In turn, phototrophic organisms (including benthic algae) absorb the metabolites necessary for growth from the environment by thallus surface. The prospects of creating a "kelp+mussel" biculture in the conditions of the White Sea have been experimentally shown [11]. Substrates with kelp seedlings are suspended between substrates with mussels, while using different placement options for substrates with kelp and mussels. It is desirable that mussels do not settle on the laminarian blade, as this worsens the commercial qualities of the *Laminaria*.

In the coastal Murman waters on the littoral and in the upper horizon of the sublittoral, mussels form independent communities – mussel banks, which can occupy a vast territory (for example, in the Tuva Inlet of the Kola Bay). Mussels are also a subdominant in littoral communities of fucoid algae (*Fucus vesiculosus* and *Ascophyllum nodosum*) and some red algae (*Palmaria palmata*, *Devaleraea ramentacea*). Table 3 presents data on the biomass and density of settlements, as well as the average size and weight indicators of mussels in littoral communities in the Kola Bay and in some bays of western and eastern parts of the Murman coast.

**Table 3.** Biomass (*B*) and density (*N*) of settlements and size-weight indicators of *M. edulis* in littoral communities (on mussel banks) in the Kola Bay and in the bays of Eastern and Western Murman coast (2006-2009).

Region	<i>B</i> , g/m <sup>2</sup>	<i>N</i> , specimens/m <sup>2</sup>	Height of shell, sm	Mollusk weight, g
<i>Kola Bay</i>				
Retinskaya Inlet	17807±4753.3	9150±1851.1	3.40±0.14	6.54±0.68
Tuva Inlet	4800±823.7	14832±450.5	2.46±0.09	4.17±0.54
<i>Eastern Murman coast</i>				
Yarnyshnaya Bay	6216±517.8	45030±8275.5	2.28±0.08	1.42±0.11
Dalnezelenetskaya Bay	2934±462.8	61167±8935.2	2.43±0.04	1.19±0.07
<i>Western Murman coast</i>				
Pechenga Bay	5486±1037.5	4185±966.7	4.32±0.07	6.84±0.34

Note. The values of the arithmetic mean and the standard error are presented.

As can be seen from Table 3, the highest biomass is characteristic of mussel settlements at the mouth of the Kola Bay, and the highest density is noted in the bays of the Eastern Murman. For all the studied areas, the predominance of young individuals (up to 3 years) of small size is characteristic. The mollusks of 11 years old are rarely encountered. Mollusks collected in the Pechenga Bay have the largest size and weight (from the studied areas). The size of the mollusks in the bays of the Eastern Murman coast is almost two times smaller, and the weight is almost three times as compared with the mollusks in the bays of the Western Murman coast, which is probably due to the temperature. Expedition

observations made in different areas of the Murman coast indicate a wide variation in both density and biomass indicators in settlements, as well as the shell size and the mollusk weight, the shell weight and the weight of mussel body.

In general, in the 2000s, it is noted that the mussel forms very dense settlements on the littoral and in the sublittoral on the Murman coast. According to the results of a complex benthic survey carried out by VNIRO employees in 2002–2005 on the littoral and in the upper sublittoral in the bays of the Murman coast [20, 21, 22], the average biomass of mussels in settlements is low and varies within 0.5–1.3 kg/m<sup>2</sup>. So, for the Teriberskaya Bay, an average density of 980 specimens/m<sup>2</sup> is noted, the biomass is 0.4 kg/m<sup>2</sup>, and for depths of 0–3 m, where the majority of mussels lives, the density can be 2255 specimens/m<sup>2</sup> and the biomass 0.7 kg/m<sup>2</sup>. A higher average biomass (1.3 kg/m<sup>2</sup>) is noted in the settlements Ura, Drozdovskaya and Ivanovskaya bays. The maximum biomass is noted in the Ura Bay, reaches 12.5–14.5 kg/m<sup>2</sup>. On the littoral and at shallow depths, small mussels prevailed – with a shell height of up to 6 mm, while deeper (5–20 m) there are also large mussels of 40–60 mm high. It is noted that on the littoral and at a depth of up to 5 m, the average biomass of mussels was higher in the areas of the coast closed from the surf compared to the biotopes of the poorly protected coast. It is also noted that the mussel is larger off the Western Murman coast than in the central and eastern parts of the coast.

The first experimental mussel plantation on the Barents Sea was organized by PINRO employees in the Western Zelenetskaya Bay in the early 1980s. Experimental studies have shown that the mussel size grown in plantation conditions significantly exceeded the mollusk size of the same age of natural settlements on the seashore [9]. In the natural settlements of mussels in the Western Zelenetskaya bay, where the first experiments on growing mussels were conducted, high density indicators were noted – 8187 specimens/m<sup>2</sup> (minimum 100 specimens/m<sup>2</sup>) and biomass 2468 g/m<sup>2</sup> (min 550 – max 5440 g/m<sup>2</sup>). It was shown that in littoral settlements, fingerlings with a shell length of less than 10 mm prevailed, and mature individuals reached a length of 17–33 mm [10].

Comprehensive comparative studies of population and organism indicators of mussels in nature and in plantation were carried out by employees of the Zoological Institute RAS at the biostation in the Chupa Bay of the White Sea. It is shown that mussels from collectors had higher dimensional parameters than mollusks from mussel banks located nearby. The size indicators of mussels from collectors approached the maximum size of mollusks from natural settlements of the White Sea and significantly exceeded the size of mussels of some populations of the Barents Sea. On the White Sea mussel plantations, commercial size (50 mm) mollusks reach for a long cultivation period – four years, which is connected with low water temperature and a long period of freezing. But it is noted that with a more careful choice of hydrological conditions when placing a mussel farm, it is possible to reduce the growing time to 3 years [11, 15, 16]. For mussel plantations, an intensive water flow through the plantation is important, since the water supplies the necessary food for mussels – plankton and detritus. Data are given that at least 1000 m<sup>3</sup> of water should pass through 1 m<sup>2</sup> of cross-section (perpendicular to the main current direction) in 12 hours on a mussel plantation [11].

In the Barents Sea, the first experiments showed that it takes at least 4 years to grow mussels to commercial size [9]. The literature provides data [7] that modern PINRO developments make it possible to harvest mussels in 2 years – 15 kg, and in three years – 16–20 kg from one collector, and the duration of mussel cultivation to commercial size (50 mm) is 3 years.

We believe that the volume of the living space of the mussel, as a sedentary filter, can be estimated approximately by the volume of water that these mollusks filter out. Note that the volume and intensity of the water flow are also important for seaweeds on the plantation, from this volume they receive the necessary nutrients and solute organic matter.

When calculating the filtration rate of mussels, the formula was used:  $V=1.656*W_t^{0.49}$  [2, 15], where  $V$  – volume of water filtered by mollusk per hour,  $W_t$  – dry body weight, at  $t=10^{\circ}\text{C}$  is the most favorable temperature for active filtration. The calculations used data on the density and biomass, size and weight of mollusks from natural communities on the Murman coast (Table 3). In Murman mussels (according to our data), the yield of the body (soft tissues) is about 30 %. For cultivated Murman mussels, the data given in the works [8, 9] were used. It was taken into account that the mussel body consists of 84 % water [11, 15]. According to approximate calculations, a mussel of a commercial size of 50 mm and a weight of 23.5 g (the Western Zelenetskaya Bay) is filtered under favorable conditions (temperature  $10^{\circ}\text{C}$ ) at a rate of 1.75 liters/hour. Let's assume that the filtration activity of shellfish in natural settlements takes, on average, 12 hours a day, then the volume of water filtered by shellfish per day will be from 5 to 21 liters.

Taking into account in the calculations the average indicators of biomass, density and size of mollusks (Table 3), then the concentration of biomass in the water stream ( $C_w$ ) organized by mussels in the physical volume of the living space per year will be  $0.07\text{ g/m}^3$  for natural settlements in Yarnyshnaya Bay (Eastern Murman coast),  $0.31\text{ g/m}^3$  in Pechenga Bay (Western Murman coast), and  $1.56\text{ g/m}^3$  for cultivated mussels in Western Zelenetskaya Bay (Central Murman coast). Thus, the data point to the huge work carried out by filter shellfish, especially in mature suspended aquaculture.

## 4 Conclusion

Further development of marine aquaculture involves the joint cultivation of kelp (*Laminaria saccharina*), mussels (*Mytilus edulis*), sea urchin (*Strongylocentrotus droebachiensis*), which are valuable commercial objects that do not require significant costs for cultivation in the northern seas. These hydrobionts occupy different levels of the trophic chain in benthic communities, providing high biomass of valuable raw materials and maintaining the quality of the environment in aquaculture plantations.

In the natural communities of the coastal Murman waters, the average biomass and population density of *L. saccharina* vary significantly depending on the biotope and amount to  $1.4\text{--}5.4\text{ kg/m}^2$  (up to  $16\text{ kg/m}^2$ ) and  $9\text{--}104\text{ specimens/m}^2$  (up to  $172\text{ specimens/m}^2$ ), respectively. Also, the individual characteristics of seaweeds are widely changing – the size and weight of the thallus, which are associated with the peculiarities of morphological and productive organization, life cycle, as well as living conditions in cold and poorly protected from wave action bays. The biomass in living space ( $C_w$ ) in natural kelp beds varied in the range of  $1.88\text{--}36.08\text{ kg/m}^3$  (average value of  $3.21\text{ kg/m}^3$ ), in aquaculture – from  $0.16$  to  $3.54\text{ kg/m}^3$  (average value of  $1.27\text{ kg/m}^3$ ). During plantation cultivation of kelp, the biomass values in the living space ( $C_w$ ) are lower than in natural settlements. Thus, it is possible to improve the structure of the kelp placement in the suspended culture.

The average density of sea urchin populations in aggregations on the bottom in benthic communities is estimated from  $2\text{--}30\text{ specimens/m}^2$ , up to  $40\text{--}70$  (and even  $100\text{--}200\text{ specimens/m}^2$ ), and the average biomass is  $0.3\text{--}1.6\text{ kg/m}^2$ , with a maximum value of  $3\text{--}6\text{ kg/m}^2$ . The biomass in the living space ( $C_w$ ) in natural populations of sea urchins varies between  $2.8\text{--}5.6\text{ kg/m}^3$ , and in cages:  $3\text{--}7.5\text{ kg/m}^3$ . Consequently, the conditions of density of sea urchins in cages and the cage volume correspond to the natural conditions of their habitats.

The biomass and density of mussel populations, the average size and weight indicators of mollusks in littoral communities in the Kola Bay and in the bays of the Western and Eastern Murman coast vary significantly. The maximum biomass values are typical for mussel banks at the mouth of the Kola Bay ( $4.8\text{--}17.8\text{ kg/m}^2$ ), and the highest density indicators are noted in the bays of the Eastern Murman coast ( $45030\text{--}61167\text{ specimens/m}^2$ ).

The predominance of individuals of younger age groups (up to 3 years old) of small size is characteristic of the studied areas. The volume of the living space of the mussel, as a sedentary filter, was calculated by the volume of water that these mollusks filter out. According to calculations, the biomass in the water flow organized by mussels within the physical space ( $C_w$ ) in natural populations of mussels in the Yarnyshnaya Bay was 0.07 g/m<sup>3</sup>, in the Pechenga Bay 0.31 g/m<sup>3</sup>, while when cultivating mussels by method "of growing" in the Western Zelenetskaya Bay was significantly higher and exceeded 1.56 g/m<sup>3</sup>.

Thus, the parameters of the population density of cultivated species in natural communities, which affect the growth of aquatic organisms, can be recommended for use in multicultural farms of kelp, mussels and sea urchins.

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