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MARINE BIOLOGY

Macrobenthos of Yenisei Bay and the Adjacent Kara Sea Shelf

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Abstract—Trawl samples were collected in the northern region of Yenisei Bay and adjacent parts of the Kara Sea shelf. A total of eight stations were taken. We found more than 200 species of benthic organisms. A consecutive replacement of benthic communities is observed when going to the north from the Ob and Yenisei estuaries to the open parts of the sea. We could distinguish four different species complexes in the investigated area: a brackish-water complex where *Saduria entomon* is dominant; an intermediate complex where *S. sibirica*, *S. sabini* and *Portlandia aestuariorum* are dominant; a transitional complex with *P. arctica* as a dominant species and with a small amount of *Ophiocten sericeum*; a marine complex where *O. sericeum* is dominant. When salinity increased, some brackish-water species were replaced by related euryhaline species. One such example was the replacement of brackish-water *Saduria entomon* isopods by two euryhaline species: *S. sibirica* and *S. sabini*. The consecutive replacement of benthic communities showed a break near Sverdrup Island. In this area the marine complex was replaced by a transitional complex with *P. arctica*.

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INTRODUCTION

The Kara Sea is one of the polar seas of Russia, characterized by a number of unique hydrological peculiarities that distinguish it from the other three Siberian seas (the Laptev Sea, the East Siberian Sea, and the Chukchi Sea). Large quantities of river water are carried into the Kara Sea from two major Siberian rivers, Ob and Yenisei, forming a freshwater layer on the sea surface (about two meter deep). The deeper layers are formed by the more saline waters from the Barents Sea and the Central Arctic basin [8].

Salinity is one of the most significant factors that designate the structure of benthic communities in this area. Numerous studies conducted in the Ob and the Yenisei Bays show that species diversity increases together with salinity when going off the Ob and Yenisei estuaries [1, 4, 8, 18, 19].

The lowest species diversity of macrobenthos is observed in the brackish-water area. This may be explained by the low temperatures, short summer period, irregular drain of fresh water and high sedimentation rate [22]. A salinity level of 5–8 psu was called critical by V.V. Khlebovich. The diversity of both fresh- and brackish-water organisms dramatically decreases within this range [16, 21, 24].

The most freshwater part of the Yenisei Bay is mainly populated by the amphipod community with *Monoporeia affinis* as a dominant. At approximately 71° N *Saduria entomon* isopods appear. Trawl samples at such locations are virtually a monoculture of these crustaceans [3]. Downstream, *Marenzelleria arctia* polychaetes and *M. affinis* amphipods begin to dominate by biomass [18]. When the salinity reaches ~30 psu the euryhaline species of genus *Saduria* (*S. sabini* and *S. sibirica*), displaced by *S. entomon* to the more saline areas, and *Portlandia arctica* bivalves begin to dominate by biomass. *Diastylis sulcata* cumaceans are very abundant outside the bay, but still within the area of the direct Yenisei influence. According to Deubel et al. [20] this species of cumaceans is dominant by both density and biomass. Further north, the high abundance of amphipods, especially *Acanthostepheia behringiensis*, cumaceans *Diastylis glabra* and polychaetes *Nephtys longosetosa* is observed [14]. The role of these species gradually decreases together with the increasing of the salinity. Further north at ~75° N an *Ophiocten sericeum* community appears, occupying the most part of the central Kara Sea. This community is located out from the direct influence of the Yenisei run-off. When the depth reaches ~100 m *Ophiopleura borealis* ophiuroid begins to dominate.

The Ob and Yenisei estuaries and the adjacent Kara Sea areas are of particular interest in assessing the frontal processes impact on the parameters of the aquatic ecosystem. Benthic fauna is the most conservative component of the whole estuarine ecosystem (in contrast to pelagic communities). The development rate of benthic communities is relatively low and, based on the composition and distribution of benthic organisms (and their residues), the seasonal and annual changes that occur in this area can be estimated [3].

The aim of our work was the study of the distribution of macrobenthic communities in the estuary of Yenisei Bay and the surrounding areas of the internal shelf of the Kara Sea, and the identification of environmental factors that determine this distribution.

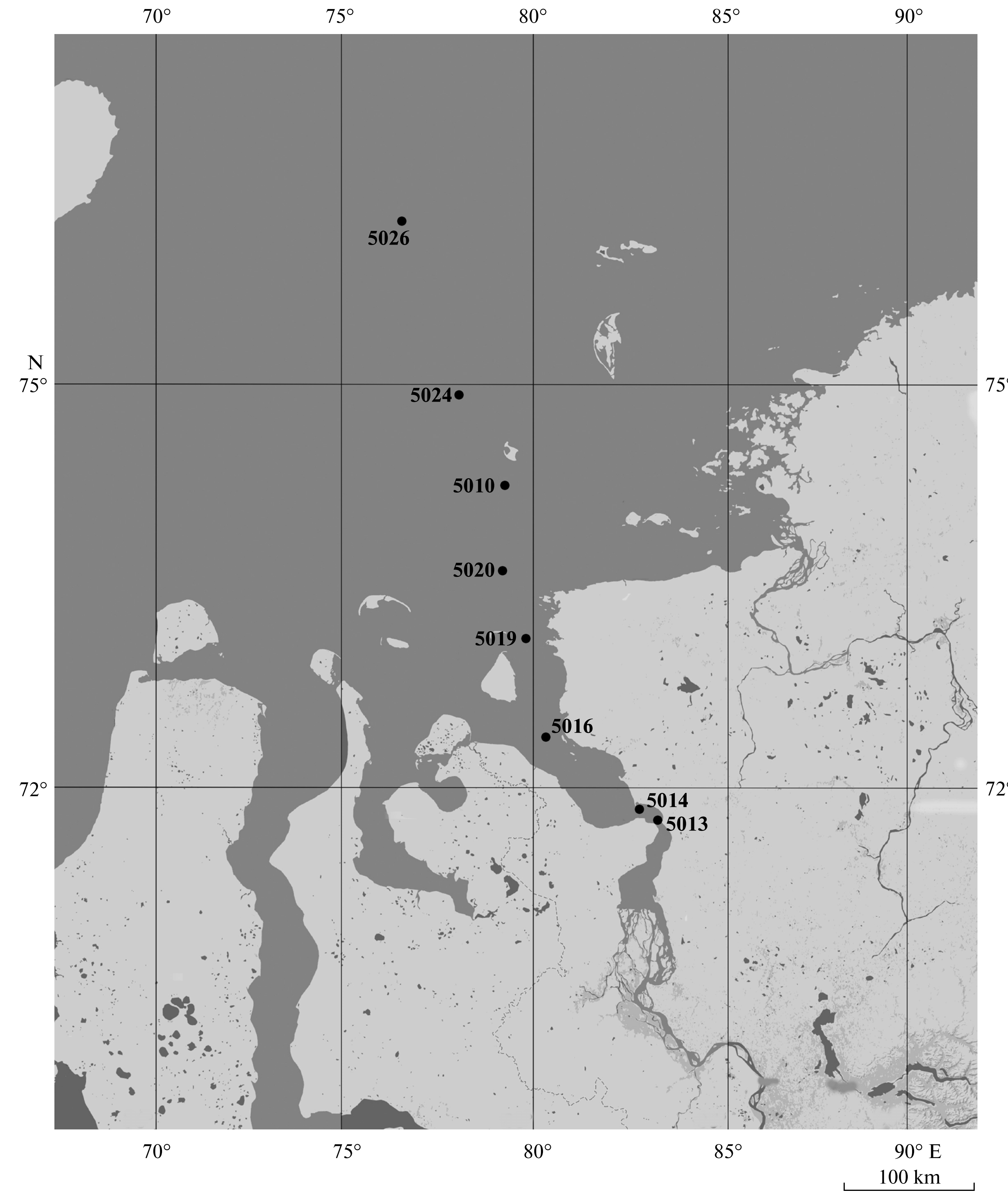

Fig. 1. Station map of the Yenisei transect.

MATERIALS AND MENTHODS

The material was obtained during the 59th cruise of the research vessel *Akademik Mstislav Keldysh* in September-October 2011. A submeridional section from 71°49.38′ N to 75°59.82′ N was made. A total of eight trawl stations were taken (Fig. 1).

A Sigsbee trawl with a steel frame (width 1.5 m) was used for collection of macrofauna. The trawl was

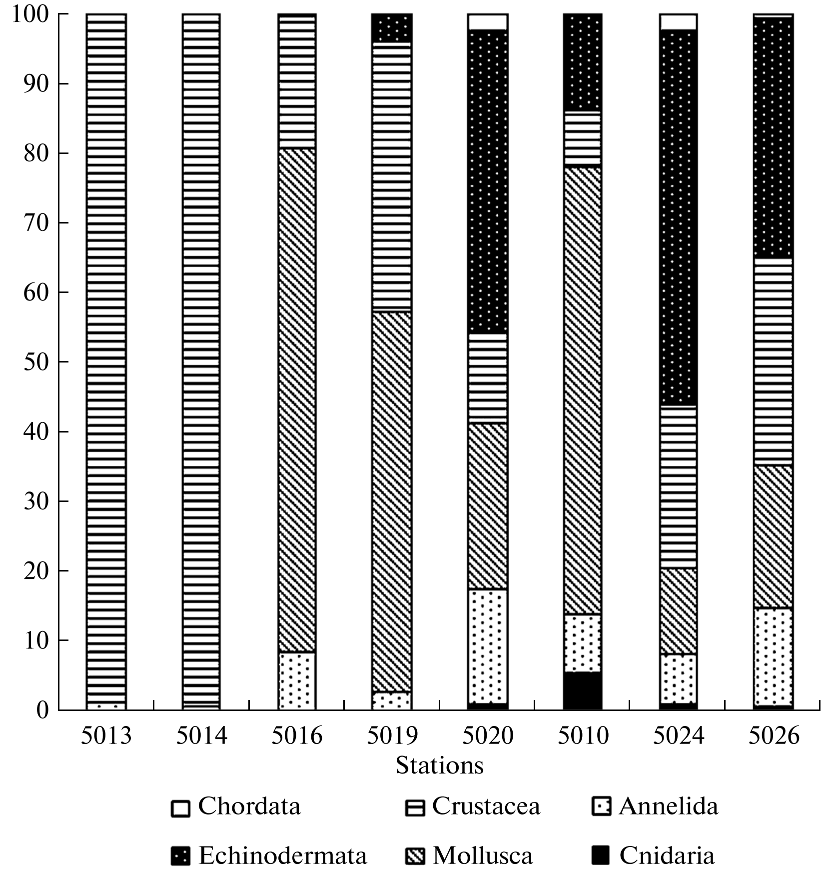

Fig. 2. Metabolic rate percentage for different macrotaxa at different stations of the Yenisei transect.

equipped with a double bag: an outer bag weaved of a double nodal caproic net made of 3.1 mm rope with a 45 mm mesh size, and an internal bag made from node-free net with a 4.0 mm mesh size. Each trawl sample was washed through a system of steel sieves with a mesh size of 5.0 and 1.0 mm. Additional washing through a hand sieve with 0.5 mm mesh size was provided when required.

The material was fixed with 6% buffered formalin, followed by a transfer to 75% ethanol. All the material was identified to the species level. The identification keys from Zhirkov [7] were used for polychaetes, from Lomakina [12] for cumaceans, from Gurjanova [5] for amphipods, from Djakonov [6] for asteroids, and the rest of the invertebrates were identified according to Gaevskaya [2] and Sirenko [9]. Each species individuals were counted and weighed. The species significance in the sample was estimated by using the abundance and biomass values and the so-called metabolic (respiration) rate calculated according to the formula described in Kucheruk and Savilova [11]:

$$p_i = \frac{B_i^{0.75} N_i^{0.25}}{\Sigma B_i^{0.75} N_i^{0.25}}.$$

Data were analyzed using the Microsoft Excel and Primer V6 programs. The similarity between the samples was calculated by using the qualitative Jaccard and Sörensen indices and quantitative Bray–Curtis index. Percentage-based values were used, not the absolute values of abundance and biomass, since the volume of trawl samples differed significantly from station to station. In addition, the Pielou index was used as a measure of evenness. Multidimensional scaling (MDS) and cluster analysis were performed on the base of the similarity matrices. We revealed the trends in the communities distribution by using the MDS-plots and cluster dendrograms. The results were tested by one-way analysis of similarity (ANOSIM), which estimates the accuracy of the unification of stations in groups.

RESULTS

Station data and the main dominants are shown in the table.

A total of more than 200 species of benthic animals were present in the samples. The percentage ratios of the metabolic rates between the different macrotaxa are shown at the Figure 2.

Generally, our data are consistent with the communities distribution patterns in this area described in lit-

Station data

Station no.	Latitude (north.)	Longitude (east.)	Depth, m	The dominant and subdominant taxa	Pielou Index	Shannon Index	Sediment (surface layer characteristics, 0–5 cm)	Water (near-bottom horizon)		
								T°, C	salinity, ‰	0_2, mL/L
5013	71°49.38′	82°59.59′	22	*Saduria entomon* *Monoporeia affinis* *Marenzelleria arctia*	0.158	0.283	Sand (small to medium grained) with pelite, plant detritus in silt deposit	9.5	0.07	7.88
5014	71°51.81′	82°11.89′	8	*Saduria entomon* *Marenzelleria arctia* *Mysis relicta*	0.433	0.776	Pelite with inclusions of plant detritus, without silt deposit	9.23	0.06	7.84
5016	72°33.19′	80°20.65′	12	*Portlandia aestuariorum* *Saduria sibirica* *Saduria sabini*	0.356	1.086	Pelite, brownish and waterlogged	0.85	19.9	6.5
5019	73°10.19′	79°51.65′	25	*Portlandia arctica* *Saduria sabini* *Saduria sibirica*	0.481	1.909	Pelite brownish and waterlogged	–0.5	31.57	7.44
5020	73°43.05′	79°23.38′	29	*Ophiocten sericeum* *Pectinaria hyperborea*	0.532	2.311	Silty pelite, liquid, highly waterlogged	–1.4	32.55	6.26
5010	74°17.58′	79°37.51′	33	*Portlandia arctica* *Colus sabini* *Musculus niger*	0.480	2.331	Sandy silt with plant detritus	–1.4	32.15	5.65
5024	74°56.91′	77°54.12′	34	*Ophiocten sericeum* *Synidothea bicuspida*	0.522	2.535	Sand (small to medium-grained) with a small amount of silt. Numerous FMN	–1.5	33.3	9.55
5026	75°59.82′	76°40.44′	62	*Ophiocten sericeum* *Saduria sabini*	0.602	2.591	Sandy silt, heavily waterlogged	–1.4	34	7.47

erature (Fig. 2). However, a number of peculiarities was present at each station.

The freshwater-most station (5013) was literally a monoculture of *Saduria entomon* isopods. However, according to abundance, *Monoporeia affinis* amphipods were prevalent. Among other taxa *Marenzelleria arctia* polychaetes and *Gammaracanthus loricatus* amphipods should be mentioned. A large amount of plant residues was found at this station. Station 5014 which was taken less than 30 km away from the previous station was very similar. The main difference was the lesser depth (8 m at station 5014 against 22 m at station 5013) and, as a consequence, the almost complete absence of silt deposit. Plant residues were present, but they were embedded deep into the dense pelite, with a low level of bioturbation. At this station *Saduria entomon* dominated and a large number of *Mysis relicta* mysids was detected, while only a few *Monoporeia affinis* amphipods were found.

At the next station (5016) located in the mouth of the Yenisei Bay *Portlandia aestuariorum* bivalves were dominating. Euryhaline *Saduria sibirica* and *S. sabini* isopods played a less important role.

Station 5019, located between Sibiryakov island and the west coast of Taimyr, was mainly populated by *Portlandia arctica* bivalves. This species replaced *P. aestuariorum*. A significant role was played by *Saduria sabini* and *S. sibirica* euryhaline isopods. Individual *Ophiocten sericeum* ophiuroids were detected in the sample.

A typical *Ophiocten sericeum* community was found at station 5020 located northwest off Dikson Island. Interestingly, according to the literature [1, 15], this community should be located far to the north from the station. At this longitude *O. sericeum* starts to dominate at about 76° N, while station 5020 was taken at 73°43′ N. *Pectinaria hyperborea* polychaetes were subdominant here. The isopods were in third place at this station.

At station 5010 taken significantly northward from station 5020 *Portlandia arctica* bivalves were dominant, whereas ophiuroids were not so common. *Colus sabini* gastropods with *Allantactis parasitica* actinarians on their shells were at the second place. Under the actinarians large nemerteans were often present. *Musculus niger* bivalves were the second subdominants at the station with the slightly lower biomass than *Colus sabini*. These bivalves formed peculiar byssus “rafts” on the loose pelite–silt sediment. *Musculus niger* was never observed among the subdominants in the Kara Sea, however similar “rafts” were found at the exit of the Ob Bay [10]. The role of isopods at this station was small. Large amounts of plant residues were found in the sediment.

Station 5024 was similar to station 5020 in many ways. *Ophiocten sericeum* ophiuroids were dominant. Interestingly, the main subdominants here were *Synidothea bicuspida* isopods. This species is quite common in the shallow parts of the Kara Sea, but it was never detected there in such quantities. *S. bicuspida* was also present at station 5010 (only two individuals). Notable were numerous large iron–manganese nodules. As a result, a nodule foulers community was formed here despite the presence of the soft sediments. The foulers community is found in the area influenced by Ob and Yenisei rivers for the first time. Bryozoans and hydroids were numerous on the nodules. In addition, sponges, soft corals of the genus *Gersemia*, *Bathyarca glacialis* bivalves, *Glaciarcula spitzbergensis* brachiopods, *Pista maculata*, *Owenia fusiformis*, *Petaloproctus tenuis*, and Spirorbidae polychaetes and ascidians were present in significant quantities. Gaps between nodules were occupied by brown ferruginous silty sands, where *O. sericeum* and *S. bicuspida* dominated. Interestingly, a large number of empty tubes from *Pectinaria hyperborea* polychaetes was found inhabited by large *Phascolion strombus* sipunculids and *Gattyana cirrhosa* polychaetes. The tubes were covered with an iron-manganese crust and the same foulers as the nodules. The amount of tubes with live *P. hyperborea* was much less. Apparently, the tubes were somehow moved to the sediment surface, since the formation of ferromanganese crusts and nodules cannot occur deep in the sediment [17]. Normally, tubes with live pectinaria are almost completely buried in the sediment. A total of more than 135 species were found here, which is more than at any other station of the transect.

The last station of the Yenisei transect (5026) represented a typical *Ophiocten sericeum* community, similar to the communities of stations 5020 and 5024 in many ways. The main subdominants here were *Saduria sabini* isopods. Community dominated by these two species is probably one of the most common in the eastern sector of the Arctic [23]

DISCUSSION

Comparison of station species lists using the Jaccard, Sørensen and Bray–Curtis indices revealed that all the stations differ from each other significantly. However, despite the peculiarity of each station, they were grouped in stable clusters.

Two freshwater-most stations, 5013 and 5014, differ from the other stations of the Yenisei transect by both qualitative and quantitative criteria: biomass, abundance, and metabolic rate (Fig. 3). For the rest of the stations the Bray–Curtis index, based on the metabolic rate, demonstrates the most detailed picture (Fig. 3).

Station 5016 is somewhat isolated due to the dominance of *Portlandia aestuariorum*. Stations 5019 and 5010 form a stable cluster, as was expected based on the species composition. Finally, three stations with the dominance of *Ophiocten sericeum* are grouped together (5020, 5024, and 5026). This is rather unusual since, as it was noted above, station 5024 differs from all other stations of the transect by the large quantity of

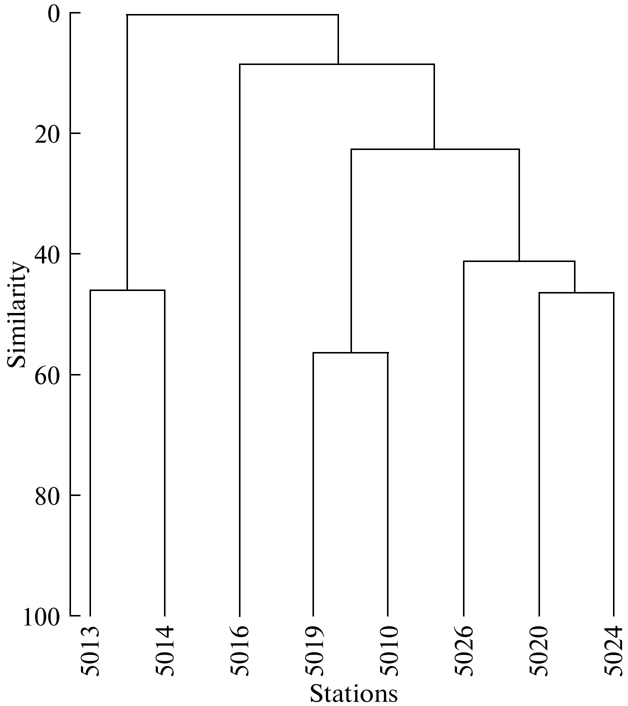

Fig. 3. Dendrogram showing frouping of stations of the Yenisei transect (Bray–Curtis index using the metabolic rate values).

foulers. Moreover, it is even closer to station 5020 than station 5026 (Fig. 3).

Stations 5019, 5020, 5010, 5024, and 5026 are grouped in a complete different way when using the qualitative indices. A dendrogram based on the Jaccard index showed a diffused cluster consisted of stations 5020, 5010 and 5024 due to the large species number at these stations. Despite the different dominant species, all of them (*O. sericeum*, *S. sabini, P. arctica* etc.) were present at every station except 5013 and 5014. Thus, the qualitative indices which consider only the species presence/absence are not enough accurate.

We can identify the following community complexes. The first is the brackish-water complex (stations 5013 and 5014) with the dominance of *Marenzelleria arctia* polychaetes and *Monoporeia affinis* amphipods. The second is the intermediate complex (station 5016) characterized by the dominance of euryhaline species of isopods and *Portlandia aestuariorum* bivalves. The third, transitional complex (stations 5019 and 5010) with the dominance of *Portlandia arctica* and the presence of *Ophiocten sericeum*, demonstrates transition between the communities dominated by bivalves and isopods and communities dominated by *Ophiocten sericeum*. The fourth is the marine complex (stations 5020, 5024, and 5026) with the dominance of *O. sericeum*. Apparently, communities of the marine complex exist outside the direct influence of the Yenisei waters. The ANOSIM results showed that the separation of stations into these four groups is not random and statistically significant at the level of 0.1%.

The number of species increases gradually from station 5013 to station 5024, showing a dependence on both the salinity and temperature of the water of the near-bottom layer (Table, Fig. 4). However, for an unclear reason, the species number at the last sta-

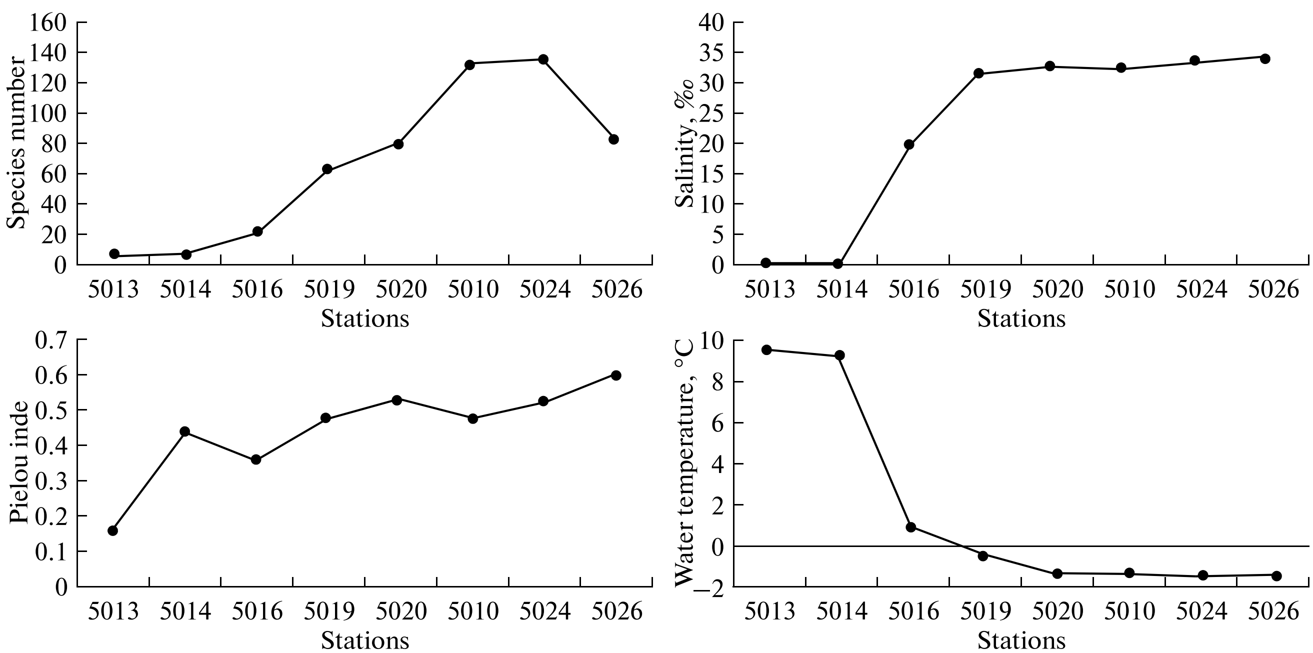

Fig. 4. Total number of species, Pielou index, near-bottom salinity and temperature at the stations of the Yenisei transect.

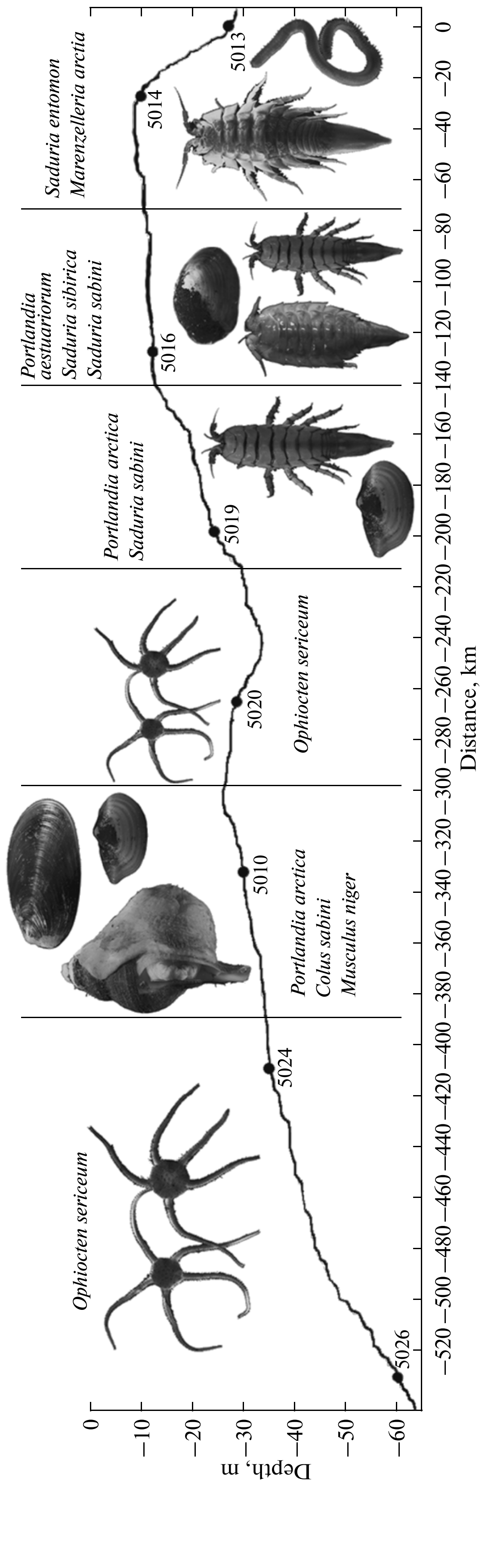

Fig. 5. Bottom relief and dominant taxa in the stations of the Yenisei transect.

tion (5026) is drastically reduced. This is probably related to the small trawl sample: it contained less than 500 individuals of different species. Almost all other stations of the transect contained more than 1000 individuals. The Pielou index was the lowest at station 5013, due to the huge amount of *Saduria entomon* isopods. At the same time, the Pielou index at station 5014 was considerably higher due to the smaller number of *S. entomon* and higher amount of *Mysis relicta* comparing to the station 5013. At the station 5016 the index value was relatively small due to the large number of *Portlandia aestuariorum*. The highest values were observed for stations of the marine complex with a dominance of *O. sericeum* ophiuroids (5020, 5024, and 5026). For the transitional complex (5019 and 5010) the Pielou index values was intermediate between stations of the brackish-water and intermediate complexes (5013, 5014 and 5016) and stations of the marine complex (Fig. 4).

CONCLUSIONS

A consecutive replacement of benthic community complexes is observed when going from the Yenisei estuary to the open parts of the sea. The replacement is expressed in the changes of the dominant taxa (Fig. 5). The previously described notion about the crustacean communities being replaced by the bivalve communities and then echinoderms is generally true. However, the borders of communities differ from those mentioned in earlier investigations. As an example, the *Ophiocten sericeum* community begins more than 2° south than according to the literature data at the Yenisei transect longitude.

A gradual change of communities along the salinity gradient can be detected. A total of four faunal complexes could be distinguished in the investigated area: brackish-water complex dominated by *Saduria entomon*, intermediate complex dominated by *S. sibirica*, *S. sabini* and *Portlandia aestuariorum*, transitional complex dominated by *P. arctica* and marine complex dominated by *Ophiocten sericeum*.

A clear substitution of freshwater or brackish-water taxa by the closely related euryhaline taxa is observed along the transect together with the salinity increase. The replacement of *S. entomon* with *S. sibirica* and *S. sabini* or the replacement of *P. aestuariorum* with *P. arctica* are the examples. A similar distribution of closely related species along the salinity gradient was previously described for the brackish-water areas of the Laptev Sea [13]. The consecutive change of benthic communities along the Yenisei transect brakes near the Sverdrup Island where the *O. sericeum* is replaced back to the *P. arctica* community.

The *Synidotea bicuspida* isopods were detected among the dominant taxa for the first time in the community dominated by *O. sericeum* and foulers.

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REFERENCES

1. T. V. Antipova and V. N. Semenov, "Composition and distribution of benthos in southwestern regions of the open Kara Sea," in *Ecology and Biological Resources of the Kara Sea* (Kola Scientific Center, Academy of Sciences of USSR, Apatity, 1989), pp. 127–137 [in Russian].
2. N. S. Gaevskaya, *Identification key to fauna and flora of the northern seas of the USSR* (Sovetskaya Nauka, Moscow, 1948) [in Russian].
3. S. V. Galkin, "Studies of macrobenthos of the Kara Sea in Cruise 49 of R/V *Dmitrii Mendeleev*, in *Benthos of high-latitudinal areas* (IORAN Press, Moscow, 1998), pp. 34–41 [in Russian].
4. S. V. Galkin, N. V. Kucheruk, K. V. Minin, A. K. Rayskiy, and E. I. Goroslavskaya, "Macrobenthos of the Ob River estuarine zone and of the adjacent regions of the Kara Sea," Oceanology (Engl. Transl.) **50** (5), 793–797 (2010).
5. E. F. Gurjanova, *Amphipods of the seas of the USSR and adjacent waters (Amphipoda—Gammaridea)* (Academy of Sciences of USSR, Moscow, 1951) [in Russian].
6. A. M. Djakonov, *The Sea Stars of the seas of the USSR* (Academy of Sciences of USSR, Moscow, 1950) [in Russian].
7. I. A. Zhirkov, *Polychaeta of the Arctic Ocean* (Yanus-K, Moscow, 2001) [in Russian].
8. L. A. Zenkevich, *Biology of the Seas of the USSR* (Academy of Sciences of USSR, Moscow, 1963) [in Russian].
9. *Illustrated keys to free-living invertebrates of Eurasian Arctic Seas and adjacent deep waters* Ed. by B. I. Sirenko (KMK, Moscow, 2009) [in Russian].
10. V. V. Kozlovskii, "Macrobenthos of the upper shelf of the south-western Kara Sea," PhD dissertation (IORAN, Moscow, 2012) [in Russian].
11. N. V. Kucheruk and E. A. Savilova, "Quantitative and ecological characteristics of benthic fauna of the shelf and upper slope of the North-Peruvian Upwelling," Byulleten MOIP Otdel Biologicheskii, **90** (6), 70–79 (1985) [in Russian].
12. N. B. Lomakina, *Cumacea crustaceans (Cumacea) of the seas of the USSR* (Academy of Sciences of USSR, Moscow, 1958) [in Russian].
13. V. V. Petryashev and A. V. Novozhilov, "Influence of hydrological regime on distribution of macrobenthos in the Laptev Sea," Issled. Fauny Morei **54** (62), 74–85 (2004) [in Russian].
14. *Modern Benthos of the Barents and Kara Seas* (Kola Scientific Center, Russian Academy of Sciences, Apatity, 2000) [in Russian].
15. Z. A. Filatova and L. A. Zenkevich, "Quantitative distribution of Benthic Fauna of the Kara Sea," Tr. Vses. Gidrobiol. Obshch, No. 8, 3–62 (1957) [in Russian].
16. V. V. Khlebovich, *Critical Salinity in biological processes* (Nauka, Leningrad, 1974) [in Russian].
17. D. S. Cronan, "Manganese nodules and other ferromanganese oxide deposits from the Atlantic Ocean," J. Geophys. Res. **80** (27), 3831–3837 (1975).
18. S. Denisenko, H. Sandler, N. Denisenko, and E. Rachor, "Current state of zoobenthos in two estuarine bays of the Barents and Kara seas," ICES J. Mar. Res. **56**, 187–193 (1999).
19. N. Denisenko, E. Rachor, and S. Denisenko, "Benthic fauna of the southern Kara Sea," in *Proceedings in Marine Science* (Elsevier, Amsterdam, 2003), vol. 6, pp. 213–236.
20. H. Deubel, M. Engel, I. Fetzer, et al., "The southern Kara Sea ecosystem: phytoplankton, zooplankton and benthos communities influenced by river run-off," in *Proceedings in Marine Science* (Elsevier, Amsterdam, 2003), Vol. 6, pp. 237–263.
21. V. Khlebovich and A. Komendantov, "Biotic communities of the Kara Sea estuarine ecosystems," Nor. Polarinst. Rap. **97**, 66 (1997).
22. A. P. Lisitzin, "The marginal filter of the ocean," Okeanologiya (Moscow) **34**, 671–682 (1997).
23. D. Piepenburg and K. S. Schmid, "Brittle star fauna (Echinodermata: Ophiuroidea) of the Arctic northwestern Barents Sea: composition, abundance, biomass and spatial distribution," Polar Biol. **16**, 383–392 (1996).
24. A. Remane, "Die Brackwasserfauna," Verh. Dtsch. Zool. Ges., 34–74 (1934).