Features of the Species and Spatial Structure of Macrobenthos in the Green Cape Lagoon (Kandalaksha Bay, White Sea)  
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Abstract—Features of the species and spatial structure of sublittoral macrobenthic communities in a lagoon ecosystem of Green Cape (White Sea) have been studied. Thirty-one invertebrate species and three species of sea grasses and algae (Zostera marina, Cladophora sericea, and Fucus vesiculosus) were found in the sublittoral zone of the surveyed lagoon. The data on the species composition, diversity, and spatial structure of macrobenthos communities indicate the predominance of littoral brackish water and marine euryhaline macrobenthos species (Hydrobia ulvae, Tubificoides benedii, Chironomus salinarius, and Macoma balthica) in the coastal region of the lagoon, marine littoral and sublittoral euryhaline species (mainly polychaetes Heteromastus filiformis, Polydora ciliata, and Capitella capitata) in the central deeper region, and marine sublittoral less euryhaline species (Pontoporeia femorata, Anonyx nugans, Nereimyra punctata, Terebellides stroemi, Astarte montagui, Micronephthys minuta, and Atylus carinatus) at the outlet of the lagoon. The ecosystem of the Green Cape lagoon belongs to lagoons heavily separated from the sea with depleted specific fauna (many littoral species) and largely influenced by the carbon load and salinity. The reduced connectivity of the lagoon with the sea due to the continued rise of the White Sea coast (4 mm per year in this area) will contribute to a decrease in the species diversity and the dominance of a few small eurytopic invertebrate species resistant to organic load, oxygen deficiency, and desalination.  

Keywords: lagoon ecosystems, macrobenthos, species diversity, spatial structure  
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INTRODUCTION  
Coastal lagoons lie at the boundary between sea and land and are characterized by an unstable hydrological, salt, and oxygen regime, which has a substantial impact on the community structure of the living organisms formed there (De Wit, 2011; Basset et al., 2013; Labai et al., 2014; Kompleksnye issledovaniya Babiego morya..., 2016, Stolyarov, 2017; Stolyarov and Mardashova, 2017; Franzo et al., 2019). Lagoon ecosystems are transient, shallow, and highly productive systems that have a limited water exchange with the sea (Kjerfve, 1994; McLusky and Elliott, 2007). Being transitional regions (from marine ecosystems to freshwater and continental ones), such ecosystems are particularly sensitive to changes in the environmental conditions such as climatic, hydrological, salinity, temperature, sedimentation rate, and organic and chemical pollution (Burkovskii, 2006; Khlebovich, 2010; Montagna et al., 2013; Khlebovich, 2015; Labay et al., 2016; Stolyarov, 2017; Telesh and Angus, 2017; De Wit et al., 2017; Stolyarov, 2019). Macrobenthic communities are a critical component of lagoon ecosystems. Therefore, the study of the species diversity and the spatial and trophic structure of the macrobenthos is especially important for understanding the general processes of the formation, functioning, and degradation of these unique objects, as well as for developing approaches to their conservation.  

The aim of this work is to study the species and spatial structure of the macrobenthos in a semi-isolated small lagoon in the White Sea. The lagoon is characterized by a three-layer hydrological structure and formation of hydrogen sulfide in the deep-water central region (Shaporenko et al., 2005). The studied communities of phyto- and zooplankton differed slightly from the open coastal areas in the White Sea (Shaporenko et al., 2005). The mass development of cryptophyte algae Rhodomonas sp. is observed in the sea in some periods (Krasnova et al., 2014). Previously, detailed studies of the macrobenthos in the lagoon have not been conducted.  

MATERIALS AND METHODS  
This study on the sublittoral macrobenthos was conducted in a small lagoon located in the apex part of the Kislaya Guba in Green Cape (Cape Zelenyi) in Kandalaksha Bay of the White Sea in August 2015 and July 2018. A total of 25 samples were collected: 20 samples in the lagoon and five samples at the outlet.
The sublittoral macrobenthos samples were collected using a Birge–Ekman dredge (area of 0.025 m²). Sediment samples were washed through a sieve with a 1-mm mesh. The washed samples were examined alive in the laboratory. The wet weight of organisms was measured to estimate the biomass.

Important environmental parameters were measured simultaneously with sampling of the hydrobiological material, such as salinity in the near-bottom water layer, sediment type, and depth measured by an echosounder at a low water level. Water salinity was measured with a WTW Cond 3110 conductivity meter (United States).

For each station the density and biomass of the species populations were estimated and the Shannon diversity index (Shannon, 1948) and Pielou’s evenness index (Pielou, 1966) were calculated. The standard errors of the mean were calculated for the average values.

In order to measure the similarity of communities formed at different stations (quantitative data), cluster analysis was performed by the average grouping method based on Pianka’s similarity matrix implemented in the PAST software package:

\[
K = \frac{2c}{(a + b + 2c)},
\]

where \(c\) is the number of common species for stations \(X\) and \(Y\) and \(a\) and \(b\) are the number of species recorded at only one of the stations.

To select the optimal degree of fragmentation of the obtained clusters, the criterion of significant similarity was used, which is calculated as the upper 95% confidence interval of the average similarity between stations.

Statistical analysis was performed with the PAST ver. 3.24 (Hammer et al., 2001) and MS Excel 2010 software packages.

**RESULTS AND DISCUSSION**

**Abiotic conditions and characteristics of the study region.** The Green Cape lagoon is located 2.5–3 km from the White Sea Biological Station (WSBS) of Moscow State University (Kandalaksha Bay, 66°31’49” N and 33°05’55” E) and is separated from the main basin by a shallow rapid which completely isolates the lagoon when the water level drops at low tide. The lagoon is well protected from the sea waves and currents and is surrounded by land on all sides (Fig. 1).

The studied ecosystem has a total length of 17662 m² (on average, 150 m in diameter) and small depths (average depths of about 2 m, and maximum depths of 5–6 m in the central deep-water area). The lagoon is slightly elongated from the west and northwest to the east. The bottom sediments in the sublittoral zone in the lagoon are mainly silts and sandy silts with a significant content of detritus (many semi-decomposed seagrasses and algae, *Cladophora sericea*, and *Zostera marina*). The water salinity during the sampling period (the beginning of August 2015, July 2018) was relatively high, 23–24‰. In the apex parts of the lagoon, the salinity decreased to 21–22‰ (Table 1).

**Species composition and general parameters of the community structure.** A total of 31 species of invertebrates and three species of seagrasses and algae (*Cladophora sericea*, *Zostera marina*, and *Fucus vesiculosus*) were found in the sublittoral zone of the lagoon (Table 2). Marine polychaetes (13 species), mollusks (five species), and crustaceans (five species) reached the highest species diversity, while brackish water oligochaetes (one species) and chironomids (two species) were rare. Mainly typical littoral brackish water and marine euryhaline species (*Chironomus salinarius*, *Orthocladius saxicola*, *Tubificoides benedeni*, *Hydrobia*...
Table 1. Environmental parameters in the Green Cape lagoon in the summer of 2015 and 2018

| Stations | Abiotic factors | Salinity, ‰ | Surface water layer | Near-bottom water layer |
|----------|----------------|-------------|---------------------|-------------------------|
|          | sediment type  | depth, m    |                     |                         |
|          | Lagoon proper  |             |                     |                         |
| 1        | Silty sand     | 1.5         | 21–22               | 22–24                   |
| 2        | Silt           | 2           | 21–22               | 22–24                   |
| 3        | Silt           | 2.5         | 21–22               | 22–24                   |
| 4        | Silt           | 3           | 21–22               | 22–24                   |
| 5        | Silt           | 3.5         | 21–22               | 22–24                   |
| 6        | Sandy silt     | 4           | 21–22               | 22–24                   |
| 7        | Silt           | 4.5         | 21–22               | 22–24                   |
| 8        | Sandy silt     | 1.5         | 21–22               | 22–24                   |
| 9        | Silt           | 2           | 21–22               | 22–24                   |
| 10       | Silt           | 2.5         | 21–22               | 22–24                   |
| 11       | Silt           | 3           | 21–22               | 22–24                   |
| 12       | Silt           | 3.5         | 21–22               | 22–24                   |
| 13       | Silt           | 4           | 21–22               | 22–24                   |
| 14       | Silty sand     | 1.5         | 21–22               | 22–24                   |
| 15       | Silty sand     | 2           | 21–22               | 22–24                   |
| 16       | Silt           | 2.5         | 21–22               | 22–24                   |
| 17       | Silt           | 3           | 21–22               | 22–24                   |
| 18       | Sandy silt     | 3.5         | 21–22               | 22–24                   |
| 19       | Silt           | 4           | 21–22               | 22–24                   |
| 20       | Silt           | 4.5         | 21–22               | 22–24                   |
|          | At the lagoon outlet | |                     |                         |
| 21       | Silty sand     | 1.5         | 23                  | 23–24                   |
| 22       | Silt           | 4.0         | 23                  | 23–24                   |
| 23       | Silt           | 2.5         | 23                  | 23–24                   |
| 24       | Silt           | 3.0         | 23                  | 23–24                   |
| 25       | Silt           | 4.5         | 23                  | 23–24                   |

*ulvae, Macoma balthica, Mytilus edulis, Mya arenaria, Arenicola marina, Phyllodoce maculata, and Fabricia sabella* dominated within the lagoon, and a larger number of marine less euryhaline sublittoral species (*Terebellides stroemii, Micronephthys minuta, Pectinaria koreni, Astarte montagui, Atylus carinatus, Anonyx nugax,* and *Asterias rubens*) was recorded at the outlet of the lagoon behind the rapids (Table 2).

The spatial distribution of species in the littoral (in the upper, middle, and lower littoral zones) and sublittoral habitats in neighboring lagoon ecosystems is considered in detail in the previous papers (Stolyarov, 2015, 2017, 2019).

The lowest species diversity and the total biomass of the macrobenthos community were recorded in the central deep-water part of the lagoon (3.5–5 m), and higher values were recorded in the littoral area with small depths (1–3 m). The area located at the outlet of the lagoon occupied an intermediate position (Table 3). The average values of the number of species and the total biomass of the macrobenthos in the littoral area and at the outlet of the lagoon exceeded two times or more the corresponding values recorded in the central part (Table 3).

Low values of the general parameters of the community structure in the deep-water area may indicate unfavorable conditions in the central basin of this ecosystem, where a large amount of detritus accumulates (a lot of semi-decomposed seagrasses and algae), and sediments are mainly represented by soft silts dominated by a community of small polychaetes. Living organisms were not found deeper than 5 m, which is
Table 2. List of macrobenthos species found in the sublittoral of the Green Cape lagoon in the summer of 2015 and 2018

| No. | Macrobenthos | Green Cape lagoon | At the outlet of the lagoon |
|-----|-------------|--------------------|---------------------------|
|     |             | Zoobenthos         |                           |
|     |             | Class Polychaeta   |                           |
| 1   | *Harmothoe imbricata* (Linnaeus) | +   | +   |
| 2   | *Nereimyra punctata* (Müller)    | –   | +   |
| 3   | *Polydora ciliata* (Johnston)    | +   | –   |
| 4   | *Scoloplos armiger* (O.F. Müller) | –   | +   |
| 5   | *Arenicola marina* (Linnaeus)    | +   | –   |
| 6   | *Fabricia sabella* (Ehrenberg)   | +   | –   |
| 7   | *Micronephthys minuta* (Theel)   | –   | +   |
| 8   | *Capitella capitata* (Fabricius) | +   | –   |
| 9   | *Terebellides stroemi* Sars      | –   | +   |
| 10  | *Pectinaria koreni* (Malmgren)   | +   | +   |
| 11  | *Phyllocoec maculata* (Linnaeus) | +   | –   |
| 12  | *Pholoe minuta* (Fabricius)      | +   | –   |
| 13  | *Heteromastus filiformis* (Claparède) | +   | –   |
|     |             | Class Nematoda     |                           |
| 14  | *Pontonema vulgare* (Bastian) Filipjev | +   | –   |
|     |             | Class Oligochaeta  |                           |
| 15  | *Tubificoides benedii* (d’Udekem) | +   | +   |
|     |             | Class Gastropoda   |                           |
| 16  | *Hydrobia ulvae* (Pennant)       | +   | –   |
|     |             | Class Bivalvia     |                           |
| 17  | *Mytilus edulis* Linnaeus        | +   | +   |
| 18  | *Macoma balthica* (Linnaeus)     | +   | +   |
| 19  | *Mya arenaria* Linnaeus          | +   | –   |
| 20  | *Astarte montagui* (Dillwyn)     | –   | +   |
|     |             | Class Crustacea    |                           |
| 21  | *Gammarus duebeni* Lilljeborg    | –   | +   |
| 22  | *Crassicorophium bonelli* (Milne Edwards) | +   | –   |
| 23  | *Pontoporeia femorata* Krøyer    | –   | +   |
| 24  | *Atylus carinatus* (Fabricius)   | –   | +   |
| 25  | *Anonyx nugax* (Phipps)          | –   | +   |
|     |             | Class Asteroidea   |                           |
| 26  | *Asterias rubens* Olivi          | –   | +   |
|     |             | Class Asciidiacea  |                           |
| 27  | *Molgula griffithsii* (MacLeay)  | +   | –   |
|     |             | Class Insecta      |                           |
| 28  | *Chironomus salinarius* Kieffer  | +   | –   |
| 29  | *Orthocladius saxicola* Kieffer  | +   | –   |
|     |             | Type Nemertini     |                           |
| 30  | *Amphiporus lactifloreus* (Johnston) | +   | +   |
| 31  | *Lineus gesserensis* (O.F. Müller) | +   | +   |
|     |             | Macrophytes (seagrasses and algae) |     |
| 1   | *Zostera marina* Linnaeus        | +   | +   |
| 2   | *Cladophora sericea* (Hudson) Kützing | +   | –   |
| 3   | *Fucus vesiculosus* Linnaeus     | –   | +   |

“+” species has been registered; “–” species not found.
probably due to the extremely stressful living conditions in this habitat (lack of oxygen, formation of hydrogen sulfide) (Kompleksnye issledovaniya Bab'ego morya..., 2016). It should be noted that values of the total density of the species populations of the lagoon proper (especially in the littoral area) were significantly higher than at its outlet, which can be explained by its considerable siltation and prevalence of small forms of macrozoobenthos (Hydrobia ulvae, small polychaetes, oligochaetes, and chironomids) (Table 3).

Thus, the data on the qualitative composition and general parameters of the macrobenthos community structure indicate a wider distribution of littoral brackish water and marine euryhaline species (characterized by high density and biomass of species populations) within the lagoon, which is, apparently, a consequence of its desalination (especially during snowmelt in early spring) and siltation. Mainly marine sublittoral less euryhaline species prevailed in the area located at the outlet of the lagoon and closely connected with the sea.

Spatial structure of the community (similarity of stations). The average similarity of stations in terms of the qualitative composition or the density of species populations of the macrobenthos or in terms of biomass in the lagoon ecosystem in the Green Cape was relatively low (about 0.3—0.4). This indicates inhomogeneity of the species structure of the macrobenthos community and differences in the species complexes in different regions of this ecosystem.

The cluster analysis for qualitative data at the level of significant similarity makes it possible to distinguish three groups of stations in the lagoon in Green Cape: a shallow littoral area (stations 8—13), central deep-water area (stations 11, 20 and stations 7, 19), and the marine area at the outlet of the lagoon (stations 23, 24, 25) and two stations (21, 22) that have low similarity with other stations, which is due to the different conditions of the existence of hydrobionts in the littoral shallow area, in the central deeper area, and in the marine area at the outlet of the lagoon (Fig. 2).

It should be noted that littoral brackish water and marine euryhaline species (Hydrobia ulvae, Tubificoides benedii, Pontonema vulgare, Chironomus salinaris, and Macoma balthica) mainly dominated in the littoral zone, marine euryhaline littoral and sublittoral species (mainly polychaetes Heteromastus filiformis, Polydora ciliata, and Capitella capitata) dominated in the central part, and marine sublittoral less euryhaline species (Pontoporeia femorata, Anonyx nugans, Nereimyra punctata, Terebellides stroemi, Astarte montagui, Micronephthys minuta, and Atylus carinatus) were dominant at the outlet of the lagoon.

The littoral community, in turn, is inhomogeneous in the structure of its species, which is confirmed by the cluster analysis performed for stations located

| Parameters | Littoral shallow region | Central deep-water region | At the outlet of the lagoon |
|------------|------------------------|---------------------------|-----------------------------|
| $S$        | 7.2*                   | 0.8**                     | 3.2*                        |
| $N$, ind/m²| 6984                   | 1345                      | 2160                        |
| $B$, mg/m² | 104289                 | 31501                     | 9052                        |
| $H_N$      | 1.9                    | 0.1                       | 1.3                         |
| $E_N$      | 0.7                    | 0.1                       | 0.8                         |
| $H_B$      | 1.2                    | 0.15                      | 0.8                         |
| $E_B$      | 0.45                   | 0.05                      | 0.5                         |

* Average values; **, standard error. $S$, number of species; $N$, total density; $B$, total biomass; $H_N$, Shannon index for population density; $E_N$, Pielou index for population density; $H_B$, Shannon index for biomass; and $E_B$, Pielou index for biomass.

Fig. 2. Dendrogram of the macrobenthic community similarity in terms of qualitative composition (Sørensen coefficient). The horizontal line shows the significant similarity level. See Table 1 for the numbering of stations.
within the lagoon (based on the biomass of populations) (Fig. 3).

At the level of significant similarity, the littoral stations located closer to the outlet of the lagoon (stations 8–1), where bivalve mollusks *Macoma balthica* dominated in terms of biomass, and further from it (stations 9–18), where populations of small species *Hydrobia ulvae* and *Tubificoides benedii* prevailed, were distinguished, as were stations of the central part of the lagoon (stations 5–20).

Thus, this analysis indicates inhomogeneity of the species structure of the macrobenthos community of the Green Cape lagoon ecosystem, which is associated with different abiotic conditions in the littoral zone (shallower, desalinated, and overgrown with macrophytes), in the central area of the lagoon (larger depths, prevalence of soft sediments with a significant content of detritus) and at the outlet of the lagoon (higher and almost stable salinity).

**CONCLUSIONS**

A total of 31 species of invertebrate animals and three species of seagrasses and algae (*Cladophora sericea*, *Zostera marina*, and *Fucus vesiculosus*) were recorded in the sublittoral zone of the surveyed lagoon. The data on the species composition and the structure of the communities of benthic organisms formed there indicate inhomogeneity of the species structure of the macrobenthos community and prevalence of mainly littoral brackish water and marine euryhaline macrobenthos species (*Hydrobia ulvae*, *Tubificoides benedii*, *Chironomus salinarius*, and *Macoma balthica*) in the littoral zone, marine littoral, and sublittoral euryhaline species (mainly polychaetes *Heteromastus filiformis*, *Polydora ciliata*, and *Capitella capitata*) in the central region, and marine sublittoral less euryhaline species (*Pontoporeia femorata*, *Anonyx nugans*, *Nereimyra punctata*, *Terebellides stroemi*, *Astarte montagui*, *Micronephys minuta*, and *Atylus carinatus*) at the outlet of the lagoon. The ecosystem of the Green Cape lagoon belongs to lagoons heavily separated from the sea with a high content of organic matter in sediments where complexes of littoral marine euryhaline and brackish water species of the macrobenthos with the dominance of small detritophages prevailed, which is, apparently, a consequence of its higher desalination (especially in early spring during snowmelt or in summer and autumn during heavy rains, etc.) and sedimentation.

Further regulation of the lagoon because of a continuing rise of the White Sea coast (4 mm per year in this area) (Romanenko and Shilova, 2012) may lead to changes in the hydrological regime over several decades and, as a result, to changes in the salt and oxygen regime in the lagoon, which will promote a reduction in the species diversity and dominance of a few small eurytopic species of invertebrate animals resistant to organic load, oxygen deficiency, and desalination.

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**COMPLIANCE WITH ETHICAL STANDARDS**

**Conflict of interest.** The authors declare that they have no conflict of interest.

**Statement on the welfare of animals.** All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

**REFERENCES**

Angus, S., Scottish saline lagoons: impacts and challenges of climate change, *Estuarine, Coastal Shelf Sci.*, 2017, vol. 198, pp. 626–635.

Basset, A., Elliot, M., West, R.J., and Wilson, J.G., Estuarine and lagoon biodiversity and their natural goods and services, *Estuarine, Coastal Shelf Sci.*, 2013, vol. 132, pp. 1–4.

Burkovsky, I.V., *Morskaya biogeotsenologiya. Organizatsiya soobshchestv i ekosistem* (Marine Biogeocenology: Organization of Communities and Ecosystems), Moscow, 2006.

De Wit, R., Biodiversity of coastal lagoon ecosystems and their vulnerability to global change, in *Ecosystems Biodiversity*, Grillo, O. and Venora, G., Eds., Rijeka: InTech, 2011, pp. 29–40.

De Wit, R., Balavoine, J., Rey-Valette, H., Lifran, R., and Ouisse, V., Restoration ecology of coastal lagoons: new methods for the prediction of ecological trajectories and...
economic valuation, *Aquat. Conserv.: Mar. Freshwater Ecosyst.*, 2017, vol. 27, pp. 137–157.

Dice, L.R., Measures of the amount of ecologic association between species, *Ecology*, 1945, vol. 26, no. 3, pp. 297–302.

Franzo, A., Ascoli, A., Roscioli, C., Patrolecco, L., Bazzaro, M., Del Negro, P., and Cibic, T., Influence of natural and anthropogenic disturbances on foraminifera and free-living nematodes in four lagoons of the Po Delta System, *Estuarine, Coastal Shelf Sci.*, 2019, vol. 220, pp. 99–110.

Hammer, O., Harper, D.A.T., and Ryan, P.D., PAST: paleontological statistics software package for education and data analysis, *Paleontol. Electron.*, 2001, vol. 4, no. 1, pp. 1–9.

Khlebovich, V.V., Applied aspects of the concept of critical salinity, *Biol. Bull. Rev.*, 2015, vol. 5, no. 6, pp. 562–567.

Kjerfve, B., Coastal lagoons, in *Coastal Lagoon Processes*, Kjerfve, B., Ed., Amsterdam: Elsevier, 1994, pp. 1–8.

Kolesniky, D.S. and Elliott, M., Transitional waters: a new definition, *Estuarine, Coastal Shelf Sci.*, 2007, vol. 71, pp. 359–363.

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