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The description and prediction of benthic biodiversity in high arctic and freshwater-dominated marine areas: The southern Onega Bay (the White Sea)

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ABSTRACT

The structure of the macrozoobenthic community in 2003–2004 in the southern part of the Onega Bay along a salinity gradient showed the poorest fauna (one species) was found in the estuarine area. In the open part of the bay the species richness up to 64 species. In the study area, as a whole, the zoobenthos abundance varied from 51 to 4590 ind. m^{-2}, biomass – from 0.51 to 651.4 g m^{-2} and lower values occurred in the estuarine part of the Onega Bay. The Shannon diversity index [$\log_2$ basis] varied considerably – from 0.69 bits in the mouth of the Onega River up to 4.56 bits at the marine stations. Liner multiple regression analysis showed that species richness is related primarily to depth, distance, temperature and the amount of $C_{org.}$ in sediments; Shannon diversity is connected with salinity, temperature, depth, amount of $C_{org.}$ in sediments and chlorophyll concentration in the water. For abundance and biomass the main determining factors were distance and concentration of $C_{org.}$ in sediments. Fresh water input from the Onega River caused variations in the salinity regime in the top of the Bay which indirectly influenced zoobenthic populations via other parameters which changed as a result of river discharge.

1. Introduction

In recent decades, estuarine areas have received attention as pollutants and fresh water supplied by riverine runoff have a considerable influence on the biota's characteristics. At the same time estuarine areas are characterized by high biological productivity (Safjanov, 1987; Deubel et al., 2003; Telesh, 2004). Moreover, the estuarine parts of the marine bays are areas of the so-called "marginal filter", where sedimentation of suspended matter takes place (Lisitsin, 1999). The features of the bottom fauna in the estuaries of the temperate latitudes of the world have been well-studied (e.g. Day et al., 1971; Elliott and Kingston, 1987; Hyland et al., 2004; Elliott et al., 2007). In contrast, the zoobenthos of the estuarine bays of the Arctic region which are characterized by high tides have been poorly studied despite them serving as breeding areas for commercial and recreational species of fish and invertebrates. There are few publications about distribution of zoobenthos in the estuarine bays of the Arctic region (Denisenko et al., 1999, 2003, 2007; Denisenko, 2009; Chertoprood et al., 2004; Udalov et al., 2004). The environmental characteristics of the estuarine bays in the Arctic seas differ from each other mainly due to the different intensity of fresh water discharges (Burenkov and Vasilkov, 1994; Dolotov et al., 2002; Shevchenko et al., 2005). This can causes a difference in distribution of zoobenthos in the bays.

Although the biomass distribution and community structure of zoobenthos of the marine part of Onega Bay has been studied in some detail (Ivanova, 1957; Kudersky, 1966; Golikov et al., 1985; Lukanin et al., 1995), the corresponding features of the estuarine ecosystem, also where the zoobenthos is important, has not yet been investigated. The zoobenthos of the southern shallow areas of the Onega Bay where the depth is less than 4 m has not been studied at all due to navigation difficulties.

The White Sea has moderate levels of contaminants (Savinov et al., 2000) and the data obtained can provide a baseline against which future adverse changes can be judged. Hence our objectives were 2-fold. Firstly, we aimed to describe the zoobenthos through its species composition, abundance and biomass and to calculate Shannon diversity index and other measures. Secondly, these data were used to examine the influence of environmental factors such as depth, salinity, temperature, concentrations of chlorophyll, suspended matter and concentration of organic carbon in sediments in order to determine the most significant factors. The significant factors can be regarded as potential environmental control factors. We need to improve our knowledge of the Onega Bay, because it is among the most important areas of the White Sea due to the high species diversity and the presence of relict boreal fauna and it has been proposed as a protected area (Larsen et al., 2004). The present study also builds on multidisciplinary environmental studies by Zoological Institute of the Russian Academy of Sciences (St.-Petersburg), Shirshov Institute, RAS (Moscow) and Institute of the water problems of the North, Karelia branch of the RAS

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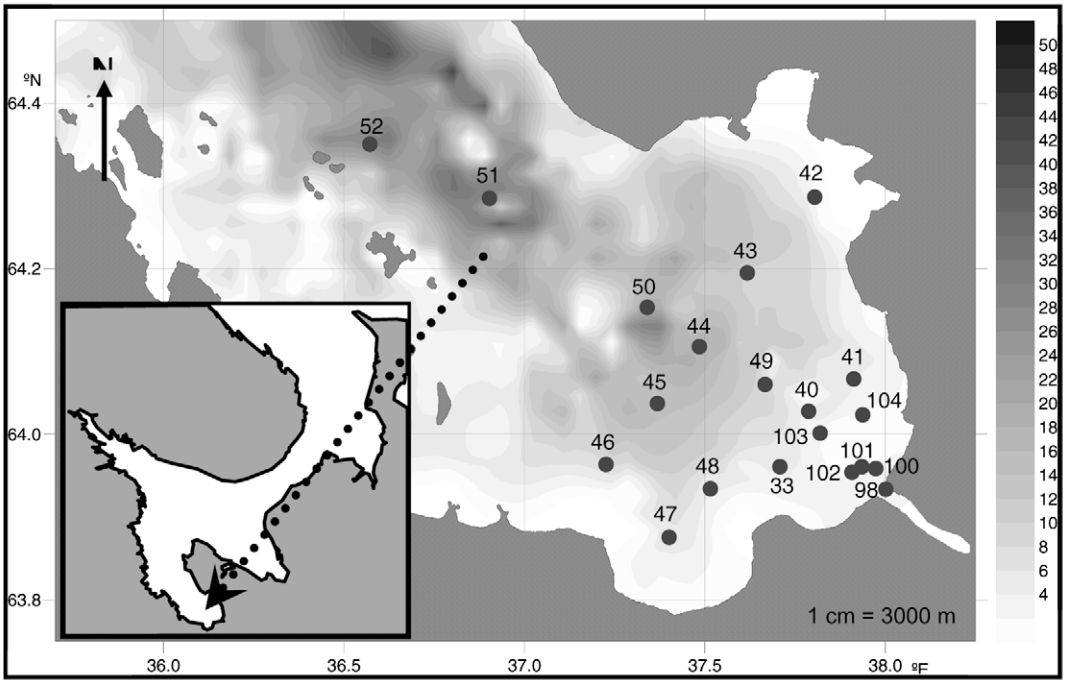

Fig. 1. Map of the study area and zoobenthos sampling station network in the Onega Bay in 2003–2004 and location of the bay in the White Sea. Depth scale in meters.

(Petrozavodsk), were carried out in 2003–2004 (Filatov et al., 2004; Dolotov et al., 2008).

2. Study area

Onega Bay is one of the largest bays in the White Sea (Fig. 1) in being c.80 km long and its width varies from 30 to 60 km. It is very shallow compared to others bays of the White Sea and its depth does not exceed 40 m. The near-bottom temperature varies from 11.1 °C in the marine part of the bay and up to 21.8 °C at the river mouth (Table 1). The lack of a sill makes water exchange with the open sea relatively unrestricted, while cold water masses from the deeper water layers of the sea basin cannot penetrate into the bay due to its shallowness. The Onega River discharges more than 15.295 km^3 $year^{-1}$ of fresh water into the bay. The near-bottom salinity varied from 1.66 in the river mouth and up to 24.6 at the marine stations. Salinity increases sharply at a distance of 5–7 km from the river mouth under a strong influence of the processes of water mixing which is induced by tidal currents and by wind-induced waves.

A prevailing strong anticyclonic inflow current enters from the north-eastern side of the bay (Babkov, 1985) and together with wind-induced and tidal currents create an intensive circulation of water masses. In the central part of the bay the speed of the permanent current amounts to 65–70 sm s^{-1} in the phase of high tidal water and it decreases to 19 sm s^{-1} at the beginning of the phase of low water (Dolotov et al., 2008). Geomorphological peculiarities of the bay creates a current pattern superimposed on by the tide, with a maximal tidal range of 3 m (Babkov, 1985; Filatov et al., 2004), that thoroughly mixes the coastal waters increasing the turbidity and forming underwater sand-dunes (Dolotov et al., 2008).

The concentration of total suspended matter which includes inorganic and organic particles in the water decreases towards the central part, from 16 mg l^{-1} in the Onega River mouth to 2 mg l^{-1} in the centre of the Bay (Dolotov et al., 2008). A higher concentration of chlorophyll-*a* as well as suspended matter is observed near the river mouth. Toward the open part of the bay its concentration decreases (Pozdnyakov et al., 2003; Filatov et al., 2004). These specific hydrodynamic features, together with a bottom morphology lacking marked depressions suitable for sedimentation of fine-grained material, lead to a predominance of hard sediments with sands of medium and coarse grain size and variable fractions of gravel. Soft bottoms with silt and sandy silt are found in shallow areas in the top of the bay at depths of 1.5–8 m and in the Onega river mouth, where a higher concentration of organic carbon in sediments occurs (Nevesskiy et al., 1977; Dolotov et al., 2008).

3. Material and methods

3.1. Field and laboratory work

Zoobenthos sampling was conducted in July 2003 and in August 2004 aboard R/V *Ecolog*, with a network of 21 stations covering the subtidal areas (Fig. 1). Station depths varied from 2.7 to 38 m and areas <6 m were sampled from the boat and station positions were determined by GPS. At each site a CTD (conductivity, temperature and depth) cast was made (Table 1). Sediment structure detail was acquired from Dolotov et al. (2008). Biological samples and environmental parameters such as depth, temperature, salinity, chlorophyll, suspended matter and concentration of organic carbon in sediments were also measured (Dolotov et al., 2008).

At each marine station three benthic samples were collected with a 0.1 m^2 van Veen grab and in shallow waters three replicates were taken with a 0.02 m^2 Ekman-Bergy grab. The sieved (mesh size 1.0 mm) samples were fixed in 4% formaldehyde solution buffered with sodium tetra-borate. In the laboratory, the samples were sieved on 1.0 mm nylon mesh under running water and transferred to 75% EtOH. All specimens in each sample were identified to the highest possible taxonomic separation, counted and weighed for alcohol wet weight. Molluscs, bryozoans and barnacles were weighed with their exoskeleton.

3.2. Calculations

Factor analysis was carried out to achieve the relationship between environmental factors and to analyse the environmental

Table 1
Sampling stations in the Onega Bay, with background information. VV = van Veen grab; EB = Ekman-Bergy grab, S = near-bottom salinity, T = near-bottom temperature. D = distance from river mouth.

Station number	Date of sampling	Depth, m	Samples, *n*	*S*	*T*, °C	*D*, km	$C_{org.}$ in sediments, %	Sediment description
98	05.08.04	4.2	3 EB	1.66	21.88	0	0.99	Mud with fine sand
100	05.08.04	3.9	3 EB	17.89	18.83	1.44	0.82	Mud with fine sand
101	05.08.04	2.7	3 EB	19.24	17.86	1.98	0.10	Muddy sand
103	06.08.04	4.1	3 EB	19. 0	17.35	5.58	0.10	Sandy-mud
102	05.08.04	3.4	3 EB	20.51	18.44	2.88	0.23	Sandy-mud
104	06.08.04	4.2	3 EB	22.45	16.55	4.14	1.10	Mud with fine sand
33/15	28.07.03/08.08.04	8	3 VV	23.1	12.37	7.92	0.11	Sand
40	27.08.03	10.4	3 VV	23.5	11.12	7.56	–	Gravel, coarse sand and clay
41/23	28.07.03/08.08.04	8.9	3 VV	23.1	11.63	7.02	1.04	Mud with sand and clay
42/22	28.07.03/08.08.04	9	3 VV	22.2	15.21	17.64	0.67	Mud with sand clay
43/21	28.07.03/08.08.04	15	3 VV	23.9	12.44	15.48	–	Muddy sand with clay
44/20	28.07.03/07.08.04	20	3 VV	21.4	12.99	16.2	–	Muddy sand with clay
45/19	28.07.03/06.08.04	16	3 VV	24.1	11.74	18.36	–	Mud with sand gray clay
46/18	28.07.03/08.08.04	7.9	3 VV	24.3	16.1	16.2	0.05	Coarse sand
47/17	28.07.03/08.08.04	6	3 VV	23.4	15.6	18.36	0.11	Mud with sand and clay
48/16	28.07.03/08.08.04	8.4	3 VV	23.8	11.59	13.32	0.05	Coarse sand
49/13	27.08.03/05.08.04	11.5	3 VV	23.7	11.36	10.8	1.66	Muddy clay
50/12	27.08.03/05.08.04	35.6	3 VV	23.6	12.57	20.88	–	Fine sand with shells
51/11	27.08.03/05.08.04	38	3 VV	24.8	12.33	33.66	–	Pebbles with sand
52/10	27.08.03/05.08.04	32	3 VV	24.3	13.08	43.56	–	Pebbles with sand

variables. The step-wise linear multiple regression analysis was used to estimate the influence of environmental variables on zoobenthos characteristics – species richness, abundance, biomass and biodiversity. The calculations were made using Statistica 6.0 (©StatSoft Inc., Moscow 2001). The similarity of stations according to environmental parameters was estimated by a clustering procedure on data obtained from each station calculated the Euclidean distances using group-average clustering to give a hierarchy of clusters (Biodiversity Professional Beta, ©The Natural History Museum and the Scottish Association for Marine Science 1998). Spatial distributions of species richness, abundance, biomass and biodiversity (see below) were made using the SURFER 7 (Golden Software, Colorado 1999).

To calculate the similarity between species composition at the stations, the Czekanowski–Soerensen index (Cz) (Czekanowski, 1909; Soerensen, 1948) was applied. The number of each taxon was used in the calculations as follows:

$$\mathrm{Cz} = 2 * \Sigma[\min(N_{sa}, N_{sb})] / \Sigma[(N_{sa} + N_{sb})] \quad (1)$$

where N_{sa} and N_{sb} = species number (per station 0.3 m^{-2}) of species “s” at stations “a” and “b”, respectively.

Determination of faunal complexes was made by using a standard hierarchical clustering procedure on data obtained from each sample using the Average Linkage Method (e.g. Pesenko, 1982; Pielou, 1984; Gray and Elliott, 2009) of the “BioDiversity Pro” software (Biodiversity Professional Beta, ©The Natural History

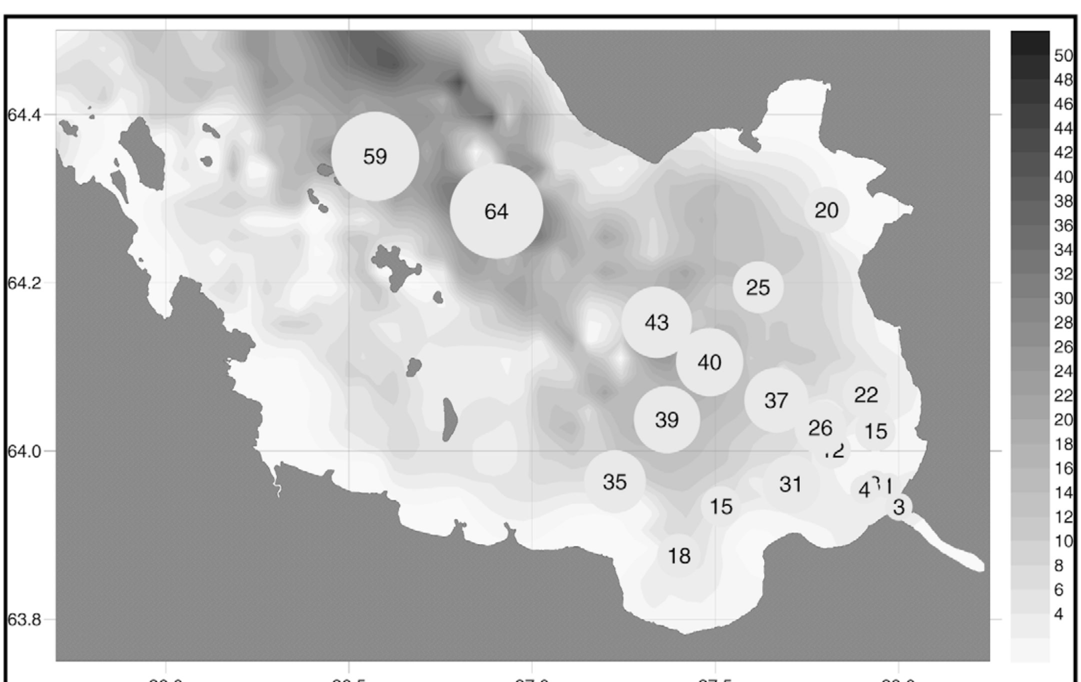

Fig. 2. Numbers of zoobenthic species at the Onega Bay study stations.

Museum and the Scottish Association for Marine Science 1998). Mean ± SD of biomass and abundance values at each station were calculated. Diversity was calculated using the Shannon index H' ($\log_2$) (Magurran, 1988) on abundance data of zoobenthos.

4. Results

4.1. Species composition and quantitative characteristics and diversity of zoobenthos

A total of 175 taxa were identified of which the most diverse group was Polychaeta, which contain 63 species in the study area, and Molluscs (mainly Bivalves – 32 species); Crustaceans included 21 species, Bryozoans −13 species, and others including Oligochaeta (2–5 species) and the freshwater bivalves *Pisidium* sp. were found at the top of the bay. Estuarine species of crustaceans (*Pontoporeia affinis*) and molluscs (*Macoma balthica*), and oligochaetes were found at the top of the bay, influenced by riverine water. Toward the open part of the bay the zoobenthos becomes more diverse and estuarine forms are replaced by marine species such as the polychaetes *Terebellides stroembi*, *Chaetozone setosa*, *Scoloplos armiger* and the bivalve molluscs *Leionucula belotti*, *Astarte elliptica*, *A. montagui*. At stations far from the top of the bay representatives of true marine fauna, such as echinoderms, bryozoans, brachiopods and barnacles were found. In whole study area polychaetes and molluscs predominate among other groups in terms of species richness (Fig. 2).

Analysis of α-diversity of zoobenthic species varies from 3 to 64 species and over the study area shows that the sites with a smaller number of species were located closer to the top of the bay and in the river mouth (Fig. 3). The stations influenced by fresh water discharge are also characterized by low species numbers and the species richness increases seaward.

Zoobenthos abundance in the study area varies considerably from 51 to 4590 ind. m^{-2} being lowest near the river mouth with the strongest influence of the fresh water discharge (Fig. 4). The most abundant groups were polychaetes at the largest number of stations, but in the centre of the bay barnacles were dominant. Biomass also varied considerably, from from 0.51 to 651.4 g m^{-2} (using the exoskeleton wet wt m^{-2}; Fig. 5). The lower values of the biomass of the zoobenthos were recorded in the mouth of

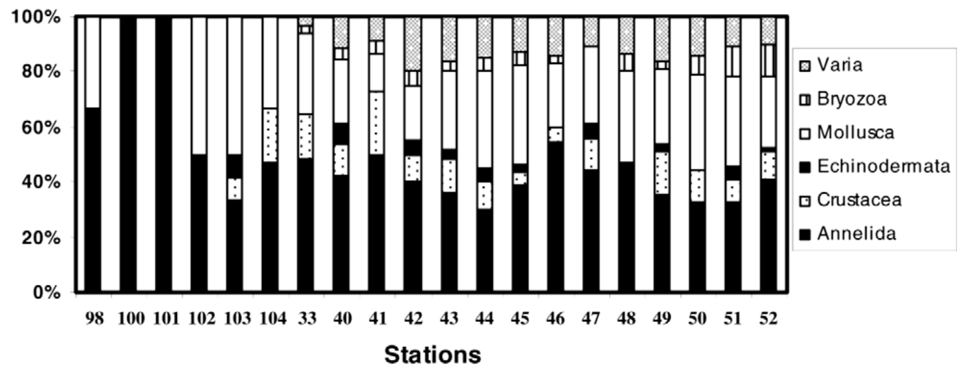

Fig. 3. Share of zoobenthic species in the main systematic groups at the Onega Bay study stations.

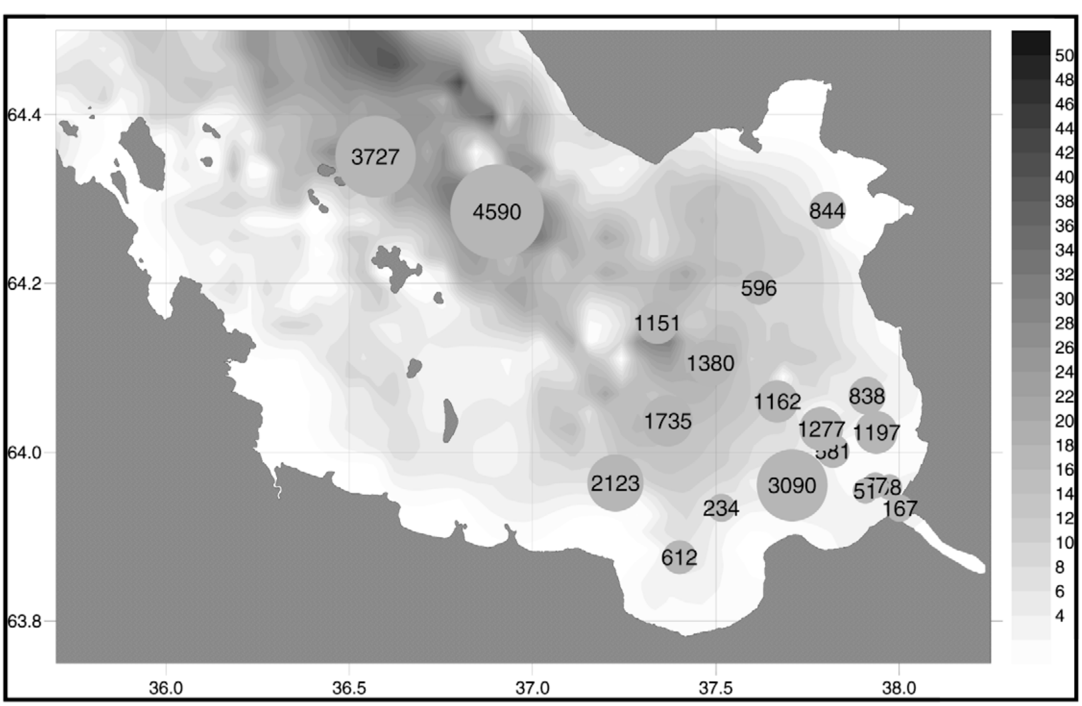

Fig. 4. Abundance distribution (ind. m^{-2}) of zoobenthos in the study area of the Onega Bay.

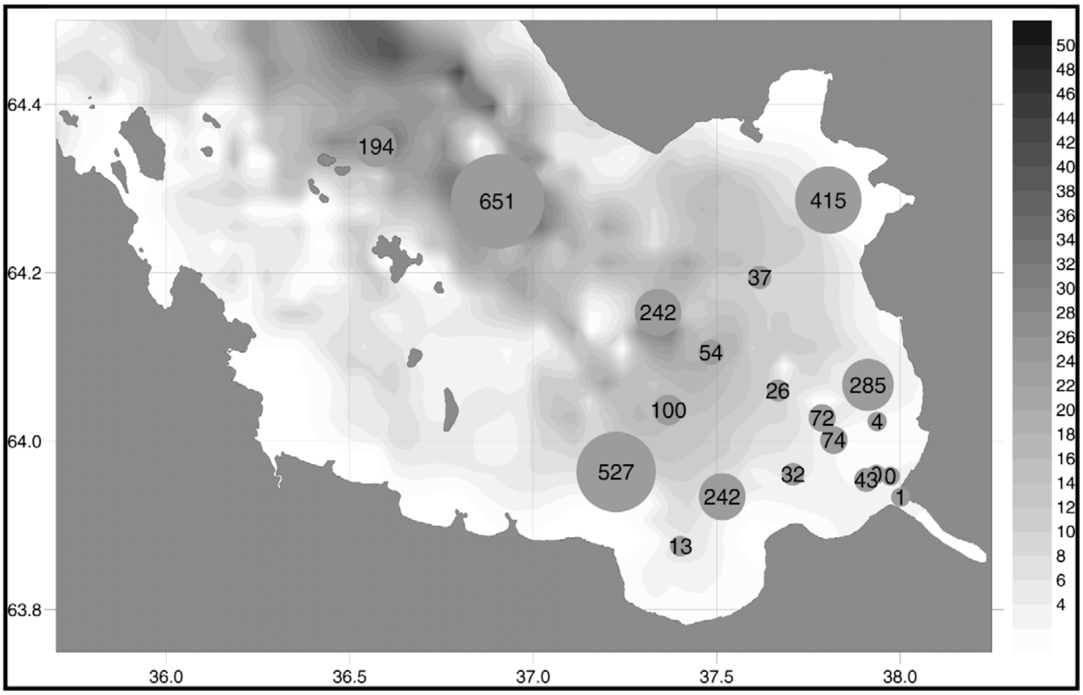

Fig. 5. Total biomass distribution (wet wt g m^{-2}) in the Onega Bay.

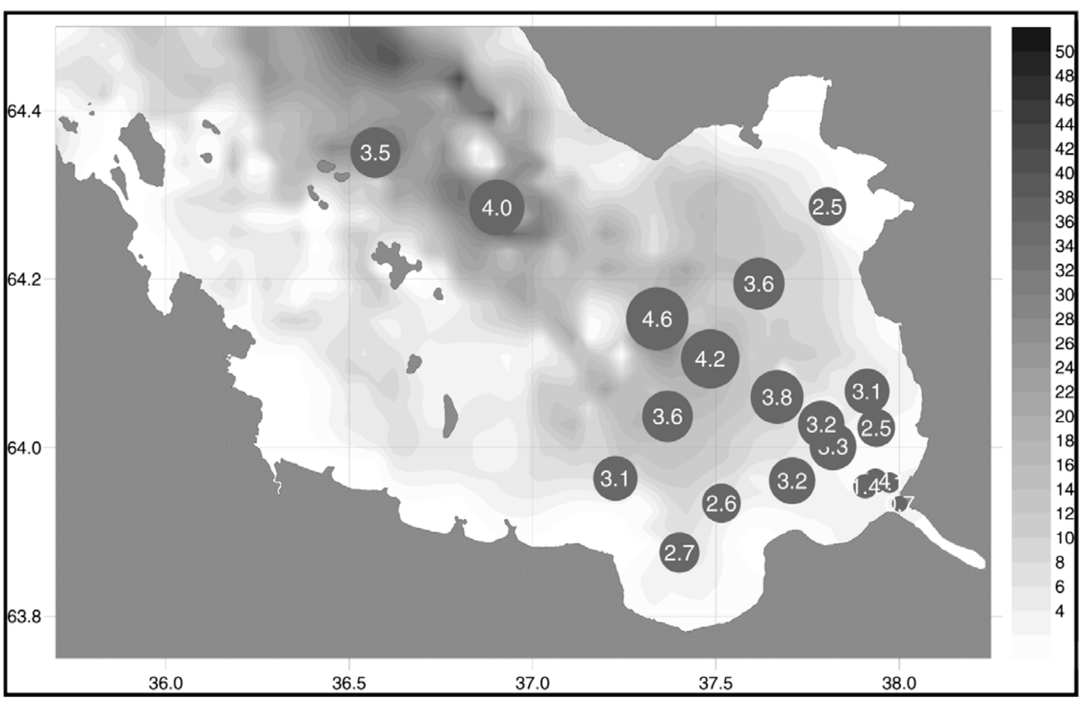

Fig. 6. Shannon diversity index ($H'\log_2$) of zoobenthos in the Onega Bay, based on abundance values.

the Onega River. Molluscs (mainly *Modiolus modiolus*, *Serripes groenlandicus*, *Arctica islandica* and *A. montagui*) generally formed the main part (from 50% to 95%) of the total biomass at most stations. At the stations with the highest values (>600 g wet wt m^{-2}) observed in the central part of the bay furthest from the river mouth, another high-biomass group appeared – barnacles (mainly *Balanus crenatus* and *Balanus balanus*) contributed 30–45% to the total biomass. Annelids dominated at the stations near to the river mouth, where the share of that group can reach 80–95%. They formed lesser biomasses at most stations, but predominated in biomass at the stations located near the top of the bay. Markedly lower biomass and abundance values of benthic organisms occurred near the river mouth.

The Shannon index of diversity varied from 0.69 in the mouth of the Onega River to 4.68 in the central part of the Onega Bay (Fig. 6).

4.2. Benthic patterns in relation to environmental variables

A clustering of environment parameters indicated three groups of stations with high level of similarity (Fig. 7). The first one

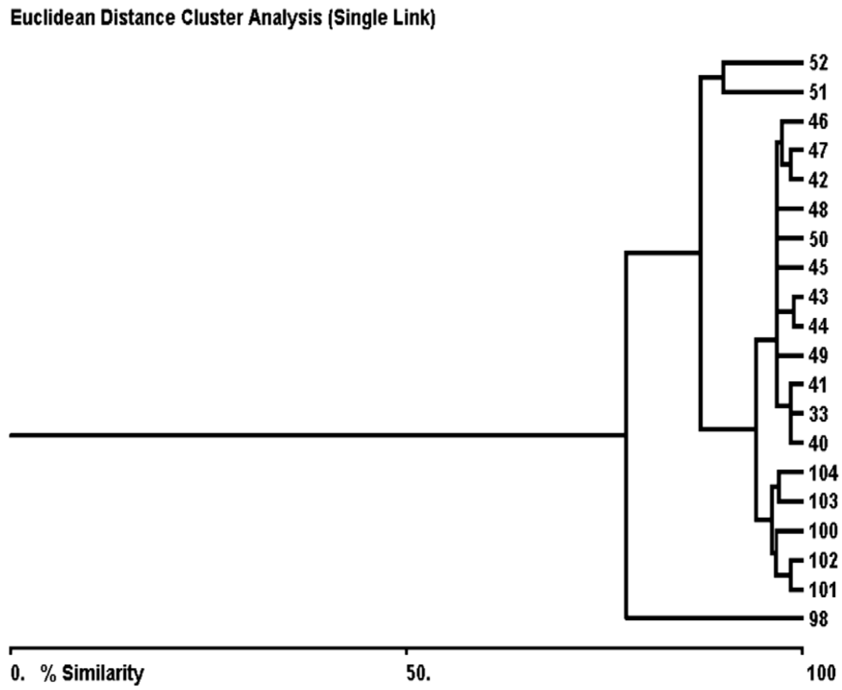

Fig. 7. Cluster diagram, showing the grouping of stations, based on similarity of environment parameters.

includes only one station, which is located in the river mouth, where there is the lowest salinity and the highest temperature, as well as highest concentrations of suspended matter and chlorophyll (Pozdnyakov et al., 2003; Filatov et al., 2004). The second group contains two stations located furthest from the river mouth (St. 51–52). The stations are characterized by the lowest temperature and by the highest salinity. The third station group includes two sub-groups: one includes stations located in shallow waters not far from the river mouth and the other one is located close to the top of the bay, but in deeper areas. The third group is located in the area with the most variable environmental conditions, due to the influence of tidal currents and wind-induced water turbidity (Dolotov et al., 2008).

Factor analysis allowed a determination of those parameters of environments that had a high influence on zoobenthic distribution. The principal factor (Factor 1) accounted for 60% of the total environmental variance (Table 2) and has a significant positive loading with depth, salinity, and distance from the top of the bay and negative relationship with temperature and suspended matter and chlorophyll concentrations (Table 2). The factor demonstrates the close inter-relationship between measured parameters. The second most important factor (Factor 2, 21.1% of total variance) has significant loadings with depth and the concentration of organic carbon in sediments.

Table 2
Principle component input in environmental factors in the study area.

Compounds	Percent of total variance	
	60.4 Factor 1	21.1 Factor 2
Depth, m	**0.656**	**−0.633**
Temperature, °C	**−0.840**	0.088
Salinity	**0.947**	0.273
Suspended matter, mg 1^{-1}	**−0.868**	−0.398
Chlorophyll-*a*, µg l^{-1}	**−0.949**	−0.187
$C_{org.}$ in sediments, %	0.079	**0.727**
Distance, km	**0.728**	−0.525

Factor 1 was highly correlated with zoobenthos characteristics for all except biomass (Table 3). However, the results (Table 3) cannot explain which environment parameter among others has the highest significance for the zoobenthic characteristics. The linear multiple regressions, however, gave this information (Table 4). Of the abiotic environmental variables measured, salinity, temperature, depth, share of $C_{org.}$ in sediments and chlorophyll concentration in the water column had the greatest effect on the Shannon diversity index. The standardized regression coefficients in Table 4 suggest the influence of all the listed factors. Species composition depended on the same factors, but salinity was substituted by distance and chlorophyll concentration was not important in explaining the zoobenthos characteristics. Temperature and distance had the stronger influence (Table 4). Abundance and biomass depend mainly on variations in two factors: distance and concentration of organic carbon in sediments. However, increasing distance is accompanied by stronger abundance and biomass increase than variations of sediment structure. Variations of temperature as well as distance, which increase from the top of the bay, had the strongest influence on abundance and biomass.

The faunal data shows a division of the assemblages into several clusters, among which the clusters belonged to freshwater and estuarine zones including freshwater and estuarine fauna are clearly identified (Fig. 8) (St. 98, 100–102). Two stations, despite the highest variability of environments at them (St. 103 and St. 104) are inhabited by marine species and belong to the group contained stations with typical marine fauna.

Table 3
Correlation of characteristics of zoobenthos with principle components in environmental factors in the study area.

Zoobenthos characteristic	Factor 1	Factor 2
Species number	**0.92**	−0.36
Abundance	**0.75**	−0.46
Biomass	0.56	−0.24
Shannon diversity	**0.89**	0.05

Table 4
Standardized regression coefficients (beta values) from multiple linear regression models relating dependent variables (biomass, abundance, Shannon diversity – *H*′, richness) to abiotic variables. *F* values are from the overall test of significance of each regression model. *T* (°C) – near-bottom temperature; Chl – concentration of chlorophyll in water column.

Depended variable	$F_{sp}(4, 15)$ $F_{ab}(2, 17)$ $F_{bio}(2, 17)$ $F_{H'}(5, 14)$	R^2	Depth (m)	Salinity	Distance (m)	T (°C)	Chl (mg l^{-1})	$C_{opr.}$ in sediments (%)
Species richness	36.807****	0.91	0.344*	–	0.378**	−0.314**	–	−0.185*
Abundance	11.668**	0.58	–	–	0.704***	–	–	−0.167
Biomass	11.668***	0.35	–	–	0.606**	–	–	0.211
H′	16.029****	0.85	0.320*	0.883*	–	−0.381*	0.573*	−0.245*

* $p < 0.1$.
** $p < 0.01$.
*** $p < 0.001$.
**** $p < 0.0001$.

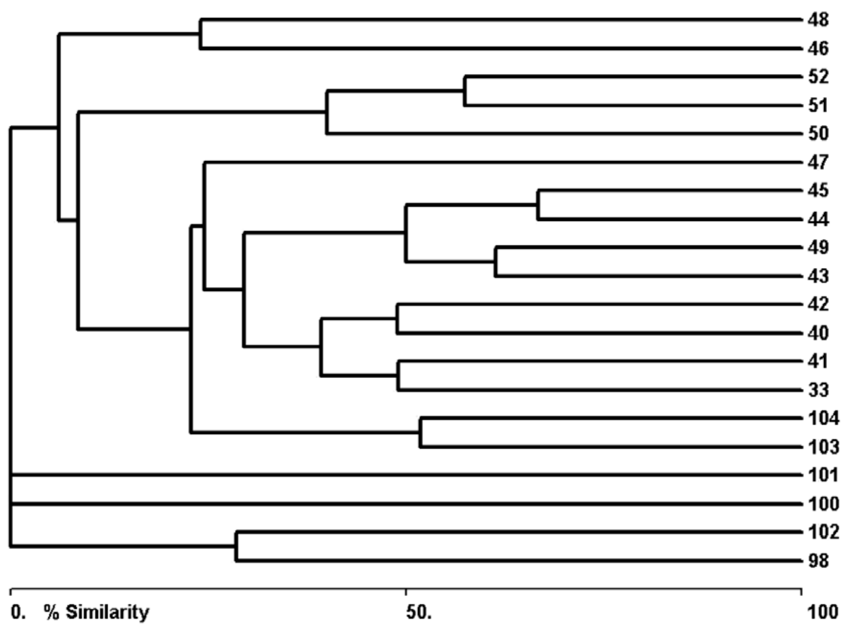

Fig. 8. Cluster diagram, showing the grouping of stations, based on percent similarity of faunal composition.

5. Discussion

Previous studies have shown that the zoobenthos communities of the Onega Bay is very rich and very diverse and well as having high energy flows (Ivanova, 1957; Kudersky, 1966; Lukanin et al., 1995; Golikov et al., 1985), but there was little information about the reasons for the high benthic richness. Furthermore, previous work only gave data for the zoobenthos of marine part of the Onega Bay and did not consider the bay as estuarine system. The studied area is only the small part of the Onega Bay that is affected by fresh water discharge and so it is not unexpected that the species richness obtained was four times less in comparison to the species richness of the whole bay in middle of the last century (585 species, Kudersky, 1966). We cannot attribute such a difference to any process of destruction, as the data of species richness published by Kudersky (1966) based on samples collected over the whole area of the Onega Bay excluded shallow areas in the top of the bay studied here. The area is influenced by river discharge and the low α-diversity in the area is natural and easily explained by the influence of fresh water discharge and presence of estuarine zone within the area of the bay. Studies elsewhere have shown that the mesohaline zone is generally characterized by poor macrofauna, that is related the high environmental variability (e.g. Khebovich, 1986; Elliott and Kingston, 1987; Elliott and McLusky, 2002). Although salinity abruptly increased immediately outside of the river mouth, the presence of mesohaline area was confirmed not only by the oceanographic parameters of water masses but also by the occurrence of typical estuarine benthic forms such as oligochaetes, crustaceans (*P. affinis*) and molluscs (*M. balthica*), which were found at stations located closer to the top of the bay. A low α-diversity of species occurred in the polyhaline area immediately adjacent to the estuarine part of the bay, although some stenohaline invertebrates were not found there. This creates the lower Shannon diversity in estuarine and transitional marine zones of the study area although the species number may be higher except for the use of the smaller size grab at the shallow stations in the top of the bay. However, the predicted number of species should be twice greater compared to the number collected by van Veen grab as shown by the grab-size/species richness curve calculated on experimental data during comparison different types of grabs (Denisenko et al., 1992).

Although the low α-diversity is a feature of similarity of the sub-arctic estuarine bay with the estuarine areas located in temperate latitudes, the difference is present in species composition in both areas. For example, molluscs (*M. balthica*, *Mya arenaria*) inhabit both the Baltic and North Seas (McLusky and Elliott, 2004), as well as in the White Sea (Chertoprood et al., 2004; Udalov et al., 2004, our observations), but some boreal species, such as representatives of genus *Abra*, are absent in the sub-Arctic region. In the Kara Sea, where water temperature conditions are much more severe in comparison to the White Sea and Baltic Sea, all the above molluscs are absent in the benthic fauna and replaced by the Arctic bivalve *Portladia esturiorum* (Denisenko et al., 2003). Furthermore, areas with unfavourable environments have a low species diversity (Warwick et al., 1987; Gray and Elliott, 2009). Most of macro-zoobenthos species in the study area avoid shallow turbulent water, as has been noted previously in other seas (Day et al., 1971).

The main reason for the disappearance of macro-zoobenthos in waters with high current velocity and turbidity is the inhibition of feeding function of invertebrates and perhaps the risk injury (Wildish et al., 1992). In the study area, due to a strong mixing of water masses, there is a transport of sediment particles along the bottom (Dolotov et al., 2008) which can cause damage of invertebrates and, as result, a decrease of their richness. For both of these reasons not only was there a lower species richness, but also a decrease of the biomass and abundance characteristics and the Shannon diversity index of zoobenthos at the shallow marine stations in comparison to deeper stations. On the other hand, water which are turbid due to tidal currents, allows the survival of marine fauna in areas influenced by fresh water discharge. Reverse currents brings salt water in bottom depressions, and burrowing invertebrates can survive during low water. A similar regularity is observed in estuarine bays in temperate waters (McLusky and Elliott, 2004).

The high temperature fluctuations, daily, seasonally and over the whole year, puts pressure on faunal structures in different bays as in the boreal waters and in Arctic bays. However, in the last case, the poor species composition in shallow waters can also be explained by its destruction during the ice melting in spring time, when the break-up of ice fields destroy surface of sea bottom, as has been shown previously for other Arctic areas (Conlan et al., 1998).

The low Shannon diversity index in the river mouth and its gradual increase towards the central part of the bay, characterized as the polyhaline zone, is a typical picture for estuarine bays. In the same time there was no notable increase of abundance in the mesohaline area, as is usually present in different estuaries located in the Arctic (Denisenko et al., 2003; Chertoprood et al., 2004; Udalov et al., 2004) as well as in the temperate areas (Elliott and Kingston, 1987; McLusky and Elliott, 2004), due to the shallowness of that part of the study area, the velocity of currents in it and the presence of turbid water. A marked gradual increase of zoobenthos biomass towards the sea basin is a typical pattern of the estuarine bays located as in temperate latitudes and in the Arctic seas (Elliott and Kingston, 1987; Denisenko et al., 2003; Deubel et al., 2003; Udalov et al., 2004). At the same time there are examples when step-wise change of biomass variations were registered in the Arctic estuarine bays (Denisenko et al., 2003; Denisenko, 2009). The increases of biomass were caused by the geomorphology of the bay bottoms. Despite the input of fresh water from the Onega River the variability in salinity regime was only found near the top of the bay and there was no large-scale negative influence of it on marine fauna due to the presence of a strong tidal cycle. For that reason tolerant marine species were found very close to the river mouth. Salinity is strongly correlated with other factors, as the factor analysis demonstrates (Table 3), and its effect on zoobenthos appears with the variation of other environments. The relationship of the characteristics of the zoobenthos with several environment parameters is confirmed by the results of multiple regression analysis (Table 4). In general the relationship of species richness, abundance, biomass of zoobenthos, species diversity with distance (as a surrogate measure of salinity) shown here agrees well with the variations of faunal characteristics that is present in other estuaries in the world (Remane and Schlieper, 1971; Elliott and Kingston, 1987; Denisenko et al., 2003; Udalov et al., 2004; Hyland et al., 2004; Gray and Elliott, 2009), although in our case there is no clear boundary between oligohaline, estuarine and polyhaline zones due to the strong water turbidity and tidal processes in this bay. At the same time the estuarine type is supported by the presence of strong salinity gradients and high values of primary production in the areas influenced by fresh waters (Filatov et al., 2004; Pozdnyakov et al., 2003). Althought the allochthonic seston did not accumulate in the barrier zone as has been recorded in other zones of the marginal filter (Lisitsin, 1999), due to active hydrodynamic processes (Dolotov et al., 2008), it supports the high-biomass of zoobenthos in the central polyhaline part of the bay (St. 51, 52).

The high variability of environmental parameters produces a discrepancy in the distribution of stations between the clusters corresponding to oligohaline, mesohaline and polyhaline zones (Figs. 7 and 8), as settlements of zoobenthos are more stable in time and space. Thus the presence of marine and estuarine species of zoobenthos in the transitional zone reflects the abundant opportunities for their adaptation to environmental variability.

The results of the study of faunal distribution in the southern part of the Onega Bay is considerably different from the information published earlier for other Arctic estuarine bays (Ob Bay and Yenisey Bay in the Kara Sea), where brackish-water fauna reflects the brackish plume into the bays' mouth (Denisenko et al., 2003) or at least to the central part of the bays (Pechora Bay in the Barents Sea, Chernaya Bay in the White Sea) (Denisenko et al., 1999; Udalov et al., 2004). This may be caused by the amount of fresh water discharge in comparison to the area of the bays being much larger.

The main distinction of the Onega Bay from the estuarine bays in temperate areas is a presence of ice cover, which stays in the area around 6–7 months. A negative influence of it is marked in shallow areas in estuarine as well as polyhaline zones. Permanent increasing or decreasing of the sea level, which takes place due to presence of tidal cycle and resultant tidal currents. The latter move the ice fields along the bottom resulting in the destruction of the surface of bottom sediments causing damage to the zoobenthos populations. The strongest influence is registered in spring during melting time, when drift ice broken from the pack-ice ploughs the bottom. After that benthic organisms are completely destroyed (Conlan et al., 1998). The negative impact of ice is shown by the presence only of young generations of species, which have smaller body size. They were found at the stations located in the area of strongest impact of ice. For example, the length of *Pectinaria hyperborea* did not exceed 10 mm at the stations in depths around 4 m (St. 103 and St. 104). At the same time *P. hyperborea* with the larger sizes (body length exceeds 30 mm) are present in the deeper parts of the bay.

6. Conclusion

The Onega Bay can be regarded as an estuarine bay and the estuarine part of the bay can be characterized as intermediate geomorphologic form, if the classification described by Davidson et al. (1991) will be used for its description. On the one hand it belongs to the geomorphologic type of "coastal plain estuary", because there is large flat plain in the top of the bay, whereas conversely it can be regarded as "complex estuary" due to its complex origin: glacial erosion, sea level rise and river erosion. In the estuarine part of the Onego Bay the distribution and variation of zoobenthos characteristics along the salinity gradient, in general, correspond to the patterns described for temperate estuarine bays (McLusky and Elliott, 2004). The main peculiarity of this area that belongs to the sub-Arctic area is the presence of ice cover during 6–7 months. This has additional negative influence on zoobenthic populations by destroying them. The other peculiarity of this sub-Arctic estuarine bay is a difference in species composition of the zoobenthos habitat in the polyhaline zone in comparison to the areas located in the warmer latitudes. The difference is caused by more severe environment conditions in the sub-Arctic seas.

The marked variations of environment factors in the study and the dependence of zoobenthos characteristics on several environmental factors reinforce the possible variability of wideness of estuarine zone during time of ice melting and high spring waters. At the same time surface imperfections of the bottom allow to euryoecious marine species to survive, due to inflow of salt marine water into bottom depression. Conversely, the destruction of the bottom by ice fields does not allow stable benthic populations to be formed because of the shallowness of the bay.

It is to be hoped that the findings of the inter-relationship between processes in the environment and variations within zoobenthos communities will enrich our knowledge about estuarine ecosystems in the Arctic.

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