

Structurally-functional characteristics of the Barents Sea zoobenthos

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Species composition and ecology of zoobenthos of the Barents Sea have been studied more thoroughly as compared to the other Arctic seas. However, published information on species, large taxa and trophic groups of zoobenthos, which constitute the basis of bottom populations, is quite contradictory (Idelson, 1933; Zenkevich & Brotskaya, 1937; Brotskaya & Zenkevich, 1939; Zatsepin & Rittikh, 1968; Kuznetsov, 1970; Semenov, 1986). The divergences in the majority of conclusions and estimations of the above-mentioned authors are due to the extremely irregular spatial distribution of sampling stations, also characteristic of benthic sampling in 1968-1970 (Fig. 1, B), which only looks uniform. The net of sampling stations executed in 1924-1938 was characterized by mosaic, aggregated and extremely non-uniform distribution (Fig. 1, A). Density diagrams show that many stations were repeated from year to year because their basic part was mainly situated along several sections directed from Murmansk to the areas of traditional fishery.

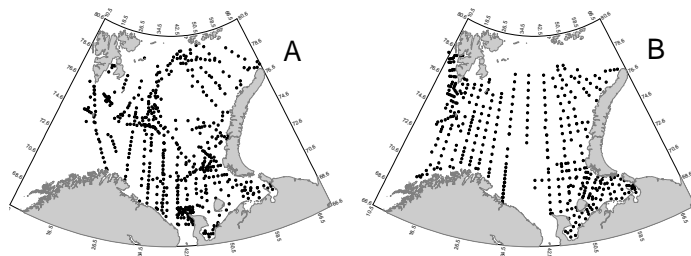


Fig. 1. Station net of quantitative zoobenthos sampling in the Barents Sea in 1924-1932 (A) and in 1968-1970 (B)

Non-uniformity of the distribution of sampling stations and the absence of necessary computing methods in the 1930s-1960s did not allow our predecessors to give a statistically proven quantitative estimation, to be able to characterize the sea and its biota as a whole. The absence of quantitative data statistically weighed concerning the area, attributed to the each station had hindered objectively the estimations too.

In the late 1960s such calculations became possible with the advent of geostatistical methods. Subsequently they were used for the development of

the GIS-technologies forming the basis of many computer programs.

The goal of the present studies is to reveal the most typical species in the region, to determine prevailing groups in taxonomic and trophic structure of the bottom populations of the Barents Sea and to detect statistical relations between different quantitative parameters, including information parameters. For these purposes statistical processing of archival benthic material from the several periods of large-scale researches has been executed using applied computer package "Golden Software", and ordinary statistical calculations were carried out using the package "Systat 9".

The results of the calculations allowed giving for the Barents Sea region the quantitative characteristics of the most common species, of taxonomic and trophic structure of the benthic population, and showing statistical relations between their different parameters and estimating their applicability.

Taxonomic and trophic structure

The estimation of dominance among the bottom organisms on species level shows that 75-80% of the total zoobenthos biomass in the Barents Sea is formed by only 22 taxa, mainly by species, and about 50% are due to 7-8 species. These are bivalve mollusks *Tridonta borealis*, *Macoma calcarea*, and *Ciliatocardium ciliatum*, sipunculid *Golfingia margaritacea*, sea urchins, basically *Strongylocentrotus pallidus*, barnacle *Balanus balanus*, and starfish *Ctenodiscus crispatus*.

The bivalve mollusks and sea urchins were regarded as dominants in many of the above-mentioned publications, but *Golfingia margaritacea* and *Balanus balanus* have been never considered previously as more or less significant species. The results of our calculations allowed attributing them to a category of dominant species.

A relative contribution of different species to the total biomass can depend on what was taken into account, wet biomass or its equivalent in organic carbon (Fig. 2, B). However in both cases the listed species remain among the dominant forms.

The estimation of the dominance degree on the level of higher taxa, mainly in the rank of class shows that bivalve mollusks form about 40% of the total biomass (Fig. 3). According to the diagram (Fig. 2), these are *Tridonta borealis*, *Macoma calcarea*, *Ciliatocardium ciliatum*, *Astarte crenata*, and some less significant species. Barnacles, Cirripedia, represented basically by two species *Balanus crenatus* and *Balanus balanus* and never considered as more or less significant group in zoobenthos of the Barents Sea, occupy the second place (15%).

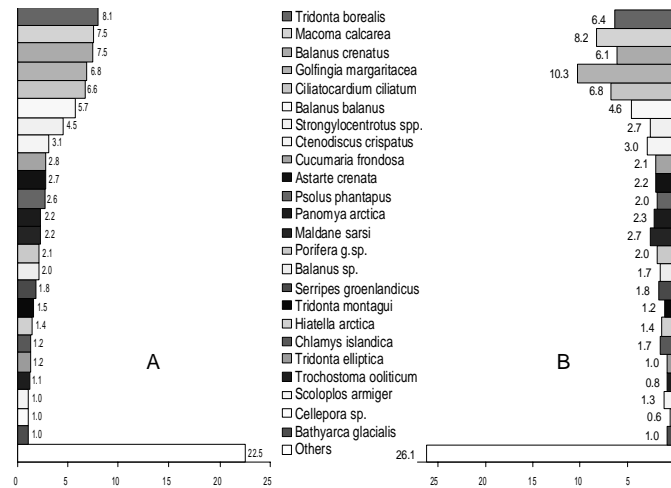


Fig. 2. Portion of different species (%) in the total biomass of zoobenthos in the Barents Sea in 1968-1970: (A) wet preserved weight; (B) organic carbon equivalent of biomass

The phylum Sipunculida according to the calculations turned out to be of great importance also, even though the group is represented mainly by one species, *Golfingia margaritacea*. Its contribution to the total biomass previously estimated as rather small. At the same time the share of the phylum Polychaeta, which traditionally is considered as the most dominant group, appeared comparable with the share of Sipunculida.

According to the feeding mode and feeding behavior the zoobenthos of the Barents Sea, in accordance with our calculations, is dominated by immobile, partly mobile, mobile and facultative suspension feeders (62-68%), which besides the already noted bivalve mollusks and barnacles (Fig. 2, 3) are represented by holoturians (*Cucumaria frondosa* and *Psolus phantapus*) also (Fig. 4). These results significantly differ from the published data, because, according to the scheme of hydrodynamic classification of near bottom water masses and the scheme of trophic structure of zoobenthos in Barents Sea by A.P. Kuznetsov (1980), surface deposit feeders and subsurface deposit feeders are of maximum importance, but not suspension feeders. A similar conclusion was made by V.I. Zatsepin and L.A. Rittikh (1968), but they estimated the importance of suspension feeders at 43.5% only. However, simple recalculation in Table 17 by Kuznetsov (1970), where areas with dominance of different trophic groups are specified, taking into account the degree of dominance of certain trophic groups in Table 27 by Kuznetsov (1980), gives a share of suspension feeders in the total biomass of

zoobenthos of the Barents Sea in 1924-1948, even exceeding that obtained by us (72%).

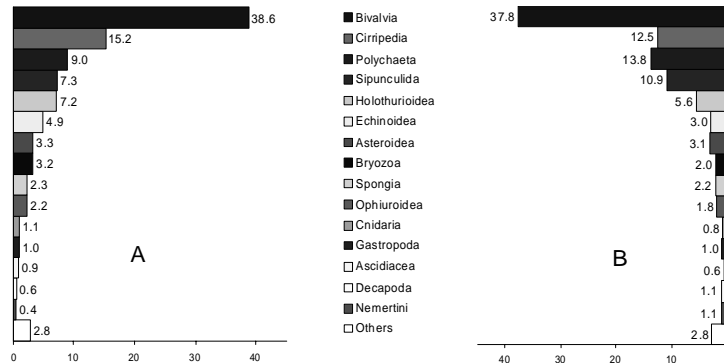


Fig. 3. Portion of large taxa (%) in the total biomass of zoobenthos in the Barents Sea in 1968-1970: (A) wet preserved weight; (B) organic carbon equivalent of biomass

From the above it follows, that zoobenthos of the Barents Sea in general is characterized by dominance of 7-8 species forming one half of the total biomass of the bottom populations, and by prevalence of bivalve mollusks and barnacles, which constitute 50% of the total biomass. According to the feeding mode, among benthic organisms suspension feeders constituting more than 60 % of the total biomass prevail.

Statistical relations of quantitative characteristics

The correlation of the basic structural blocks of bottom ecosystems at the local Barents Sea scale is determined by statistical and functional interrelations between quantity parameters of biota on the level of a biocenosis and a population. Analysis of quantitative characteristics of zoobenthos (the grab samples) has revealed the existence of good statistical interrelations between biomass, number of trophic groups, density of individuals in populations, number of species (taxa) and some information indexes (Fig. 5).

The biomass is directly proportional to the average individual weight of individuals, which is theoretically typical only of populations of the same age-group of organisms, and the number of trophic groups is proportional to the total number of individuals in a sample (abundance). The higher the number of species (taxa) in a sample, the higher the number of trophic groups, the total number of individuals (abundance), the total biomass, the values of diversity indexes calculated from abundance and from biomass, and also the diversity of trophic groups calculated from the number of species (taxa).

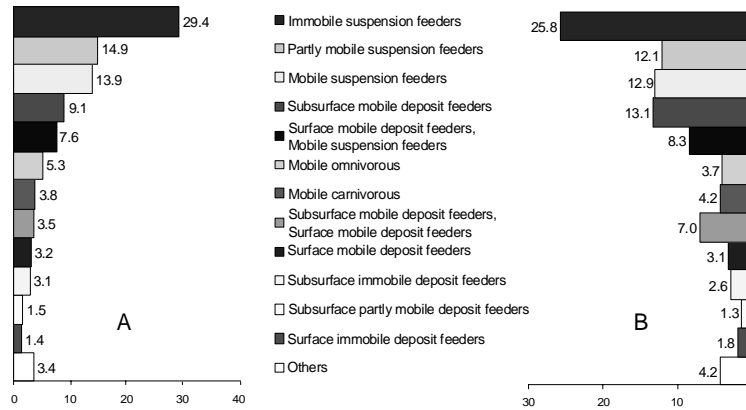


Fig. 4. Portion of animals of different feeding modes (%) in the total biomass of zoobenthos in the Barents Sea in 1968-1970: (A) wet preserved weight; (B) organic carbon equivalent of biomass

Unfortunately, in the published literature on marine biology the author could not find any concrete description or discussion of interrelations similar to those noted here. Of publications dealing with a similar topic mention may be made only of the book by E. Odum (1971), where the correlation between the total number of species and their abundance in communities from the salt marches and laylands is illustrated, and the book by A.F. Alimov (2000) where Shannon's index values are regarded in relation to the total biomass and average individual weight of specimens in freshwater communities.

Nevertheless, many of the interrelations presented in this paper logically do not contradict the general principles of the organization and functioning of multi-species ecosystems, and their existence is unequivocally supported by results of statistical calculations carried out on numerous modern and archival materials of marine zoobenthos, represented by different arrays of data.

At the same time only the diversity of trophic groups calculated from the number of species (taxa) increases with growth of the total number and biomass. The last one, probably, specifies the existence of mechanisms providing the decrease of a competition in dense populations.

Not all of the above mentioned interrelations have been reliably revealed in marine areas of smaller sizes (the Gorlo Strait of the White Sea, the Cheshskaya Bay, the Pechora Sea, etc.). This can suggest existence of spatial scale fractal in the structure of marine zoobenthos.

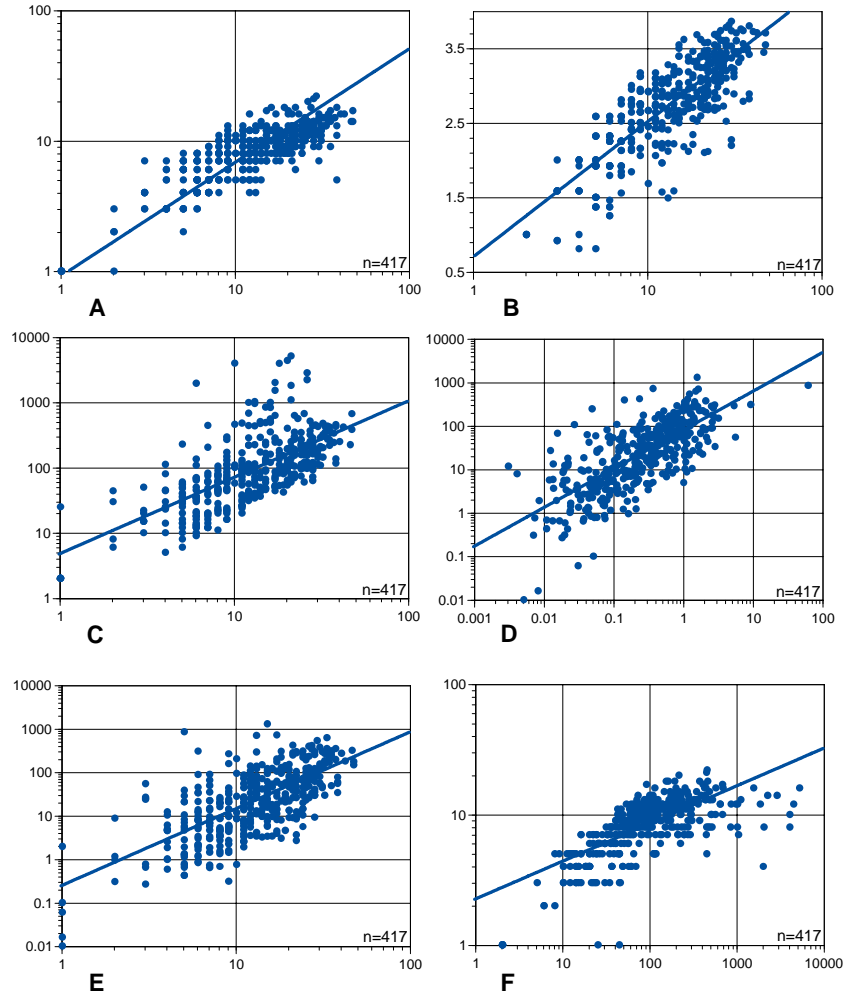


Fig. 5. Statistical relations between quantitative characteristics of zoobenthos in the Barents Sea in 1968-1970: (A) number of species (n/m^2 , on the X-axis) and number of trophic groups (n/m^2 , on the Y-axis), $R^2 = 0.688$; (B) number of species (n/m^2 , on the X-axis) and information diversity of trophic groups by the number of species ($bit/species$, on the Y-axis), $R^2 = 0.653$; (C) number of species (n/m^2 , on the X-axis) and total abundance of individuals (ind/m^2 , on the Y-axis), $R^2 = 0.450$; (D) average weight of an individual (g of wet preserved weight, on the X-axis) and total biomass (g/m^2 of wet preserved weight, on the Y-axis), $R^2 = 0.537$; (E) number of species (n/m^2 , on the X-axis) and total biomass (g/m^2 of wet preserved weight, on the Y-axis), $R^2 = 0.482$; (F) total abundance of individuals (ind/m^2 , on the X-axis) and number of trophic groups (n/m^2 , on the Y-axis), $R^2 = 0.488$

The interrelations revealed allow concretizing and simplifying the procedure of studying the structure of bottom communities of the seas, where the total species list in Arctic regions only approximates five thousand species (Sirenko, 2001).

Comparative analysis of parameters of the interrelations revealed will give many more unequivocal results of monitoring observations of short-term and long-term fluctuations of zoobenthos under the influence of natural and anthropogenic factors

Practical application of estimations of information diversity indexes

Along with the analysis of usual statistical relations between various quantitative characteristics of bottom population, of considerable interest is the analysis of information indexes of species diversity in abundance and biomass.

Macrozoobenthos diversity values estimated from abundance of species are poorly related statistically with values of diversity calculated from biomass values, but their ratio, as was shown by McManus and Pauly (1990), can be regarded as an index describing the type of prevailing life strategy (*r* or *K*) in species assemblages. Being a formalized modification of the graphic method of Warwick (Warwick, 1986), the index is used in marine biology for an estimation of the stress in bottom communities under the influence of anthropogenic and natural stress factors (Warwick & Clarke, 1991). Initially, it was offered to estimate the presence or absence of stress from the relative position of the normalized curve of cumulative values of the abundance and biomass of the species, which were ranged by the decrease of these parameters. In case of position of the biomass curve above the abundance curve it was concluded that stress was absent, when the curves were situated otherwise it was concluded that stress was present, and in case of crossing of the curves it was concluded that the situation was close to stressful (Warwick, 1986). In the first case *K*-strategy prevails, in the second case *r*-strategy prevails in communities analyzed.

The first type of strategy (*K*-strategy) is inherent in organisms characterized by high density populations, having small body sizes, short life-span, high fecundity and living in unstable environmental conditions. The second type of strategy (*r*-strategy) is typical of the organisms characterized by low density populations, having large enough body sizes, long enough life-span, low fecundity and living in stable environmental conditions. McManus and Pauly (1990) proposed to estimate the mutual position of the curves by the difference of the areas between the curves and abscissa, and by the ratio of Shannon's diversity indices calculated from biomass and abundance of species. Both methods yield reliable results correlating with $R^2 = 0.83$.

In the first case the values of the difference vary from -1 to +1 with the

critical value equal to 0, but the procedure of calculations is labor-consuming. In the second case the result varies from 0 to ∞ (theoretically), with the critical value equal to +1. These disadvantages are completely eliminated, when instead of the ratio of Shannon's diversity indices the difference of Pielou's evenness values (or relative entropy) is used (Pielou, 1966; Berlant, 1986). The values of the initial relation well correlate ($R^2 > 0.84$) with the difference of evenness values calculated from biomass and abundance of species in a sample, which allows deducing a new index easily as:

$$D_E = SH'(SpB) / \text{Log}(N) - SH'(SpA) / \text{Log}(N) \quad (1),$$

or:

$$D_E = [(SH'(SpB) - SH'(SpA))] / \text{Log}(N) \quad (2),$$

where $SH'(SpB)$ is Shannon's diversity index calculated from biomass, $SH'(SpA)$ is Shannon's diversity index calculated from abundance of species in the sample.

A similar mathematical expression can be constructed on the basis of Simpson's index in the form of probability that any two individuals from the sample, chosen at random, are from the same species. Index proposed (2) varies from -1 (in situations where stress is absent, which corresponds to K -strategy) to +1 (where a very strong stress is present, which corresponds to r -strategy).

Additional special research is still needed for an estimation of sensitivity level of the index, even though it can be assumed that its applicability has been proven. Thus, in the Kola Bay of the Barents Sea the analysis of the state of sublittoral zoobenthos has shown clearly zones with unstable bottom communities. These zones are situated in areas of the bay subject to anthropogenic impact coming from the cities located on the coast. In the southern part of the bay, the negative anthropogenic impact is apparently amplified by freshwater discharge from the Tuloma and Kola rivers.

Zones with unstable zoobenthos communities were recorded in the Pechora Sea for two periods of observations (1924-1925 and 1958-1959). They coincide with the areas located west of the Kara Gate, Yugorskiy Shar and Pomorskiy straits, and west of the Dolgiy Island. Having analyzed the configuration of these zones and probable reasons of their appearance, it is possible to make a preliminary conclusion that in the first case the zones probably mark the areas of storm input of great amounts of suspended matter, including organic matter, from the adjoining areas of the Kara Sea.

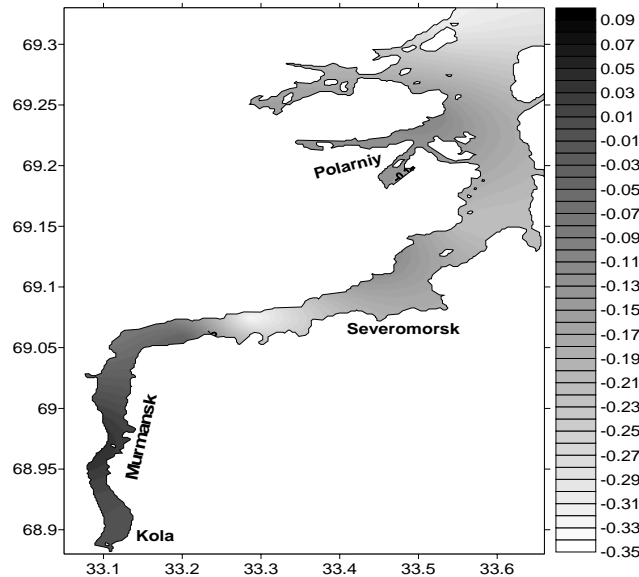


Fig. 6. Zones of unstable zoobenthos communities (dark areas) in the Kola Bay (designed on materials of MMBI, 1995)

The other reason of appearing of zones with unstable zoobenthos populations in areas near the Kara Gate and the Yugorskiy Shar straits can be periodic inflows of cold waters from the Kara Sea, with increasing in the cold years, when advection of the Atlantic waters to the Barents Sea is weakened (Karcher *et al.*, 2003).

The unstable state of zoobenthos communities near the Pomorskiy Straight apparently was caused by a high concentration of suspended material in the water column, induced by long storms of the south-western direction. Sediment roiling by storms on the shoal around the Dolgiy Island and its further transportation in the north-western direction by permanent currents, apparently, also take place and have a negative impact on benthic populations. Besides, according to aerial survey, molting and premigratory aggregations of sea ducks (Krasnov, *et al.*, 2004), zoobenthos consumers, occur in this area.

In all cases the prevalence of *r*-strategy in the zones described is the result of short allogenuous successions in the bottom populations. Secondary autogenous successions, where *r*-strategists also prevail, (for example, after avalanche sedimentation) are unlikely.

The anthropogenic factor during the periods examined cannot be regarded as the cause of ecological stress in the Pechora Sea because economic activity in the region began in the late 1960s and was not significant until the 1990s.

Thus, the proposed index can be used for revealing and mapping of zones with ecologically unstable bottom communities, which are subject to stress owing to negative influence of anthropogenic or natural factors. Calculation of the index is not complicated and is possible on the materials collected at different periods. However this does not exclude using of traditional and tool techniques of environment assessment and can be regarded as a useful addition to resources and methods available.

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