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Some features of the quantitative distribution of sipunculan worms (Sipuncula) in the central and southern Barents Sea*

KEYWORDS
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Evgeny A. Garbul[1,⋆]
Natalia A. Anisimova[2]

[1] Murmansk Marine Biological Institute,
Kola Science Centre of Russian Academy of Sciences,
Vladimirskaya St. 17, Murmansk 183010, Russia;

e-mail: Garbul@mmbi.info

⋆corresponding author

[2] Polar Research Institute of Marine Fisheries
and Oceanography (PINRO),
Knipovich St. 6, Murmansk 183763, Russia

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Abstract

The article reports on the current state of the sipunculan fauna of the central and southern parts of the Barents Sea. The main quantitative parameters (biomass and abundance) of the sipunculan populations are obtained, and the contribution of sipunculids to the total benthos biomass is assessed. The major factors causing long-term variations in Sipunculidae distribution and abundance are evaluated for the area in question.

The investigations show that the most commonly encountered sipunculan species are *Nephasoma diaphanes diaphanes*, *N. abyssorum abyssorum* and *Phascolion strombus strombus*. The main contribution to the total benthos biomass comes from the two species most typical of the Barents Sea benthic fauna: *Golfingia*

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margaritacea margaritacea and *G. vulgaris vulgaris*. It is possible that the reduction in *Golfingia* biomass between the 1970s and 1990s, described in the article, is due to changes in the sampling methodology.

1. Introduction

The first data on the Barents Sea sipunculan fauna were reported by N. K. Zenger in 1870 (Zenger 1870). In the first half of the 20th century, two reviews of the Gephyrea of USSR seas were written (Vagin 1937, Zatsepin 1948). At that time, the term Gephyrea was used for the group of marine coelomic worms without obvious segmentation – sipunculans, priapulids and echiurids. Extensive data on the Barents Sea Sipuncula is given in the monograph by G. V. Murina (1977) on the sipunculan fauna of Eurasian Arctic and boreal waters.

Sipuncula is a relatively species-poor phylum consisting of about 150 species and subspecies worldwide (Cutler 1994); the checklist for Arctic seas has fewer species. According to these publications there are 7 Sipuncula species living in the central part of the Barents Sea and East Murman inshore waters: *Phascolion strombus strombus* (Montagu 1804), *Golfingia elongata* (Keferstein 1863), *G. margaritacea margaritacea* (Sars 1851), *Nephasoma eremita* (Sars 1851), *N. improvisa* (Théel 1905), *N. diaphanes diaphanes* (Gerould 1913) and *N. abyssorum abyssorum* (Koren & Danielssen 1875). As Brotskaya & Zenkevich (1939) mentioned in their benthos research data, only *G. m. margaritacea* of the above species formed a significant biomass in the Barents Sea in the first half of the 20th century. However, its dense populations were basically concentrated in the central part of the Barents Sea and off the west coast of the Novaya Zemlya archipelago. The proportion of sipunculans in the total benthic biomass in those areas reached 50%, whereas the mean biomass was 15–65 g m^{-2}. A second full-scale benthos survey in the Barents Sea undertaken by the Polar Research Institute of Marine Fisheries and Oceanography (PINRO) in 1968–1970 revealed a considerable decrease in the Gephyrea biomass. Its share of the total benthic biomass has decreased tenfold (Denisenko 2007). Further reductions in the biomass and area of distribution of those species in the central Barents Sea were discovered during benthic research in the area in 2003 (Denisenko 2007).

Generally, despite Sipuncula being widespread in Arctic bottom communities, data on the numbers of species and their role in the Barents Sea's benthos are quite fragmentary and scanty.

The latest similar study of the quantitative distribution of Sipuncula in the Arctic was carried out off the west Spitsbergen coast (Kędra & Włodarska-Kowalczuk 2008). Until recently, no dedicated research of the quantitative distribution of Sipuncula had been carried out in the Barents Sea as a whole, although in the last few years several publications by one of the present authors have appeared describing the quantitative distribution of these invertebrates in particular parts of the Barents Sea (Central basin, the Novaya Zemlya archipelago, Franz Josef Land, the Pechora Sea) (Garbul 2007, 2009, 2010).

The purpose of this study is to give details of the contemporary diversity of sipunculans and their abundance in the southern and central Barents Sea.

2. Material and methods

Material was collected during a multidisciplinary scientific expedition of PINRO on r/v 'Romuald Muklevich' in August–September 2003. 315 samples of macrozoobenthos were taken from 63 benthic stations in the central and southern Barents Sea (Figure 1).

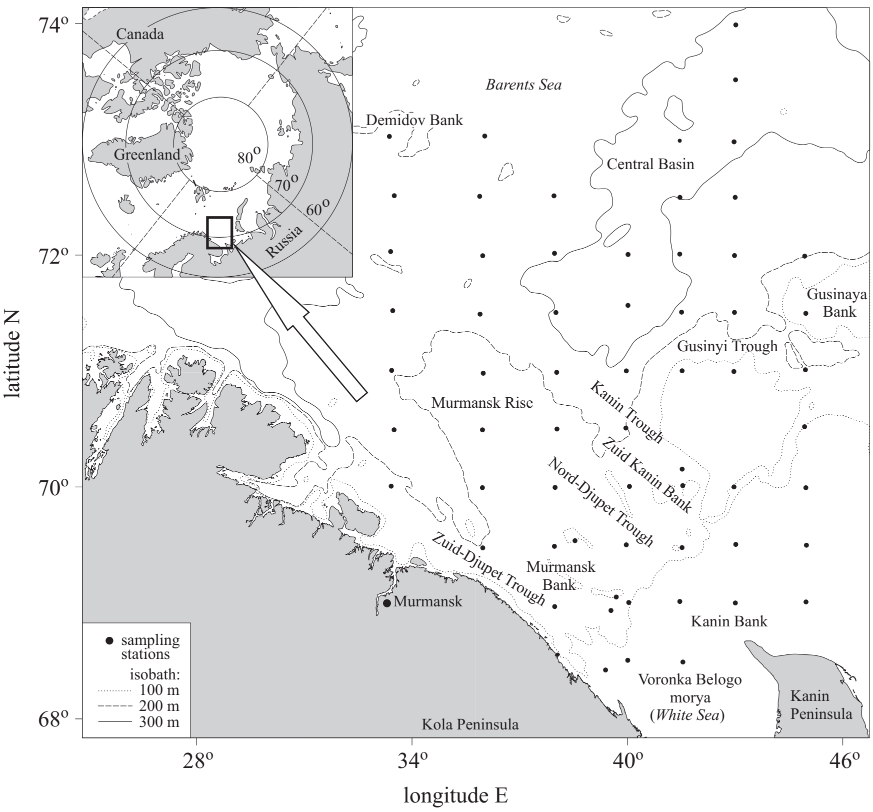

Figure 1. Location of benthic stations during the cruise of r/v 'Romuald Muklevich' 2003. (The names of the main geomorphological structures are reproduced from Matishov et al. 2009)

The data from two research cruises of the Murmansk Marine Biological Institute (MMBI) on the r/v 'Dalnye Zelentsy' in 1996 and 1997 were used for analysing the long-term dynamics of Sipuncula densities in the central Barents Sea (Garbul 2010). Primary data from the PINRO cruise on r/v 'N. Maslov' in 1968–70 and the literature data from the 2003 cruise of r/v 'Ivan Petrov' in the central Barents Sea were used (Denisenko 2007, Cochrane et al. 2009).

Quantitative samples of macrozoobenthos were taken with a 0.1 m^2 van Veen grab in five replicates at each station. The material was washed through a soft 0.5 mm mesh sieve and fixed with 4% formaldehyde buffered by sodium tetraborate. The animals extracted during sample sorting were preserved in 75° ethyl alcohol. Biomass values correspond to the wet weight. The taxonomic identification of Sipuncula was carried out by E. A. Garbul. The mean biomasses and abundances of species were estimated, disregarding the stations where those species were absent. The mean values are listed

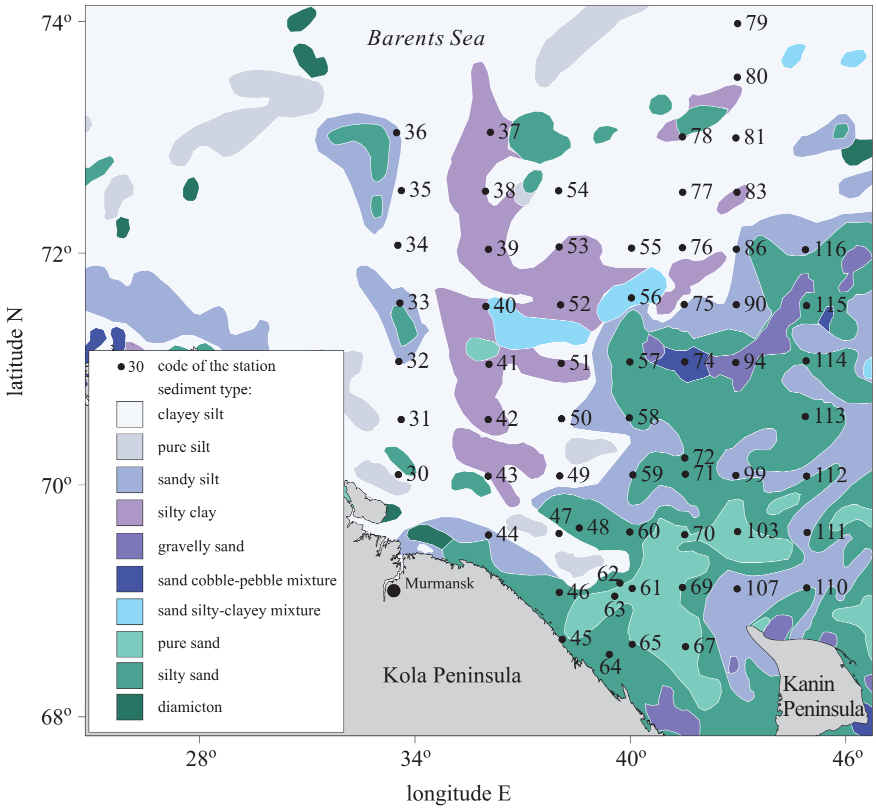

Figure 2. Distribution of principal sediment types in the central and southern Barents Sea (according to Gurevich 1995)

with the standard error. Frequency of occurrence was calculated as the ratio of the number of stations where a species was present to the number of all the stations, expressed as a percentage. The bottom salinity at the sampling time corresponded to the normal ocean salinity. The bottom temperature during sampling was from −1 to +6°C.

The distribution of principal sediment types in the research area is shown in Figure 2.

The Golden Software MapViewer (version 7.1) program was used for constructing the maps. The samples obtained from a sandy bottom during the cruise on r/v 'Dalnye Zelentsy' in the south-eastern Barents Sea in 1992 were used for defining van Veen grab (catch area 0.1 m^2) and Ocean-25 grab (catch area 0.25 m^2) catches. 12 samples were selected (6 from each grab) at two stations. The catch was determined by the size composition of the specimens caught by the different types of grabs. The average mass (the ratio of the biomass of each species to its quantity) was used as the size composition.

3. Results

A total of 9 Sipuncula species were recorded in the research area. In addition to the seven species already known, two new species (*Nephasoma lilljeborgi* (Danielssen & Koren 1880) and *Golfingia vulgaris vulgaris* (de Blainville 1827)) were found here for the first time.

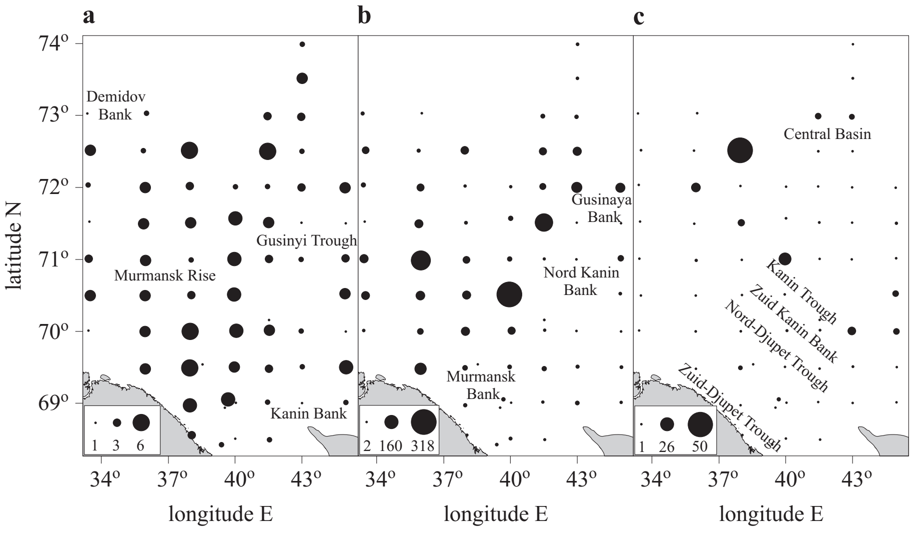

Figure 3. Distribution of sipunculans in the study area of the Barents Sea, according to the research data of 2003; a) species density [sp./0.5 m^2]; b) abundance [indiv. m^{-2}]; c) biomass [g m^{-2}]

Sipunculans are well represented in the study area of the Barents Sea as they were observed at all the stations. The main features of the quantitative distribution of sipunculans in the southern Barents Sea are shown in Figure 3.

The species density in the study area varied from 1 to 6 sp./0.5 m^2 and averaged 2.9 ± 1.5 sp./0.5 m^2. High levels of species diversity were recorded in the Central Basin, Murmansk Bank and Nord-Djupet Trough areas (Figure 3a), where the sediments contained a large fraction of silt (Figure 2). The diversity of species in samples was the least in the eastern and south-eastern parts of the study area, where sediments are hard and sandy, and the salinity lower.

Sipunculan abundance in the study area varied from 2 to 318 indiv. m^{-2} and averaged 50.0 ± 7.5 indiv. m^{-2}. The abundance was lowest – to within a few indiv. m^{-2} – in the Murmansk Bank, Gusinaya Bank and Gusinyi Trough areas (Figure 3b, Table 1) and was high (to within

Table 1. Main quantitative characteristics of Sipuncula species in the south-central part of the Barents Sea according to the sampling of 2003

Species	Frequency of occurrence [%]	Biomass [g m^{-2}] Mean value (min–max)	Abundance [indiv. m^{-2}] Mean value (min–max)
Phascolion s. strombus	56	0.132 ± 0.025 (0.002–0.48)	5.8 ± 0.8 (2–22)
Golfingia elongata	40	0.023 ± 0.005 (0.002–0.078)	7.8 ± 1.6 (2–32)
Golfingia v. vulgaris	27	3.219 ± 1.497 (0.008–14.78)	2.6 ± 0.3 (2–6)
Golfingia m. margaritacea	30	5.700 ± 2.009 (0.004–35.88)	3.9 ± 0.6 (2–12)
Nephasoma eremita	6	0.018 ± 0.008 (0.002–0.036)	3.5 ± 0.1 (2–6)
Nephasoma a. abyssorum	63	0.038 ± 0.005 (0.002–0.135)	32.9 ± 5.6 (2–204)
Nephasoma d. diaphanes	65	0.029 ± 0.007 (0.001–0.188)	29.0 ± 7.4 (2–246)
Nephasoma lilljeborgi	13	0.009 ± 0.005 (0.002–0.042)	12.5 ± 7.5 (2–64)
Nephasoma improvisa	6	0.004 ± 0.002 (0.002–0.009)	3.5 ± 1.0 (2–6)

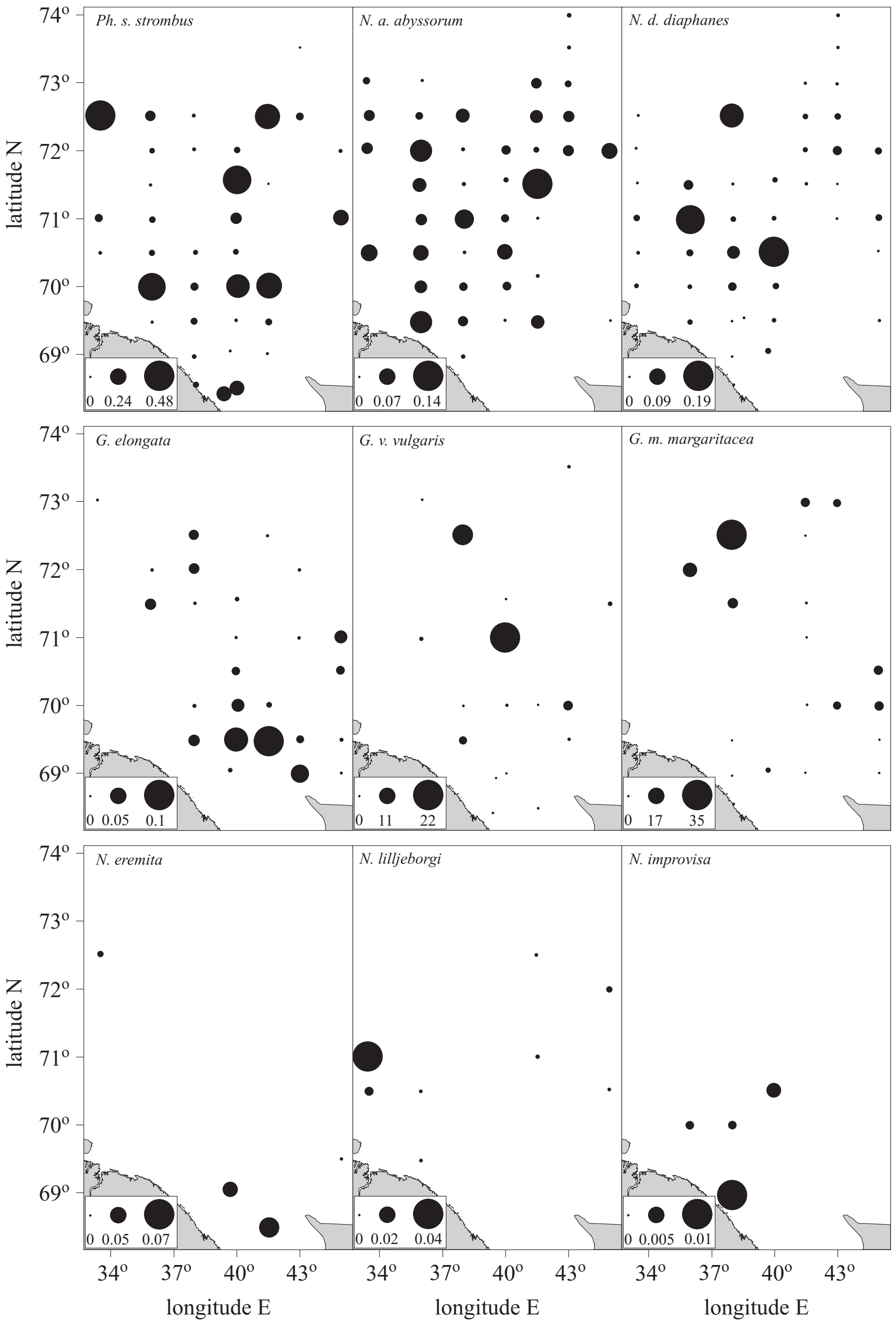

Figure 4. Distribution of sipunculan species biomass [g m^{-2}] in the southern and central Barents Sea in 2003

some hundreds indiv. m^{-2}) in the Murmansk Rise, Central Basin and Kanin Trough areas. Small *Nephasoma* species (*N. abyssorum abyssorum* and *N. diaphanes diaphanes*) were the most abundant in the samples.

The biomass of sipunculans in the study area varied from 0.001 to 51 g m^{-2} and averaged 2.7 ± 0.9 g m^{-2}. The biomass and species diversity of sipunculans was the highest in the central Barents Sea, at the station located on the western slope of the Central Basin (Figure 3c, Table 1). The main contribution to the biomass at that station was from *G. margaritacea margaritacea* (35.9 g m^{-2}) and to a lesser degree from *G. v. vulgaris* (14.8 g m^{-2}). These species (separately or together) were dominant at the other stations with high sipunculan biomasses. A low sipunculan biomass was typical of the Gusinyi Trough, with its substrate of gravel and silty sand (Figure 2).

The main characteristics of the different sipunculan species distributions in the study area are listed in the Table 1 and Figure 4.

4. Discussion

Previously, it had been thought that the most commonly encountered sipunculan species in the Barents Sea were *Golfingia margaritacea margaritacea*, *Phascolion strombus strombus*, *G. vulgaris vulgaris* and *Nephasoma eremita*. The other sipunculans from the Barents Sea were known from only a few single finds and were considered atypical of the area (Murina 1977).

The data obtained (Figure 4, Table 1) shows that some individual *Nephasoma* species are more widespread in the Barents Sea than was earlier thought. *N. diaphanes diaphanes* and *N. abyssorum abyssorum* are the most common sipunculans in the samples in the study area. They are present in almost all samples and exceed in number even such common Barents Sea species as *Ph. s. strombus*. Large in size and considered to be typical of the Barents Sea, *Golfingia* species were less common in the samples. Unlike the *Nephasoma* species and *Ph. s. strombus*, they are widespread mainly in the eastern part of the study area but are practically absent from its western part and the Murman coastal zone. Other Sipuncula species form small local populations in the central and southern Barents Sea (Figure 4).

These changes in species occurrence are most probably due not to their real quantitative fluctuations but rather to differences in sampling and evaluation methodology. The investigated samples were washed through a 0.5 mm mesh sieve, and their primary treatment (selection of animals from the non-washed grains of sediment) was very thorough (in the land-based laboratory with the use of optical equipment). Both techniques improved the accuracy of counting small individuals, most of which are from the *Nephasoma* genus.

This research encourages one to reconsider existing concepts of the distribution of *Golfingia* species in the Barents Sea. As mentioned above, it had earlier been accepted that among the sipunculan species of the Barents Sea it was *G. m. margaritacea* that was dominant in terms of all quantitative parameters – frequency of occurrence, biomass and abundance. However, the presence of another large species of this genus – *G. v. vulgaris* – in the Barents Sea was accepted as a fact only by expert taxonomists.

Recent data shows that *G. v. vulgaris* has turned out to be as common a species in the Barents Sea as *G. m. margaritacea.* Detailed taxonomic treatment of the sipunculan samples has shown that the frequency of occurrence of both species in the southern Barents Sea is virtually the same and that differences in quantitative factors are not significant (Table 1). The maximum and mean biomasses and abundance of *G. m. margaritacea* in the study area exceeded that of *G. v. vulgaris* only by a factor of 1.3–2.4. This means that one third of the total sipunculan biomass in the study area consists of *G. v. vulgaris.* A similar situation was observed in the other area of the Barents Sea with a high density of sipunculan populations off the Novaya Zemlya archipelago coast (Garbul 2009). According to the data of 1996, the mean biomass of *G. m. margaritacea* in the area was 30.8 ± 10.0 g m^{-2} and that of *G. v. vulgaris* was 7.2 ± 7.1 g m^{-2}. Moreover, according to these same data, the mean biomasses of *G. v. vulgaris* and *G. m. margaritacea* in the central Barents Sea, given the equal frequency of occurrence, were 13.0 ± 5.5 g m^{-2} and 6.4 ± 3.6 g m^{-2} respectively (Garbul 2010). This example illustrates the point that both *Golfinia* species are typical of the benthic fauna of the Barents Sea and form quantitatively comparable populations.

As in the case of *Nephasoma* species, there are methodological reasons for the underestimation of the role of *G. v. vulgaris* in the biocoenotic structure of the Barents Sea bottom fauna. Both *Golfingia* species (*G. v. vulgaris* and *G. m. margaritacea*) are morphologically highly variable. At the same time, there are only a few size and morphological differences between them. As a rule, therefore, field identification without special skills is difficult. Large individuals in particular are hard to identify because their basic external taxonomic characteristics differ only marginally: the presence of hooks on the introvert and the skin texture. Furthermore, in the field key for marine benthic organisms (Gayevskaya 1948) commonly used on Russian scientific cruises, *G. v. vulgaris* is absent from the identification key of the Sipuncula of the Russian Arctic. As a result, the fact that *G. v. vulgaris* was present in the sipunculan fauna of this region was ignored in most benthic investigations in the Barents Sea, and all large sipunculan individuals of the *Golfingia* genus were automatically recorded as *G. m.*

margaritacea, presumed to be a single species, widely distributed in this area.

As Denisenko (2007) pointed out, the biomass and distribution pattern of sipunculans in the Barents Sea (in common with other species and groups of benthic organisms) evolved to a remarkable extent during the course of the past century. In particular, Denisenko found that the Gephyrea biomass had decreased significantly in the northern and central parts of the Barents Sea over the period from 1968–1970 to 2003. According to his data (Denisenko 2007), the mean Gephyrea biomass declined almost five fold in this period, from 12.9 ± 3.0 to 2.6 ± 0.6 g m^{-2}. This phenomenon also applies to Sipuncula, because this taxon is the main constituent of Gephyrea (on average for the Barents Sea, 97–98% of the Gephyrea biomass consists of Sipuncula). The data obtained in 2003 for the mean biomass of sipunculans in the southern and central Barents Sea (2.7 ± 0.9 g m^{-2}) correspond well with Denisenko (2003) as regards the mean biomass of Gephyrea in the north-central Barents Sea (2.6 ± 0.6 g m^{-2}). From the above, we can assume that the decrease in Gephyrea biomass in the last quarter of the 20th century, as reported by Denisenko, also applied to the sipunculan fauna in the study area.

An analogous connection can be traced within the main biomass-forming group of sipunculans in the Barents Sea – the species of the *Golfingia* genus (i.e. *G. m. margaritacea* in the studies of Denisenko (2007), and *G. m. margaritacea* and *G. v. vulgaris* in ours). According to Denisenko (2007), the mean biomass of golfingian sipunculans in the northern and central parts of the sea decreased fourfold (from 27.5 ± 4.4 to 6.9 ± 0.9 g m^{-2}) from 1968–1970 to 2003 and in the southern and central parts of the sea by a factor of 3.5 (from 15.6 ± 4.7 to 4.4 ± 1.3 g m^{-2}) according to the 2003 data.

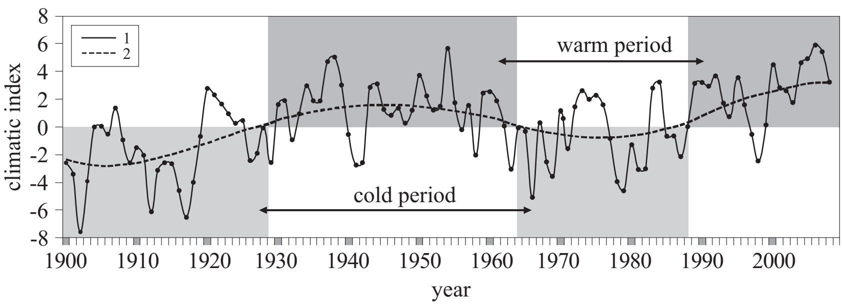

Figure 5. Interannual changes in climatic index (reflecting the cumulative variability of major indicators of climate such as sea and air temperature and ice coverage) of the Barents Sea (1), and its quasisecular cycle (2) (according to Boitsov 2006)

Denisenko (2007) considered that the key reason for the 2003 decrease in sipunculan biomass that he recorded was warming, observed in the Barents Sea from 1989 till the present (Boitsov 2006, Matishov et al. 2009) (Figure 5).

However, the data from the benthic research of 1996–97 (Garbul 2010) did not provide any compelling evidence to support this statement. The mean biomass of sipunculans within the study area according to the 1996–1997 data was estimated at 2.85 ± 1.12 g m^{-2}, which agrees statistically with the 2003 data (2.7 ± 0.9 g m^{-2}). Consequently, the decrease in sipunculan biomass in the central Barents Sea, registered both by Denisenko (2007) and ourselves, took place between 1970 and 1996, and is most likely not related to warming. A sharp decrease (several times) in sipunculan biomass during the short period of positive temperature anomalies prior to 1996 seems unlikely. In fact, large macrozoobenthic organisms respond to hydrological fluctuations with a delay of a few years. So, for *Golfingia m. margaritacea*, there is evidence for a 6-year delay in biomass correlation with water temperature (Denisenko 2007). Moreover, the available data leads to the following conclusion: the strong warming trend of the last 20 years has not affected the sipunculan biomass in the south-central Barents Sea, because there were no significant changes in this biomass during the 8-year period of extremely high positive temperature anomalies between 1996 and 2003 in the southern Barents Sea.

Predation and the negative effect of bottom fishery are also factors that could have led to such a significant reduction in sipunculan biomass during 1970–1996. The most active predators include the large red king crab (*Paralithodes camtschaticus*), introduced into the Barents Sea in the 1960s, and the long rough dab (*Hippoglossoides platessoides limandoides*).

A study of the red king crab's feeding selectivity in the Barents Sea has shown that it is an active predator of Sipuncula. These invertebrates make up about 1% of the total biomass consumed by the crab (Manushin & Anisimova 2008). Superficially, this amount appears to be of no consequence, but one should remember that the abundance of mature red king crabs in the southern Barents Sea is around 40–50 million individuals (Sokolov & Milyutin 2008). However, the fact that the considerable increase in red king crab abundance in the Barents Sea has occurred only since 1998 (Figure 6) and that its dense concentrations in the open part of the sea have been rising significantly only since 2000–2003, excludes the red king crab from the list of possible reasons for the sipunculan biomass reduction during 1970–1996.

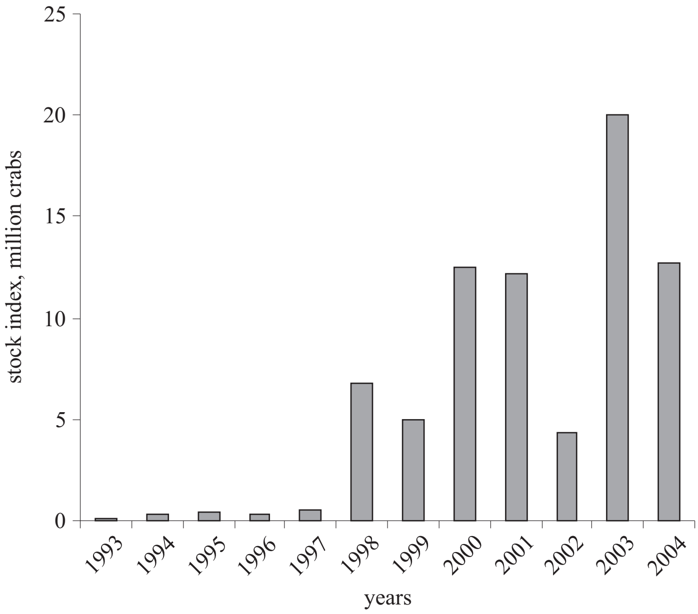

Figure 6. Dynamics of the total red king crab stock index in the Russian part of the Barents Sea (from Anisimova et al. 2005, with alterations)

Sipunculan worms (mostly large individuals of the genus *Golfingia*) are extensively consumed by the long rough dab, a typical benthos feeder, which is widespread in all parts of the Barents Sea. According to MMBI research in the central Barents Sea in 2006, large individuals of *Golfingia* were found in 20% of feeding fish stomachs. Even so, no documented data showing a significant population increase of the long rough dab for the period 1970–1996 could be found. Otherwise, such data could have provided a reason for the mass consumption of sipunculans and the degradation of their communities.

It has been shown that bottom trawling in the Barents Sea, especially in its southern part, is a major factor affecting the total benthic biomass and its main components (Denisenko & Denisenko 1991, Denisenko 2001, 2007, Lyubin et al. 2010). Nevertheless, the long-term dynamics of the bottom trawling intensity in the Barents Sea does not provide grounds for seeing it as the key reason for the decline in sipunculan populations in 1970–1996. Neither the maximum and nor the average long-term bottom trawling intensity for this period exceeds the values for the previous years. Besides, the dynamics of trawling activity in the second half of the last century shows a falling trend (despite significant interannual fluctuations) (Figure 7). Another thing is that this period witnessed rapid technical improvements to bottom trawling gear, thereby reducing

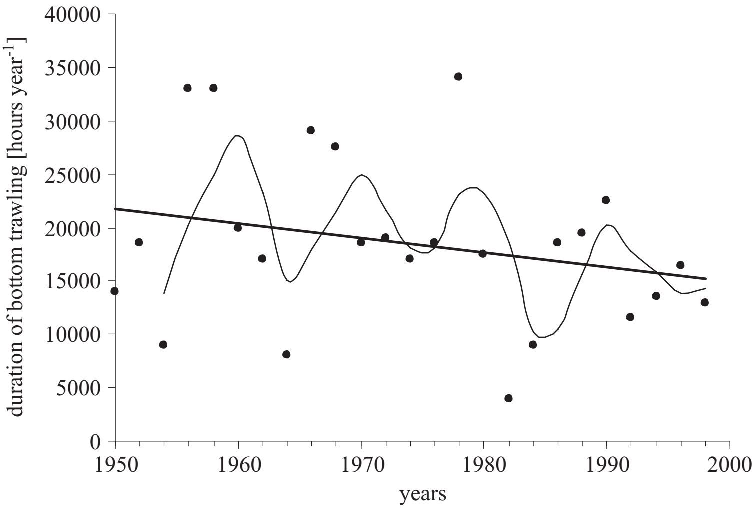

Figure 7. Long-term dynamics of trawling intensity in the Barents Sea (according to Denisenko 2007, with developments and additions). The thin line on the picture shows the three linear filtering points; the thick line shows the linear approximation of the data

its negative effect on the benthos: the lower panels of the trawl were fitted with large-diameter rubber discs in place of the smaller-diameter metal rollers.

Thus, none of the factors mentioned appears to be responsible for the reduction in sipunculan biomass registered in the last quarter of the 20th century.

However, it is possible that the reduction in *Golfingia* biomass between the 1970s and 1990s, described in the article, is due to changes in sampling methodology. It was during this very period that Russian researchers began to use the van Veen grab instead of the Ocean-25. The latter grab has both a larger sampling quadrat and penetrates the sediment to a greater depth, which is important for the efficient catching of large *Golfingia* species, which live deep down in the sediments. Analysis of catches with the two types of grabs has shown that the catch size of invertebrates with greater biomass, and consequently, with greater individual sizes, rises with increasing sampling area (Figure 8).

When used on a clay substrate, the difference in catch size would probably be larger still, because of the unequal penetration of the grab into the substrate. As a result, a considerable part of the benthic biomass is not taken into account when a van Veen grab is used (Garbul & Lubina 2011). Moreover, the probability of catching large invertebrates in an Ocean-25 grab is noticeably higher than with a van Veen grab.

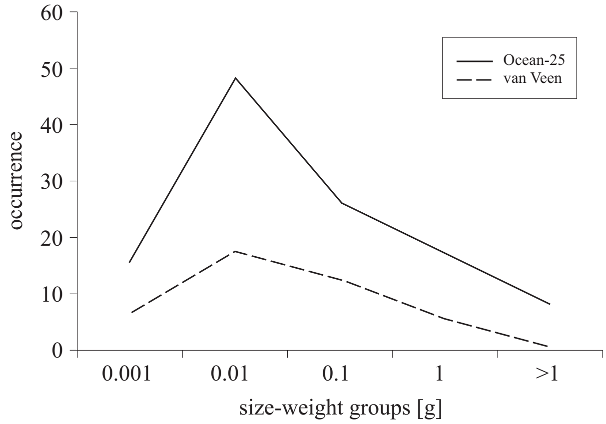

Figure 8. Catches with the van Veen and Ocean-25 grabs on a sandy substrate (according to Garbul & Lubina 2011)

5. Conclusions

The species of Sipuncula most commonly encountered in the southern and central parts of the Barents Sea are *Nephasoma d. diaphanes*, *N. a. abyssorum* and *Phascolion s. strombus*.

Among the Sipuncula species inhabiting the southern and central Barents Sea, the main contribution to the total benthic biomass is from two species of the *Golfingia genus* – *G. m. margaritacea* and *G. v. vulgaris*. Both species are typical of the benthic fauna of this area and form quantitatively comparable populations.

During the period from 1970 to 1996 a significant decrease (3.5–5 times) in sipunculan biomass took place in these parts of the Barents Sea, but this process is unrelated to climatic factors (warming), predation or fishery dynamics. Between 1996 and 2003, the total biomass of Sipuncula did not change significantly, despite increasing red king crab predation and the long period of extremely high positive temperature anomalies in the Barents Sea.

The reduction in *Golfingia* biomass between the 1970 and 1990 is evidently due to changes in sampling methodology.

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