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Research Article

An Overview on Distribution and Abundance of Meiobenthic Foraminifera in the Black Sea

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Abstract
A research program to study Black Sea meiobenthos yielded extensive data on foraminifera with either a soft or a hard shell. Samples were taken in different parts of the Sea, ranging from shallow bays to the layer of constant hypoxia overlying sulphidic waters. A review of new information on the species composition of single-chambered foraminifera (i.e. monothalamids, sometimes termed 'allogromiids') is presented. The data on the ratio of the number of soft-shelled monothalamids and multi-chambered hard-shelled foraminifera in shallow water on the shelf and in the layer of permanent hypoxia are given. It is shown that in many habitats the number of single-chambered species is higher than total number of multi-chambered taxa. Monothalamids are more resistant to hypoxia, they are found closer to the boundary of sulfidic waters, and they occupy deeper sediment layers.

Key words: soft-shelled and hard-shelled foraminifera, coastal, deep-water, hypoxia, Black Sea.

Introduction

In recent years, extensive data on the Black Sea meiobenthos, in particular foraminifera, have been obtained. Here, we present new data based on samples collected in different areas of the northern half of the Sea, and in the southern part of the Sea infront of the Bosporus Strait at depths where the oxygen content of the bottom water ranges from normoxic to varying degrees of permanent hypoxia and complete anoxia. We used the "operational" definition of meiobenthos to include organisms that pass through a sieve of 1 mm mesh size and are retained on a 63 micron sieve. We considered all meiobenthic organisms, both protozoan and metazoan and including the permanent as well as the temporary meiofauna that represent juvenile stages of macrobenthos (Bougis 1950; Mare 1942; Higgins & Thiel 1988; Chislenko 1961; Giere 2008; Sergeeva 2004; Sergeeva & Gulin 2007; Sergeeva *et al*. 2012, 2013; Soltwedel 2000). This work is still ongoing and to date, only generalized data on the distribution of leading taxa are published (Sergeeva *et al*. 2010). The results show that taxonomic groups may differ in their tolerance to particular environmental factors, however, the most complete data can be obtained by studying the individual species. Unfortunately, the lack of specialists slows the definition of species.

These remarks apply in particular to the foraminifera of the Black Sea, notably the monothalamids ("allogromiids in the broad sense'; Anikeeva *et al*. 2013; Gooday *et al*. 2006, 2011), i.e., all soft-shelled, single-chambered foraminifera with either organic or agglutinated test walls. These include many new species requiring descriptions and there are still many forms that are identified only to the genus or family level (Sergeeva & Anikeeva 2004; Gooday *et al*. 2011; Sergeeva et al. 2010). The data obtained concern the so-called "meiofaunal foraminifera" (Gooday 1986), i.e. smaller forms that are retained on a 63-µm-mesh sieve. We present data on multichambered meiobenthic foraminifera with calcite shells, although not all the material has been analysed yet and so we lack detailed knowledge of the species composition. However, these results allowed us to clarify the relative abundance of monothalamous foraminifera with soft shells and multi-chambered foraminifera with hard shells at different depths. Some previously unknown features of the distribution of foraminifera in the Black Sea, associated with habitat characteristics, are also described.

The purpose of this study is for the first time to summarize the existing and original data on the Black Sea allogromiids and to compare some of their ecological characteristics to those of hard-shelled foraminifera.

Material and Methods

Sample collection and processing

The material was collected in different years in the coastal and deep-water areas of the Black Sea (Table. 1, Fig. 1).

Table 1. Sampling information for different research vessel cruises. (MUC= multiple corer, GC= gravity core, PsC=pushcorer, BG= Bottom grab “Ocean-25”, PBG= Petersen’s bottom grab).

R/V, Cruise No	Sampling data	Water depth (m)	Station numbers	Investigated area	Core type
Academic Kovalevsky, 102	1986	20–140	17	the shelves of Bulgaria, the Caucasus and Turkey	BG
Professor Vodyanitsky, 45	1994	76–607	12	North-West Black Sea	BG
Professor Vodyanitsky, 53	1999	23–260	12	North-West &	BG
Poseidon, 317/3	October.2004	182–252	8	NW Black Sea	MUC
Meteor, 72/2	March 2007	120–240	11	NW Black Sea	MUC, PsC
“Arar” (ITU)	November. 2009	75-300	9	Istanbul Strait’s outlet area (Bosporus)	MUC, GC
Maria S. Merian, 15/1	April.2010	80-294	13	Istanbul Strait’s (Bosporus) outlet area of the Black Sea	MUC, GC
Maria S. Merian, 15/1	May 2010	83-375	25	NW of the Black Sea	MUC,, PsC
Professor Vodyanitsky, 64	July 2010	30 – 121	16	West and south the Crimea	BG, GC
Professor Vodyanitsky, 68	November,2010	19-123	26	NW, W and S the Crimea	BG
Professor Vodyanitsky, 70	August. 2011	10-145	32	NW, W and S the Crimea	BG
Felucca	2001-2011	3 – 35	>100	Bays of Sevastopol	PBG, Scuba divers.

In coastal areas, a diver obtained sediment cores up to 5 cm long using a meiobenthic tube (surface area 18.1 cm^2). 'Ocean-0.25' and Petersen grabs were subsampled in the same way. In deep-water areas the 'Ocean-0,25' grab, multiple corer (MuC), gravity corer (GC) and push corer (PsC) were used to take samples for studying the vertical distribution of meiofauna. The sediment cores were sectioned into the following horizontal layers: 0-1, 1-2, 2-3, 3-4 and 4-5 cm. The samples were collected at coastal sites using a Petersen grab. All the samples were preserved in 75 % alcohol, which as we know from previous experience, preserves morphological structures without distortion. In the laboratory, the sediment was carefully washed on sieves with mesh sizes of 1 mm and 63 µm. The fraction retained on the sieves was stained in Rose Bengal before being sorted in water under a binocular microscope for "live" (stained) organisms, which were identified to higher taxa (Type, Class, Order). Stained foraminifera were extracted using a Bogorov chamber. The soft-walled specimens were picked out using a glass pipette and placed in cavity slides with a mixture of glycerol (50 %) and water (50 %) (Sergeeva *et al*. 2010).

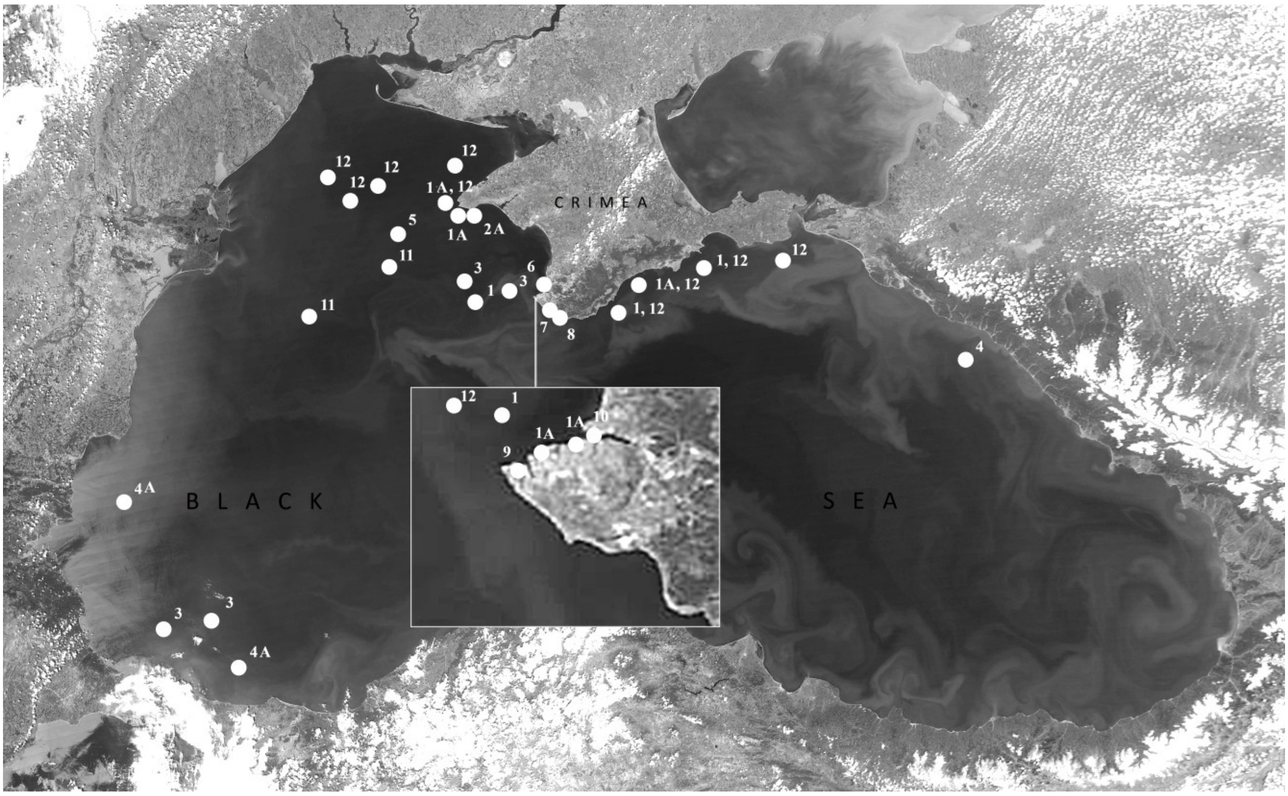

Figure 1. The study areas where foraminifera were found: **1** - Cruise 53 of R/V 'Prof. Vodyanitsky' (1999); **2** - Meiobenthos sampling in the area of Cape Tarkhankut; **3**- Meiobenthic stations in the Istanbul Strait (Bosporus) outlet area of the Black Sea (R/V 'Arar' cruise, November 2009 and R/V 'Maria S. Merian' cruise, April 2010; **4 and 4a** - Cruise 102 R/V 'Academic Kovalevsky', 1986; **5**- The studied Crimean area of the Black Sea, Cruise 45 R/V 'Prof.Vodyanitsky' (1994); **6**- Sampling in Uchkuevka-Lyubimovka region (2003); **7**- Sampling in Balaclava Bay (2005); **8**-Sampling in Laspi Bay (1999); **9**- Sampling in Kazach'ya Bay (2004); **10**- Sampling in Sevastopol Bay (2001); **11**-Investigated area with a view of the main seep field in the northwestern Black Sea (general spot-like field of black dots) and also with indication of a seabed structure (cruises of RV 'Meteor', 2007 and 'Maria S. Merian', 2010) ; **12**- Cruises 64, 68 & 70 R/V 'Professor Vodyanitsky' (2009-2012).

Results and Discussion

New data on the fauna of the Black Sea foraminifera

The history of the study of the Black Sea foraminifera has been reviewed repeatedly (Golemansky 1999; Mikhalevich 1968; Vorobyova 1999; Temelkov 2008, 2010; Temelkov *et al*. 2006). The first 10 species of hard-shelled foraminifera in this area were found in the 1880s (Pereyaslavtseva 1886) and by 1968 the number had risen to 26 species (Mikhalevich 1968). Currently, there are more than 100 species known from this region (Temelkov *et al*. 2006; Yanko 1990; Yanko & Troitskaya 1987).

Reports on individual findings of smaller, monothalamous soft-shelled foraminifera first appeared in 1960s (Valkanova 1964; Mikhalevich 1968). The rapid accumulation of data on monothalamous soft-shelled foraminifera was linked to the systematic collection of meiobenthic material from the Black Sea (Sergeeva & Kolesnikova 1996) using modern bottom samplers. A large proportion of the species proved to be unknown to science and requiring careful description. Although only 13 species from the Black Sea have been formally described, other forms are known that can be identified up to genus or family level (Sergeeva *et al*. 2010; Sergeeva & Anikeeva 2013). The rate at which these species have been discovered, and the proportion of previously known forms, is very revealing; most have been found for the first time and described as new species. The Table 2 lists all of the species of soft-shelled foraminifera from the Black Sea, as well as forms identified only to genus.

Table 2. The list of species of soft-shelled monothalamous foraminifera in the Black Sea.

№	Species	Year of finding	Source
1	*Hipocrepinella hirudinea* Heron-Allen et Erland, 1932	1968	Mikhalevich, 1968
2	*Lagynis pontica* Golemansky, 1999	1970	Golemansky, 1999
3	*Vellaria pellucidus* Gooday, 1992	1986	Sergeeva, Anikeeva 2004
4	*Vellaria sacculus* Gooday, 1992	2004	Sergeeva, Anik., 2006
5	*Tinogullmia lukyanovae* Good., Anik., Serg., 2006	1986	Good., Anik., Serg., 2006
6	*Tinogullmia* cf. *riemanni* Gooday, 1990	2007	Serg., Anik., Good., 2010
7	*Psammophaga simplora* Arnold , 1982	1994	Sergeeva 2004
8	*Goodayia rostellatum* Serg., Anik., 2008	2006	Sergeeva, Anikeeva 2008
9	*Nellya rugosa* Good., Anik., Pawl. 2011	2008	Good., Anik., Pawl. 2011
10	*Cedhagenia saltatus* Good., Anik., Pawl. 2011	2008	Good., Anik., Pawl. 2011
11	*Guanduella podensis* Temelkov, 2010	2009	Temelkov, 2010
12	*Bellarium rotundus* Anik., Serg., Gooday 2013	2010	Anik., Serg. Good. 2013
13	*Krymia fusiformis* Anik., Serg., Gooday 2013	2010	Anik., Serg., Good. 2013
	Forms with the specified name of the genus		
14	*Tinogullmia* sp.	1994	Serg., Anik., Good., 2005
15	*Psammosphaera* sp.	2006	Temelkov *et al*. 2006
16	*Vellaria* sp.C	2006	Serg., Anik., Good., 2010
17	*Vellaria* sp.1	2007	Serg., Anik., Good., 2010
18	*Bathyallogromia* sp.1	2007	Serg., Anik., Good., 2010
19	*Bathyallogromia* sp.2	2007	Serg., Anik., Good., 2010
20	*Nodellum*-like form 3	2007	Serg., Anik., Good., 2010
21	*Nodellum*-like form 4	2007	Serg., Anik., Good., 2010
22	*Tinogullmia* sp.1	2010	Serg., Anik., Good., 2010
23	*Conqueria* sp.	2010	Serg., Anik., Good., 2010
24	*Psammophaga* sp.	2010	Serg., Anik., Good., 2010

The total number found in the Black Sea forms (morphotypes) of soft-shelled foraminifera exceeds 40 (Sergeeva *et al*. 2010, Sergeeva & Anikeeva 2013). For example, for genus *Vellaria*, *Psammophaga* and some others there are indications of several forms with obscure species affiliation. The thirteen species from the Black Sea can be assigned to named species are illustrated in Fig. 2.

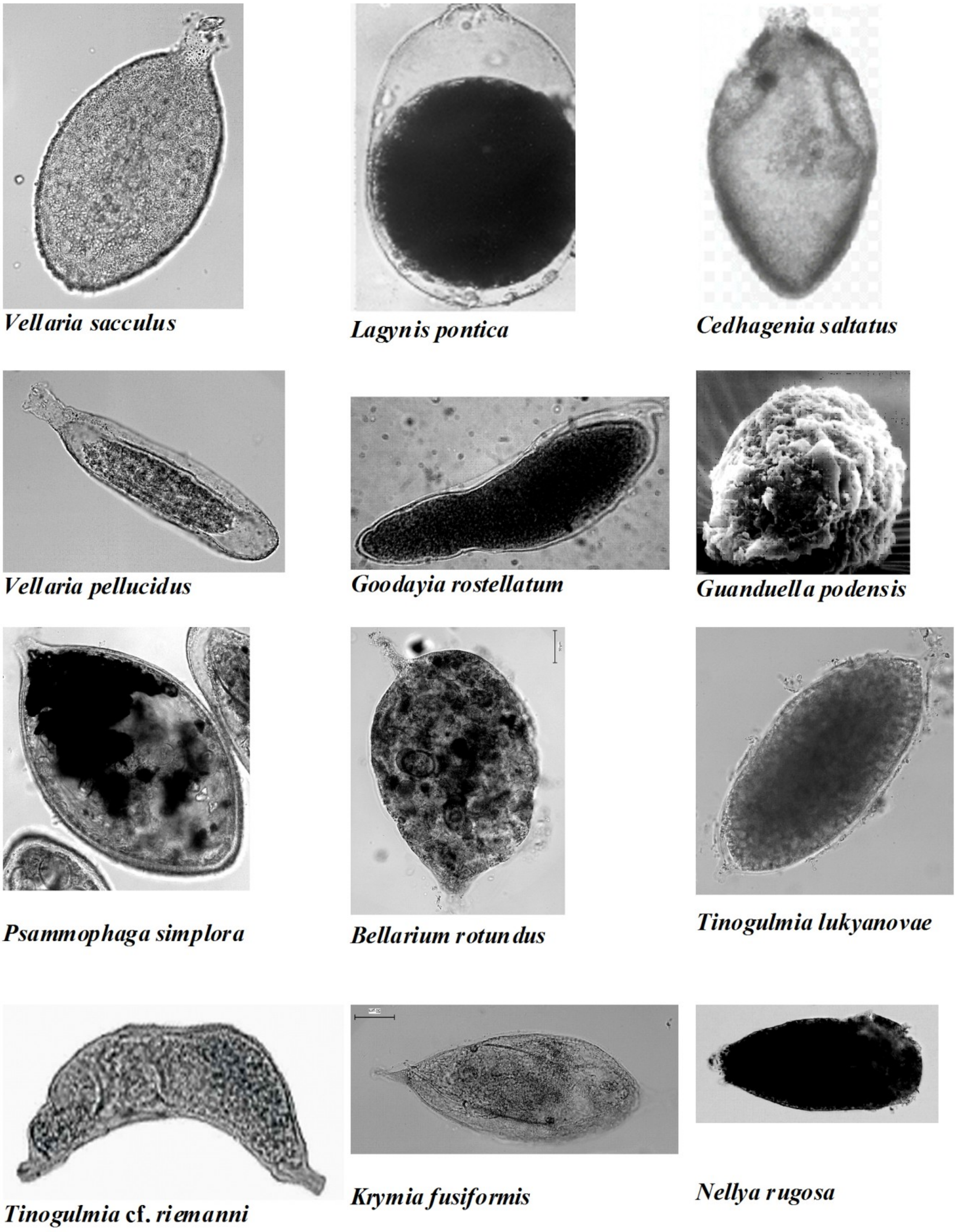

Figure 2. The species of the Black Sea soft-shelled foraminifera.

Distribution and abundance of foraminifera in some parts of the Black Sea

Bays and coastal areas

Data on the distribution of foraminifera at shallow depths obtained by divers in many of the bays around Sevastopol, and samples taken from ships, give an idea of the diversity of this group in many coastal areas of the Crimea, from the depths of 10-11 m. The focus was on allogromiids.

Soft-shelled foraminifera were found at 16 of the 32 stations sampled in bays, which reflects the level of their occurrence. These assemblages are often dominated by *Psammophaga simplora*, which occurs at 10 stations ranging in depth from 10 to 17 m. In Sevastopol Bay, *P. simplora* occurs in sediments that range from silt and silty sand (particle size range <0.1 - 0.25 mm) to more coarse-grained sand (0.25-0.5 mm and 0.5-1 mm) (Anikeeva 2005). This species represent from 20 to 100% (average 75%) of total allogromiids (Anikeeva 2005, 2007).

The dominant species determines the overall abundance of allogromiids. Available data suggests that *Psammophaga simplora* reproduces in the winter. This is based on two observations. First, from December to March there were only more a small-size specimens of the species. Second, at stations with a prevalence of *P. simplora*, their number exceeds 30 thousand ind.$\cdot$m^{-2} only from December to April, while densities in the summer are much lower (about 5 thousand ind.$\cdot$m^{-2}) (Anikeeva 2007).

Another soft-shelled monothalamid frequently encountered in coastal waters is *Vellaria pellucidus*. In general, 8 monothalamid species occur in shallow-water areas around Sevastopol, but in the samples from the coastal waters of the entire Crimean peninsula, preliminary estimates suggest that there are at least 20 allogromiids that await species identification. In Omega Bay, *V. pellucidus* occurs consistently but the most abundant species is *V. sacculus* (300 thous. ind.$\cdot$m^{-2}). In this bay 1–3 species of allogromiids are usually found, but in May and September, the number of species rises to 5-6. The average density of allogromiids in Omega Bay during the year was 24 thous. ind.$\cdot$m^{-2}, and in May there was a peak population of nearly 400 thous.ind.$\cdot$m^{-2}. The largest contribution to this peak was made by *V. pellucidus, V. sacculus* and *B. rotundus.* The peak of abundance in May can be related to the greater depth of the sulfidic layer and redox-cline in the sediment.

In Sevastopol Bay, the average number of soft-shelled foraminifera during the year is 7.6 thous. ind.$\cdot$m^{-2}, and the maximum 17 thous. ind.$\cdot$m^{-2}. Here, the most abundant species, *V. pellucidus, T. lukyanovae* (Fig. 3) and *V. sacculus,* reached densities of more than 8 thous.ind.$\cdot$m^{-2}. We also note a high tolerance of *Goodayia rostellatum* Sergeeva & Anikeeva 2008 and *Tinogullmia* sp. to oxygen deficiency (Sergeeva et al. 2005).

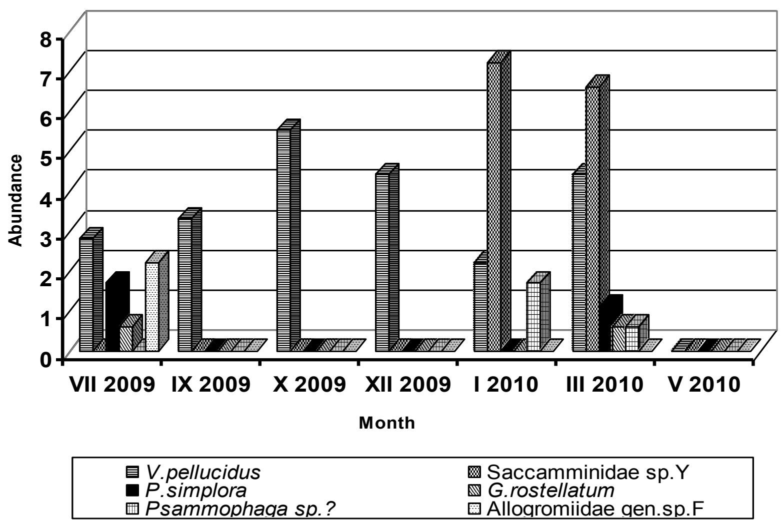

Figure 3. Average abundance (thousand ind. $\cdot$m^{-2}) of the main species of soft-walled monothalamid foraminifera in Sevastopol Bay (data from Sergeva & Anikeeva 2013)

The composition and abundance of allogromiids was investigated in other bays along the coast in the vicinity of Sevastopol. A total of 6 species of soft-shelled foraminifera were found in Balaclava Bay (Gooday et al 2011), among which *V. pellucidus* was dominant (Sergeeva & Anikeeva, 2006). In Kazach'ya Bay 9 species of allogromiids were found (Sergeeva & Anikeeva, 2006). Repeated surveying on RV 'Professor Vodyanitsky' in the *Phyllophora* field and the Karkinitsky Gulf showed that soft-shelled forms predominated among the meiofaunal foraminifera (Sergeeva *et al*. 2012, 2013a). Thus, in a sample collected at a depth of 30 m during Cruise 68 (July 2010) hard-shelled multichambered foraminifera had a density of 2.6 thous. ind.· m^{-2}, considerably less than the density of soft-shelled monothalamids (30.9 thous. ind.·m^{-2}). During cruise 68 (November 2010) hard-shelled foraminifera were represented by single specimens at several stations in the *Phyllophora* field. In both cases, the number of monothalamids in the *Phyllophora* field was generally low compared with Karkinitsky Gulf (see below). Only in a few places did abundance increased to 50 thous. ind.·m^{-2}, reaching 200 thous. ind.·m^{-2} at one station (Sergeeva & Anikeeva 2006). Fig. 4 summarizes the ratio of different species of allogromiids and the obvious differences between the surveyed sites. However, we should note that in some areas we conducted several surveys and so the values presented are averages for the year, while in other areas the results are based on single samples. Furthermore, the depth and sampling seasons, as well as the habitat types, are not consistent.

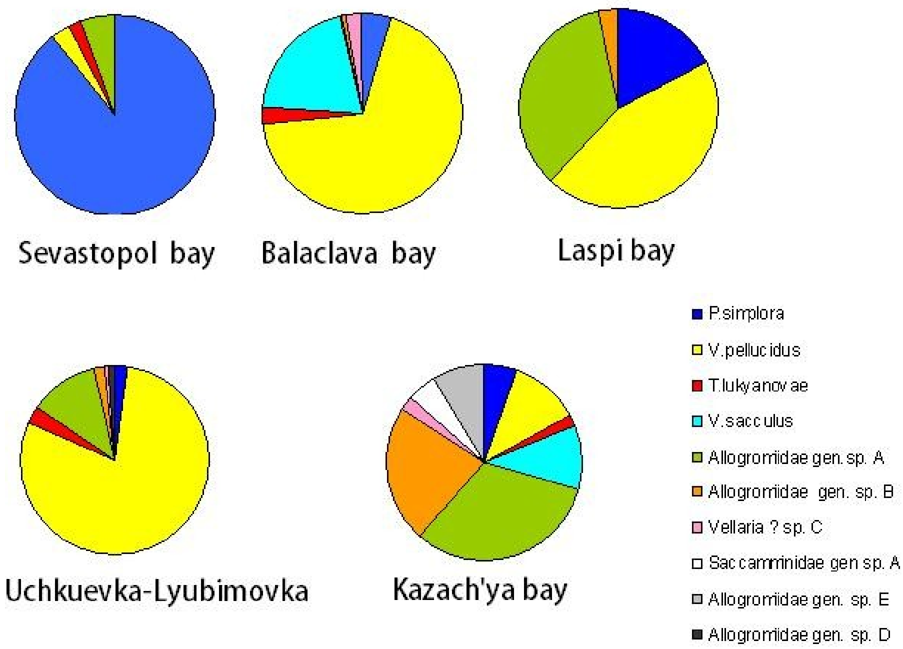

Figure 4. The percentage ratio of soft-shelled monothalamous foraminiferal species in the Sevastopol region of the Black Sea (data from Sergeeva & Anikeeva 2006).

Little is known about the distribution of individual species of allogromiids or their environmental needs. According to our data, *P. simplora* is widespread within the Azov-Black Sea basin. This species is found on the shelves of Bulgaria, the Caucasus and Turkey, western, south-western and southern regions of the Crimea. It is found also in the Azov Sea. It is a dominant meiobenthos species at depths of 142 - 260 m on the south-west of Crimea, reaching a population density of 86-116 thous. ind.·m^{-2}. Monothalamids, especially *P. simplora*, are among the subdominants of meiobenthos communities in methane gas seeps areas at a depth of 77-172 m south-west of the peninsula of Crimea (Sergeeva 2003; Sergeeva & Anikeeva 2006).

North-western shelf of the Black Sea

The so-called Zernov's *Phyllophora* field diminished greatly during the eutrophication of the 1960s-1980s (Zaitsev & Mamaev 1997). In the 1990s, the Nematoda and Foraminifera dominated in this area. In 2010-2011 total number of meiobenthos increased slightly, while the predominant groups were Nematoda and Harpacticoida (Sergeeva & Mazlumyan, 2002; Sergeeva *et al*. 2013a).

Repeated surveys during cruises of the RV 'Professor Vodyanitsky' in the *Phyllophora* field and the Karkinitsky Gulf showed that soft-shelled forms predominated among the meiofaunal foraminifera (Sergeeva et al. 2012, 2013a). Densities of soft-shelled monothalamids (30.9 thous. ind.$\cdot$m^{-2}) were much higher than those of hard-shelled multi-chambered foraminifera (2.6 thous. ind.$\cdot$m^{-2}) in a sample obtained at a depth of 30 m (cruise 64, July 2010). During cruise 68 (November 2010), hard-shelled foraminifera were encountered only once at several stations in the *Phyllophora* field. Monothalamid numbers in the *Phyllophora* field in both cases was generally low compared with Karkinitsky Gulf (see below). Only at a few sites did abundance increase to 50 thous. ind.$\cdot$m^{-2}, and at one station their density reached 200 thous. ind.$\cdot$m^{-2} (Fig. 5).

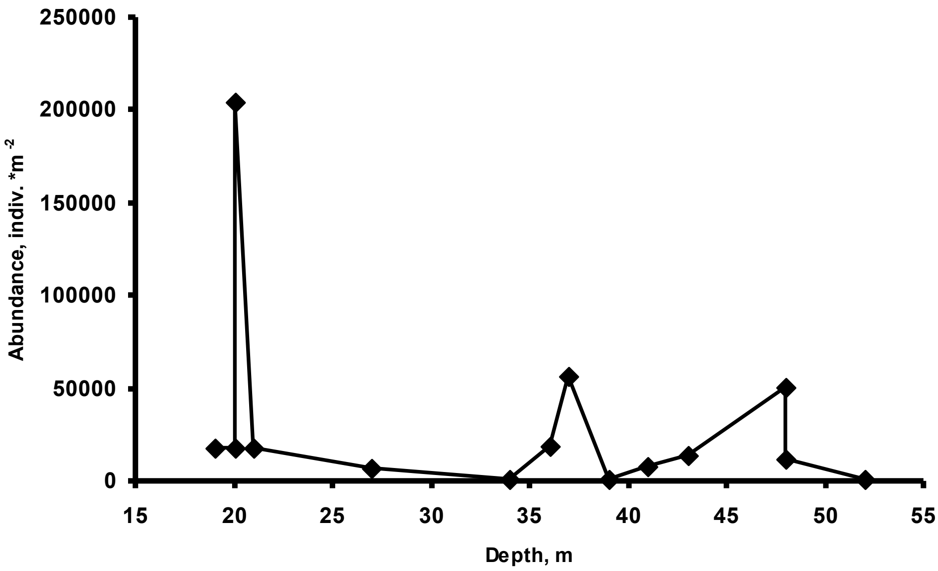

Figure 5. Density of monothalamous foraminifera along the depth gradient across the *Phyllophora* field (68 cruise).

In comparison with the neighboring area, Karkinitsky Gulf, the foraminiferal fauna, especially the hard-shelled multi-chambered taxa, of the *Phyllophora* field, remains subdued, despite signs of a decline in eutrophication in many areas of the Black Sea (Zaika *et al*. 2004).

In Karkinitsky Gulf this decline is not evident and the numbers of monothalamids was much higher at all the stations, reaching peaks of up to 500-600 thous.ind.$\cdot$m^{-2}. Attention is drawn to the following trend with water depth. At a depth of 10-11 m, the monothalamid numbers were low, then increased to reach a peak at depths of 30-40 m. At depths greater than 40 m, Karkinitsky Gulf merges into the *Phyllophora* field, and the number of monothalamids declines to a minimum. Multi-chambered foraminifera with a hard shell exhibit the same change in numbers with depth (Figs.6, 7).

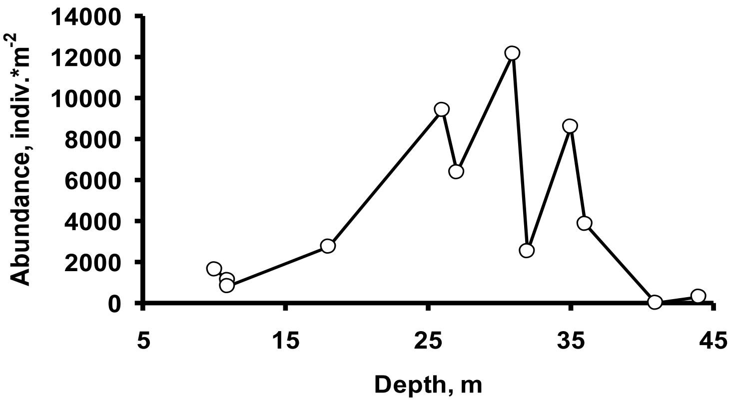

Figure 6. Distribution of hard-shelled multi-chambered foraminifera along the depth gradient in the Karkinitsky Gulf (68 cruise).

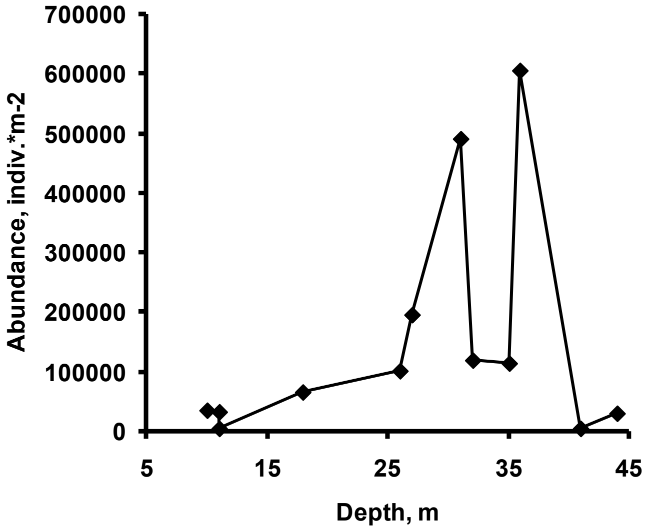

Figure 7. Distribution of soft-shelled foraminifera along the depth gradient in the Karkinitsky Gulf (70 cruise).

Distribution of meiofaunal foraminifera along transects to depths greater than 50 m.

An increasing number of foraminifera, both soft-shelled monothalamids and hard-shelled multichambered, with increasing distance from shore and water depth has been described for the Karkinitsky Gulf and is supported by the data on the Yalta transect. Here, the numbers of both types of Foraminifera is small at a depth of 30 m and rises to depths of 80-90 m. But it can not be considered a general rule, because along the Yevpatoria transect (cruise 64, 2010) densities for monothalamids with soft shells were 31 thousand ind.$\cdot$m^{-2} at a 30-m depth, 29 thous. ind.$\cdot$m^{-2}, at 70 m depth and only 8 thous. ind.$\cdot$m^{-2} at 93 m depth. In contrast, hard-shelled multi-chambered foraminifera occurred at densities of 2 thous.ind.$\cdot$m^{-2} at a depth of 30 m and were entirely absent at depths of 70 and 93 m.

During the 70th cruise multi-chambered foraminifera with hard shells were absent at a depth of 96 m on the same transect but at 145 m they occurred at a density of 2 thous.ind.$\cdot$m^{-2}. Densities of soft-shelled monothalamids were 13 thous. ind.$\cdot$m^{-2} at 96 m, and 8 thous.ind.$\cdot$m^{-2} at 145 m (Fig. 8).

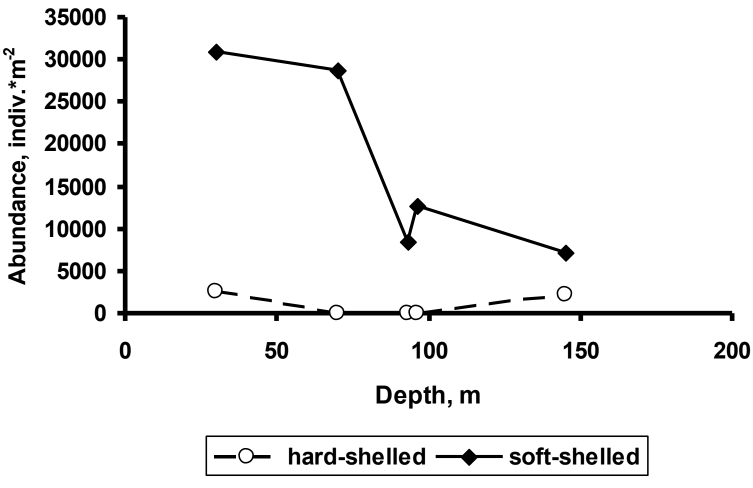

Figure 8. Distribution of foraminifera by depth along the Yevpatoria transect (The solid line – soft-shelled monothalamids, dashed line – hard-shelled multi-chambered foraminifera).

On a transect near Karadag (Crimea) densities of hard-shelled multichambred foraminifera were 1.5-2 thous. ind.$\cdot$m^{-2}, at 20-60 m. At depths of 100-120 m they were not found. Monothalamids peaked (84 thous. ind.$\cdot$m^{-2}) at a depth of 24 m, declining to 8-10 thous. ind.$\cdot$m^{-2} at 110 m and 5 thous. ind.$\cdot$m^{-2} at 120 m (Fig. 9).

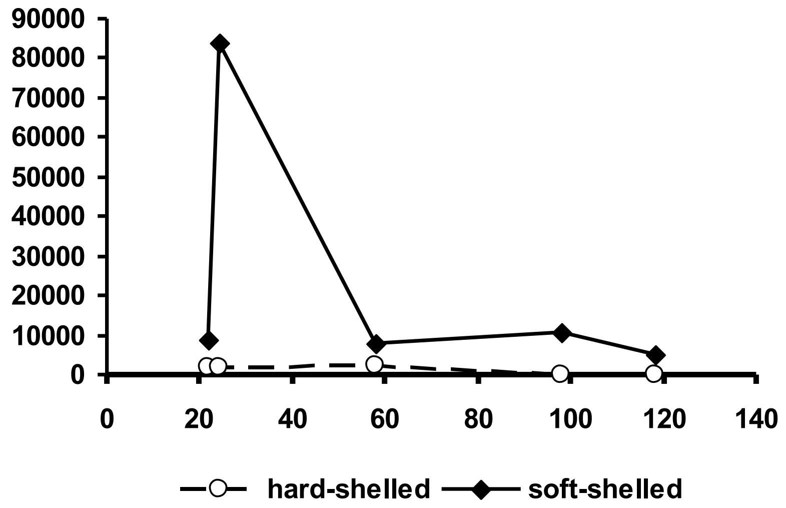

Figure 9. Distribution of two foraminiferal groups along the depth gradient near Karadag.

In general, the number of hard-shelled multi-chambered foraminifera decreases at depths of 75-150 m, possibly reflecting the intensification of hypoxia on approaching the zone of sulphidic waters. The monothalamids, however, occur over a wider range of depths in the Black Sea, including the zone of constant hypoxia. For example, *Bathyallogromia* sp. occurs at a depth of 130 m (Sergeeva *et al*. 2010) and *Tinogullmia* sp. and *Psammophaga* sp. at depths of 150 - 160 m. Sergeeva et al. (2010) recognized three *Vellaria* or *Vellaria*-like species living in the deeper (150-230 m depth) part of the NW Black Sea where the bottom water is severely hypoxic and sulphidic. *Goodayia rostellatum* is found at 150 -190 m depth.

In the north-western part of the Black Sea samples obtained during a cruise aboard the RV 'Meteor' (February-March 2007) reveal that both groups of foraminifera (with calcareous shells and soft-shelled monothalamids) exhibit similar changes with depth (Fig. 10).

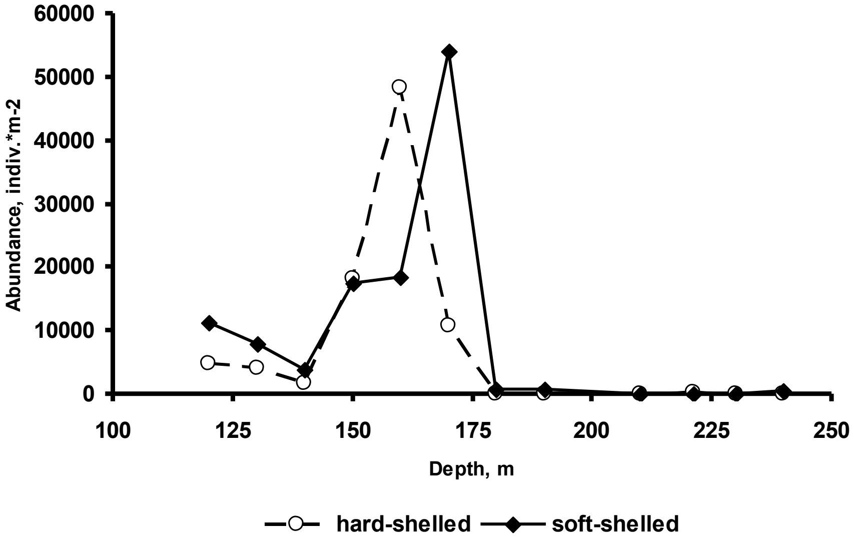

Figure 10. Foraminifera distribution along the depth gradient on the edge of the shelf in the North-western part of the Black Sea (RV 'Meteor', 2007).

A peak was observed in the number of calcareous forms at a depth of 160 m (48 thous. ind.$\cdot$m^{-2}), while allogromiids peaked at 170 m (54 thous.ind.$\cdot$m^{-2}). The densities of both groups declined sharply after the peak. Hard-shelled foraminifera were almost never encountered at a depth of 180 m, and soft-shelled monothalamids at 190 m. For comparison, nematodes also exhibited maximum densities at 160 m, with much lower densities at 180 m. This is no doubt due to the influence of the boundary zone of sulphide waters.

In samples obtained in another area of the north-western part of the Black Sea at two polygons (I – 83.7-212 m depth, II - 100-375m depth), during RV 'Maria Merian' cruise in April 2010, monothalamid and multi-chambered foraminifera had major peaks at a depth of 138 m. The monothalamid peak was higher (240 thous.ind.·m^{-2}) than that of the multi-chambered taxa (154 thous. ind.·m^{-2}). Both groups also showed small peaks at depths of 155-163 m, where monothalamids densities reached 63 thous. ind.·m^{-2}. Multi-chambered foraminifera occurred in minimum numbers at a depth of 167 m and monothalamids occurred at 204 m depth (Fig. 11).

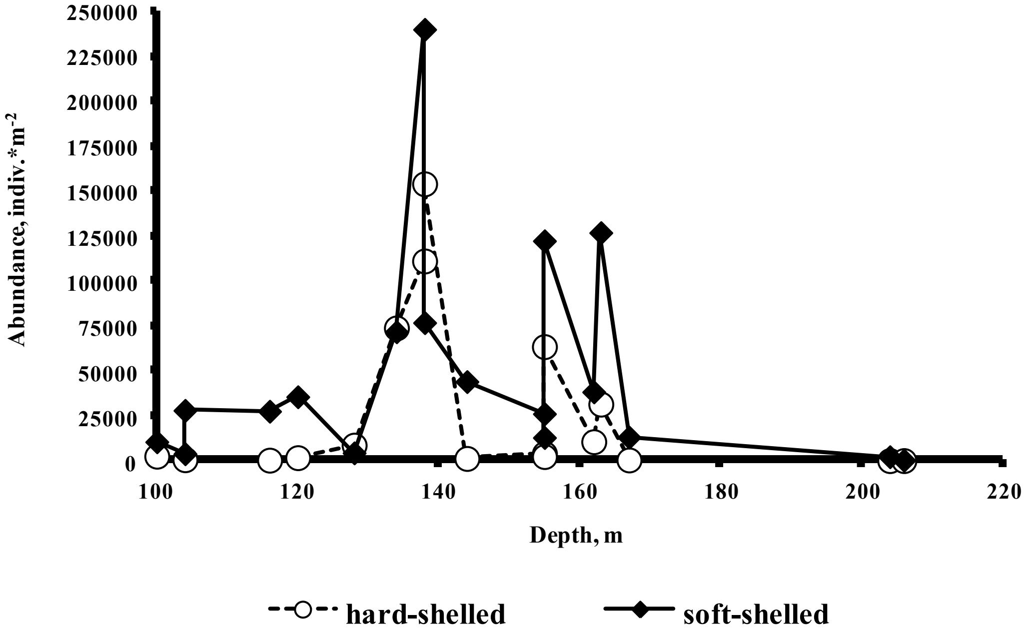

Figure 11. The distribution of foraminifera with soft shells (monothalamids) and hard shells (multi-chambered) along the transect on the second polygon (RV 'Maria S. Merian', May 2010).

These data from two study areas in the north-western part of the Black Sea document variations in the depth of the abundance peaks of foraminifera. Depth transects in the Black Sea reveal similar peaks in the densities of other meiofaunal taxa, for example, polychaetes and harpacticoids (Sergeeva & Zaika 2013; Kolesnikova et al. 2014), as well as distinct gradients in certain environmental factors (temperature, oxygen, food, *etc*). Thus, the peaks in abundance reflect the fact that the species or the group in question are in an optimal environment. This is especially true for species forming a "belt of settlement" in a limited range of depths (Zaika & Sergeeva 2000, 2012). A similar phenomenon was observed in the two groups of foraminifera under discussion. Although each group is composed of many species, they have some common environmental preferences.

Sediments on transects in the Caucasus were sampled using a corer at depths of 20 to 140 m. Multi-chambered hard-shelled foraminifera were usually not numerous (typically up to 10 thous. ind.·m^{-2}), but a large peak was observed at a depth of 40 m (246 thous. ind.·m^{-2}), and a second much smaller peak (19 thous. ind.·m^{-2}) at a depth of 110 m. The maximal density of soft-shelled monothalamids in this region reached 50 thous. ind.·m^{-2} at a depth of 30 m, although their numbers were usually not more than 5-8 thous. ind.·m^{-2}. Thus in the Caucasus region, soft-shelled monothalamids were subordinate in numbers to the hard-shelled multichambered forms (Fig. 12). Perhaps this is due to the use of a corer that creates a bow wave, displacing the lighter monothalamids during the sampling process. The main hard-shelled species were *Eggerella scabra*, *Ammonia compacta, Lagena pellucidum*, *Elphidium pontica,* while *Psammophaga simplora* and *Vellaria* sp. were the dominant monothalamids at 171 m. (Fig. 12)

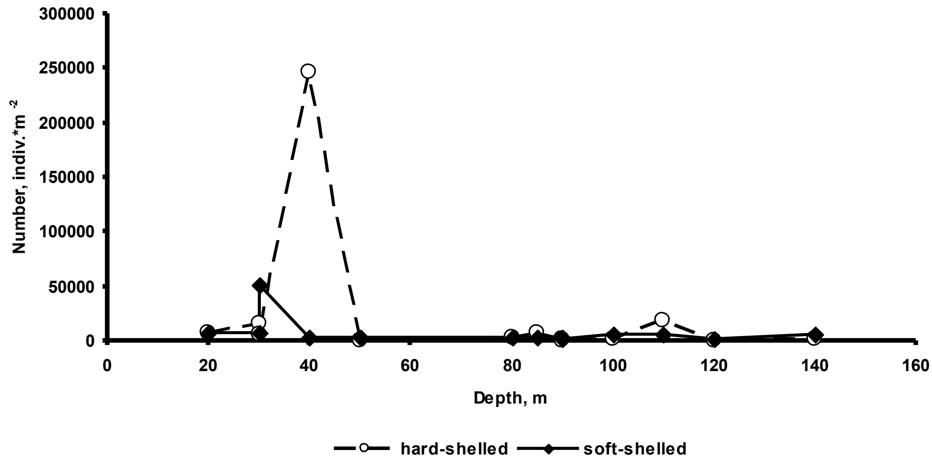

Figure 12. The distribution of foraminifera with soft shells (monothalamids) and hard shells (multi-chambered) in the Caucasus (Cruise 102 of R/V 'Prof. Kovalevsky', 1986).

The area of the Bosporus Strait

In the southern part of the Black Sea we studied the region before the Bosporus. This is very different from the north-western area in terms of deep-water benthic habitats. Here, the environmental conditions are modified by the influence of salty and normoxic waters that come from the Sea of Marmara with the lower jet stream. Increased salinity leads to the enrichment of the biota due to the permanent introduction of propagative stages of organisms from the Sea of Marmara. The introduction of oxygenated water at the seabed may increase the variability in the depth of the hypoxic-anoxic transition zone, and, in general, shift the limit of oxygenated water to greater depths. Finally, the periodic pulsating current activity of the lower Bosporus plays the important role (Özsoy *et al*. 2001). As a result, diversity in this region increased both in terms of occurrence of species and groups, and the general development of the benthos.

In the area of the Bosporus Strait peaks of multi-chambered and monothalamous foraminifera have also been recognised. The following features deserve attention: (1) the presence of two or more peaks, (2) the difference in the depth of the peaks in the two groups discussed, (3) the location of the peaks at different depths during the two surveys.

Two transects were sampled in different seasons in the area of the Bosporus. During a cruise of the RV 'Arar' a transect across the depth range 75 to 300 m revealed density peaks for both groups of foraminifera at depths greater than 80 m (Sergeeva & Mazlumyan 2013); multichambered hard-shelled forms showed a peak at a depth of 82 m (66.5 thous. ind.·m^{-2}), monothalamids at 88 m (37 thous. ind.·m^{-2}) (Fig. 13).

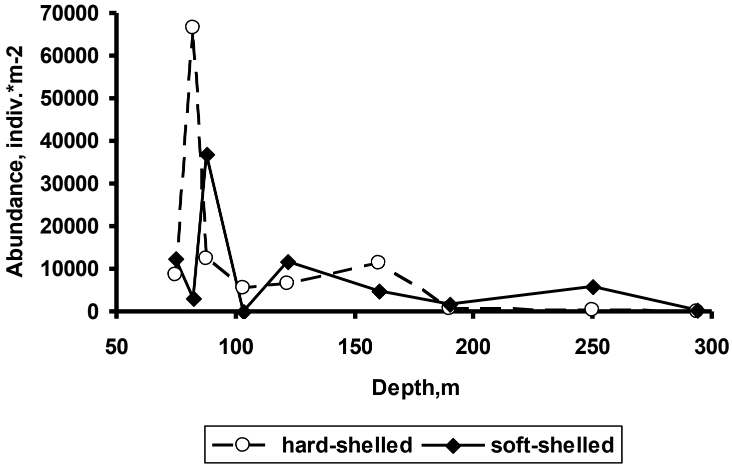

Figure 13. The distribution of foraminifera with soft shells (monothalamids) and hard shells (multi-chambered) in the Bosporus area (data from RV 'Arar' cruise, November 2009).

With a further depth increase, the abundance of both groups decreased, but not smoothly. Monothalamids showed a second small peak (11.5 thous. ind.·m^{-2}) at a depth of 122 m. Hard-shelled multi-chambered foraminifera have a second peak at a depth of 160 meters. These two foraminiferal groups continue to meet until a depth of 250 m.

Actually we note that at depths of up to 150 m, the number of multi-chambered foraminifera is often higher than that of monothalamids. At the depths of 190-250 m the number of multi-chambered foraminifera is less than 1 thousand ind.·m^{-2}, whereas the density of monothalamids is 6 thous. ind.·m^{-2} at a depth of 250 m and 260 ind.·m^{-2} at a depth of 300 m.

The genus *Hyperammina* is largely responsible for the peak of foraminifera with a hard- shells at a depth of 82 m. This form has fragile arenaceous shell. The largest representatives of *Hyperammina* belong to the macrobenthos. Numerous specimens of *Ammonia compacta* (Hofker) and *Eggerella scabra* (William) are also responsible for this peak (Sergeeva & Mazlumyan 2013).

A second survey was carried out in the Bosporus area during cruise of RV 'Maria Merian' (April 2010). Meiobenthos samples were taken on a transect that spans the depth range from 80 to 300 m. During this second survey the numbers of soft-shelled monothalamids was significantly higher than that the hard-shelled forms at all studied depths (Fig. 14).

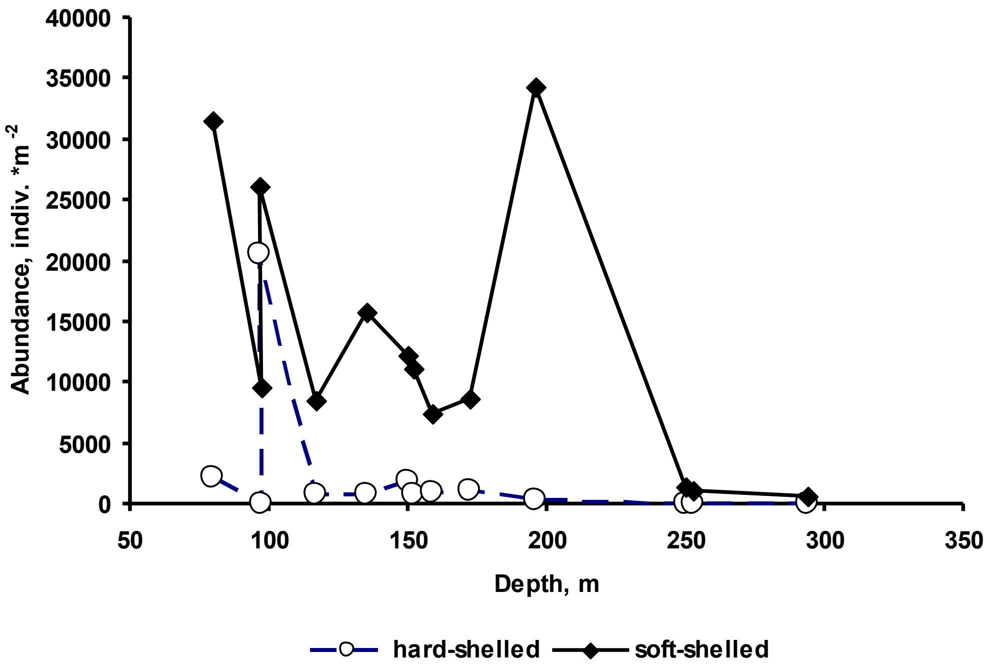

Figure 14. The distribution of foraminifera with soft shells (monothalamids) and hard shells (multi-chambered) in the Bosporus area (data from R/V 'Maria S. Merian' cruise, April, 2010).

The number and position of the peaks and the maximum depth at which foraminifera occur varied. The number of monothalamids was 31.5 thous.ind.·m^{-2} at a depth of 80 meters. Then it dropped to a second peak (15 thous. ind.·m^{-2}), decreased to a minimum (7.4 thous. ind.·m^{-2}) at a depth of 159 m before rising to a major peak at a depth of 196 m (34 thous. ind.·m^{-2}), Below that depth, the number of monothalamids decreased rapidly to 1.4 thous.ind.·m^{-2} at 250 m, and 700 ind.·m^{-2} at 294 m depth.

The density of multi-chambered foraminifera with hard shells never exceeded 1000-2000 ind.·m^{-2}, except for sharp peaks (20.5 thous. ind.·m^{-2}) at depths of 96 m and 200 m.

It should be noted that significant differences between these two surveys have been identified in other groups of meiobenthos (Zaika & Sergeeva 2012, Sergeeva & Mazlumyan 2013, Kolesnikova *et al.* 2014). A likely explanation is that there are pulsations in the intensity of currents carrying water from the Sea of Marmara through the Bosporus Strait. The depths of the zone of constant hypoxia were investigated. Saltier water originating from the lower reaches of the Bosporus is normoxic and near-bottom currents reduce the level of hypoxia. Therefore, hypoxia increases during periods of low current velocity whereas at higher velocities hypoxia is attenuated. This leads to a change in the densities of meiofauna, including foraminifera. A strong enrichment of the lower layers of oxygenated water leads to a shift in the sulphide zone boundary to depths of over 200 m. The meiobenthos penetrates correspondingly to greater depths.

Comparing these two surveys, we note that the number of multi-chambered foraminifera generally declined substantially across the transect in the period between the two surveys. At the same time, the number of monothalamids increased somewhat, and this group of foraminifera was recorded in low numbers (less than 500 ind.$\cdot$m^{-2}), even at a depth of 300 m. These differences, as well as the differences seen in the other meiobenthos groups, are undoubtedly associated with the above-mentioned power oscillations of the lower current of the Bosporus. These fluctuations affect not only the meiobenthos.

The macrobenthos in this area occurs at much greater depths compared with other regions, and this is also related to the influence of the Bosporus (Sergeeva et al. 2011). This means that the sediment is more deeply bioturbated, increasing the depth of oxygen penetration and consequently the depth to which the meiobenthos, and in particular the foraminifera, occur.

Table 3 provides a concise summary of data on the penetration depth of the foraminifera in the sediment.

Table 3. Penetration of foraminifera into the sediment at different depths in the Bosporus area. (RV 'Arar' cruise, November 2009).

Depths in the sediment (cm)	Water depths (m)								
	75	82	88	103	123	162	190	250	300
	Hard								
0 -1	1	1	1	1	1	1	0	0	0
1- 2	1	1	1	1	1	1	1	0	0
2- 3	0	1	0	1	0	0	1	1	0
3- 4	1	1	0	0	0	0	0	0	0
4- 5	0	0	0	0	0	0	0	0	0
	Soft								
0 -1	1	1	1	1	1	1	1	1	1
1- 2	1	1	1	1	0	1	0	1	0
2- 3	0	1	0	0	0	0	0	1	0
3- 4	0	0	1	1	1	0	1	1	0
4- 5	0	0	1	0	0	0	0	0	0

The data on the transect in the Bosporus area (RV 'Arar', 2009) concern the presence (1) or absence (0) of foraminifera in layers 1 (0-1 cm), 2 (1-2 cm), *etc*. This method was first applied by us in order to show the stratified distribution of meiobenthos (Sergeeva & Zaika 2013).

It can be seen that at 75-82 m water depth, the multi-chambered foraminifera with a hard shell penetrate no deeper than layer 4 (3-4 cm), while those from a depth of 88 m only penetrate as far as layer 3 (2-3 cm), and then not always. The data available indicate that with increasing water depth in the Black Sea hypoxia increases and this leads to the rise redox-cline to the surface of the sediment.

This was clearly shown in the meiobenthos data from the northwestern part of the Sea (Sergeeva *et al.*2012). But here, at the depths of 190 and 250 m, foraminifera were absent at the surface, possibly due to accidental causes. Monothalamids often occurred in layer 4 at the deeper stations, and in one sample they were even found in layer 5 (4-5 cm) (Table 4). Furthermore, they were observed in the surface layer at a depth of 300 m. This suggests that monothalamids are more resistant to hypoxia.

Table 4 summarises data from the RV 'Maria S. Merian' cruise in the same area on the vertical distribution of the two foraminiferal groups in the sediment. These data show that calcareous foraminifera are usually not observed even in the layer 2 at depths exceeding 90 m. In the Bosporus area they penetrate into the sediment to more than two centimeters only at depths of 75-80 m, where macrobenthos densities and bioturbation is high. Other occurrences at great depths can be considered random. On the second transect multi-chambered foraminifera with a hard shell are not present at all stations - their distribution is patchy. Below 100 m, they are found only in the top layer. In contrast, monothalamids are present at all stations and in a greater number of layers. Only at a depth of 135 m do they almost completely disappear in layer 4 (3-4 cm).

Table 4. Penetration of foraminifera into the sediment at different depths in the Bosporus area (RV 'Merian' cruise, April 2010).

Depths in the sediment (cm)	Water depths (m)										
	80	93	97	117	135	150	152	159	172	196	300
	Hard										
0 - 1	1	0	1	1	0	1	0	1	1	1	0
1 - 2	1	0	1	0	0	0	0	0	0	0	0
2 - 3	1	0	0	0	0	0	0	0	0	0	0
	Soft										
0 -1	1	1	1	1	1	1	1	1	1	1	1
1- 2	1	1	1	1	1	0	0	1	1	0	1
2- 3	1	1	0	0	1	1	0	0	0	1	0
3- 4	1	0	1	1	0	0	0	0	0	1	0

Comparison of the distribution of monothalamous and multi-chambered foraminifera with soft and hard shells, respectively, in the depth of the sediment, supports the conclusion that the former have a greater tolerance to hypoxia.

Conclusions

In many studies, data on the distribution of fossil foraminifera are used for reconstructing past environmental conditions. A special analysis of the distribution and abundance of monothalamids showed that this group has somewhat different ecological preferences compared to other groups of foraminifera for example, in terms of their tolerance to permanent severe hypoxia. These data indicate that the smaller the group used as a bio-indicator, the more reliable the results.

Indeed, the more species included in any group of organisms, the wider the range of tolerance to environmental factors. Therefore, by using any meiobenthic taxon (foraminifera, nematodes, harpacticoids etc.) for bio-indication, individual species will give more reliable results that a higher-level grouping. The more precise species determination is made and the type of habitat detail clarified for the different stages of the species development, the more confident you can use this species as an indicator of the degree of hypoxia and to predict its occurrence as conditions change. This is shown on the example of meiobenthic harpacticoids and polychaetes of the Black Sea (Kolesnikova *et al.* 2014; Sergeeva *et al*. 2013b; Zaika and Sergeeva 2008, 2012).

The detailed study of monothalamids in the Black Sea has only just started. As a first step, we focus on certain species (*Bathyallogromia* sp., *Tinogullmia* sp., *Goodayia rostellatum* Sergeeva & Anikeeva 2008 and *Vellaria* sp.) found at depths of 150-300 m, in order to clarify the limits of the concentration of oxygen (or at least depth) at which they occur. It is an interesting task for future research.

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