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RESEARCH ARTICLE

Influence of abiotic factors on the abundance of Foraminifera in the Odessa Sea Region, Black Sea

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Abstract

Based on long-term data, regularities in the dynamics of the distribution and the average long-term abundance of taxocene representatives Foraminifera depending on some abiotic factors (type of bottom substrates, depth, bottom water temperature, oxygen regime) are discussed. The high concentration of Foraminifers in the Odessa Sea Region (OSR) was a characteristic of silty substrates at a depth of 16-20 m (average 133,134.5±21,745.1 ind m^{-2}, maximum 835,000 ind m^{-2} during hypoxia). The Foraminifera played a greatest role in the formation of the total abundance of meiobenthos in spring, with a deficit of dissolved oxygen in the lower layers of water. An active increase in numbers was observed both at a low dissolved oxygen content of 1-4 mg/l and at 9 mg/l O_2.

Keywords: Odessa Sea Region, Black Sea, Foraminifera, abiotic factors

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Introduction

Foraminifera play a very significant role in the biogeochemical cycle of inorganic and organic matter of bottom sediments of marine water bodies (Galtsova *et al.* 2001). Their study is of great scientific interest in many aspects, such as species richness of Foraminifera in marine ecosystems of various trophic levels, formation of quantitative indicators and the degree of their dominance in the meiobenthos community, and the composition and morphological changes of Foraminifera shells as an indicator of the type and level of pollution of the marine environment. At present ecologists are increasingly using foraminiferan as an indicator species for environmental monitoring of marine areas subject to anthropogenic influences (Bresler and Yanko 1995). Some species of benthic Foraminifera can be used as an indicator species for pollution of the aquatic environment with heavy metals (Yanko *et al.* 1998). It has been reported that under extremely unfavorable conditions in the bental of eutrophic waters, Foraminifera can be the dominant group of meiobenthos in numbers. For several decades, monitoring studies of the quality of the marine environment of the northwestern Black Sea indicated a dominant population density of representatives of the nematode-foraminiferan or foraminiferan-nematode complexes of meiobenthic organisms (Vorobyova 1999; Vorobyova and Kulakova 2009). The use of Foraminifera as indicators of the marine environment susceptible to anthropogenic impact is justified (Yanko and Troitskaya 1987). The purpose of this work is to describe the role of abiotic factors (substrate type, depth, temperature, oxygen regime) in the formation of quantitative indicators of Foraminifera in the Odessa Sea Region.

Materials and Methods

This study was based on materials (499 samples) of the expeditions carried out in 1994-1999 and 2005-2015 in the Odessa Sea Region (OSR) of the Black Sea (Figure 1). Sampling was carried out according to the standard station pattern (Vorobyova and Bondarenko 2008) at depths of 5-27 m using a Petersen bottom grab (opening area 0.25 m^2). At each station, depending on the type of substrate from the monolith brought by the bottom grab, as a rule, 2-3 parallel quantitative samples were taken with a sampler with an area of 10×10 cm. Then they were washed through a system of benthic sieves. To capture meiobenthos, a nylon mill sieve with a mesh size of 70-90 μk was placed on the lower sieve. Further, the samples were fixed with 4% formalin, while staining with Bengal Pink. Under laboratory conditions, the sample was viewed in the Bogorov chamber under a binocular.

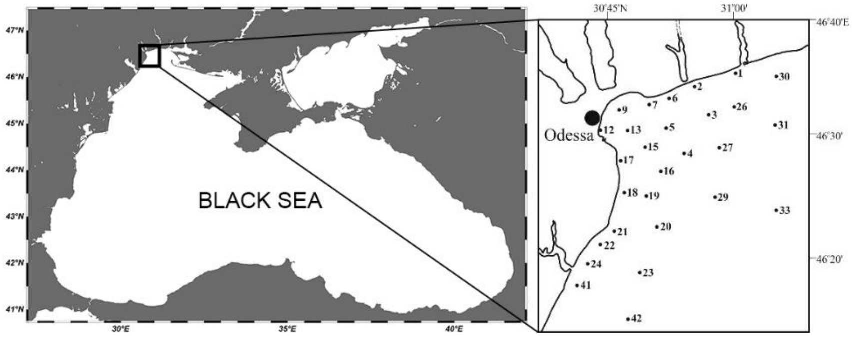

Figure 1. Sampling stations in the Odessa Sea Region of the Black Sea

Results and Discussion

The most important abiotic factors for benthic Foraminifera are: salinity, type of bottom substrate, depth, temperature of the bottom layers of water, the amount of dissolved oxygen, and the content of organic matter. In this regard, we can conclude that the patterns of distribution of bottom foraminifers are controlled by a large number of environmental characteristics.

During the indicated period of research, 157 stations were located at a depth of 5-32 m with silty soil. It is known that the most favorable substrate for Foraminifera is a mixture of silt, sand and detritus (Burkovskij 1992; Phleger 1960). In the summer period complex environmental situations are often developed, associated with the accumulation of a large amount of organic matter and a low content of oxygen dissolved in the bottom layers of water.

At the same time, during summer, the proportion of foraminifers in the total number of meiobenthos organisms increased sharply. Crustaceans, juvenile mollusks and other representatives of small invertebrates in this period often die. In the summer of 2005, in most sites in the OSR, the oxygen content in the bottom layers was 2-4 mg/l. The abundance of foraminifers settlements in this period ranged from 250,000 to 835,000 ind·m^{-2}, their share of the total number of meiobenthos was very high, which was 82.6-94.9%. The average long-term population abundance of Foraminifera for the study period was 50730.7±9827.5 ind·m^{-2}. The average long-term indices of foraminiferan concentrations in the OSR are the highest on silty soils (Figure 2).

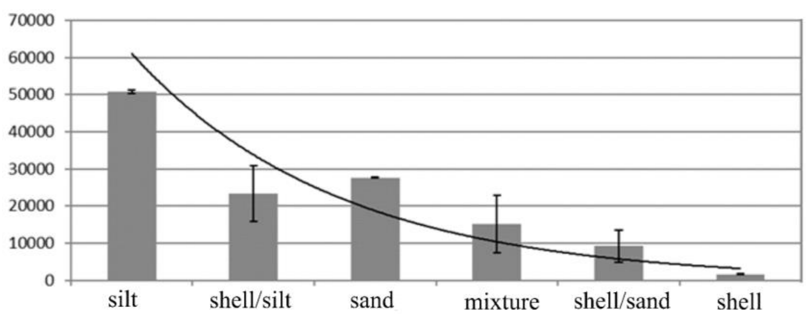

Figure 2. Long-term average density indices (ind·m^{-2}) of Foraminifera settlements on various substrates

On silted shells (42 stations) the occurrence taxocene of Foraminifera was 61.9%, with an average abundance of 23333.7±10601.9 ind·m^{-2}. The maximum number of protozoa in this biotope was 400000 ind·m^{-2}. The lowest average foraminifers abundance indicators are characteristic for shells and shells with an admixture of sand, which were 9062.1±3211.0 ind·m^{-2}and 1592.3±1136.4

ind·m^{-2}, respectively. The biomass of the group under consideration was low due to the small size of Foraminifera. Their role in the total biomass of meiobenthos was much lower than in the total number of organisms. However, low body weight does not reduce their significance in bottom biocenoses as a feed object. According to Kiseleva (1975), in the food lump of polychaetes *Alitta succinea* (Leuckart, 1847), the occurrence of foraminifers was 48%, and in *Gediste diversicolor* (O.F. Müller, 1776) it was 57%. In 40% of the examined mollusks *Retusa truncatella* (Bruguiere, 1792), the food consisted only of Foraminifera.

Of the benthic Foraminifera the dynamics of their distribution at different depths was well pronounced. Three Foraminifera complexes were distinguished in the northwestern shelf of the Black Sea: shallow 0-35 m, relatively deep 36-70 m and deep 71-150 m (Yanko and Troitskaya 1987). The distribution of these organisms shows close correlation with depth, because this factor determines many other parameters: illumination, temperature, oxygen and carbon content (Blum and Taldenkova 2002). Thus, the depth is an integral parameter (Mokievsky 2009), which is important for the northwestern part of the Black Sea with its diverse and dynamic conditions of abiotic factors. The shallow-water complex of Foraminifera was represented in the OSR. The analysis of the distribution density of Foraminifera populations in the OSR was carried out according to the results of ten-year observations at depths from 5 to 27 m. But even in this small range of depths, a clear zonality was visible in the distribution of Foraminifera abundance (Figure 3).

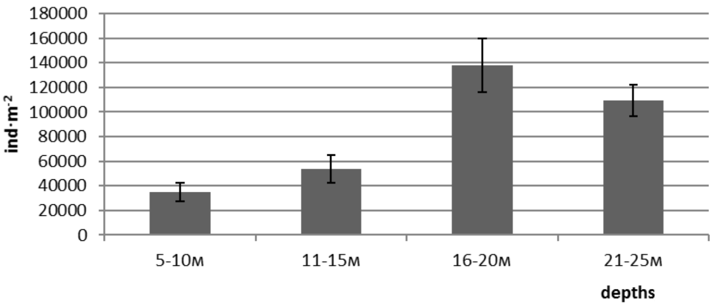

Figure 3. Long-term average density indices (ind·m^{-2}) of foraminifer settlements at various depths

The lowest average densities of foraminifers settlements were recorded during the study period (92 stations) in the shallow water (5-10 m) as 35,103.7±454.0 ind·m^{-2}. The maximum average long-term indicator of the density of Foraminifera settlements was recorded in the depth range of 16-20 m as 133,134.5±217,45.1 ind·m^{-2} (occurrence 83%). Their maximum accumulations (1,237,500 ind·m^{-2}) were noted at a temperature of bottom water layers of 14ºC and salinity of 16‰. Here, the foraminifers were the dominant group of meiobenthos. They formed about 60% of its total abundance of organisms. As the depth increases, the density of foraminifer's settlements decreases. The long-term average indicator of their population density was 109,524.5±12,907.5 ind m^{-2}. In the benthal with this range of depths more than 20 m (182 stations) the occurrence of Foraminifera was 81%. A high number of protozoa was recorded in 2005 (up to 835,500 ind·m^{-2} and 520,000 ind·m^{-2}), which comprised to 91.1-94.5% of the total number of meiobenthos. It must be emphasized that the high abundance of Foraminifera was confined to zones with a low oxygen content (2-4 O_2 mg·l^{-1}).

In the northwestern part of the Black Sea in general, and OSR in particular, Foraminifera play a significant role in the formation of the total number of meiobenthos (Figure 4). Their dominance as well as the dominance of representatives of the Foraminifera-Nematoda complex, may indicate deteriorating environmental conditions.

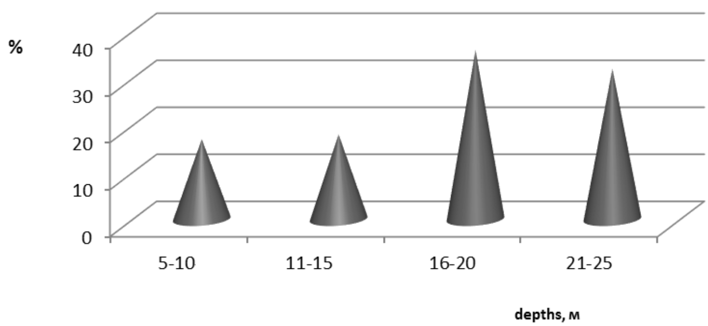

Figure 4. The long-term average indicator of the percentage (%) of Foraminifera in the total number of meiobenthos at various depths in the Odessa Sea Region

The temperature regime of the bottom layers of water is of great importance in the formation of quantitative indicators of the taxocene Foraminifera. In this paper, we analyzed the annual dynamics of their average indicators. The formation of environmental quality in the benthal is largely dependent on the processes occurring in the upper layers of the sea. Of particular importance for the quality of the environment in the benthal is the mass development of microalgae in the surface layers. Their subsidence after dying introduces a large amount of organic matter into bottom sediments (Graf *et al.* 1982; Thiel *et al.* 1989). In this regard, the formation of the abundance of Foraminifera settlements is very dynamic throughout the year (Figure 5).

In different years in spring, the water temperature at the bottom varied widely from 4 to 16°C, but at 81.3% of stations it was 4-8°C. Salinity in this period were 15-17‰ with a satisfactory oxygen regime of 8-11 O_2 mg·l^{-1}. In the spring, at 122 stations, the occurrence of foraminiferan was high as 82%. Their average long-term indicator of population density in the OSR was 146,275.4±1,898.2 ind·m^{-2} (maximum 980,000 ind·m^{-2}). The highest concentrations of the taxocene Foraminifera were recorded in 2005, their share in the total number of meiobenthos at most stations was 93.7-94.4%. Over the period of many years of research in the spring, the average proportion of Foraminifera in the total abundance of meiobenthos were 43.6%. Such indices of Foraminifera in spring can serve as an indicator of the season when a large amount of organic matter accumulates at the bottom. Unicellular algae from the near-surface layers of the sea sink to the bottom after mass development and dying off. As a result, the quality of the marine environment at the bottom is deteriorating.

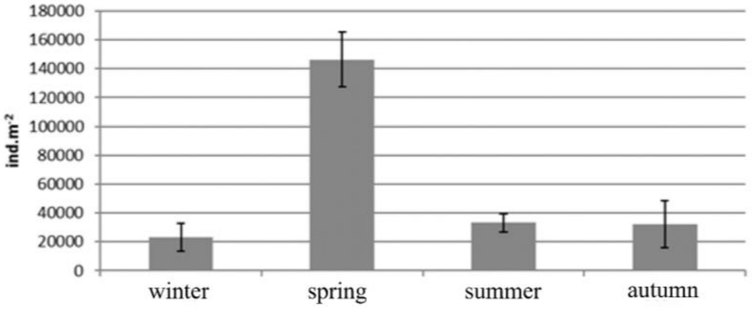

Figure 5. The average long-term abundance (ind·m^{-2}) of Foraminifera in different seasons

To analyze the formation of quantitative indicators of protozoa in summer, 190 samples were analyzed (2005-2015). The temperature in the bottom layers of the water varied depending on the depth from 9°C to 24°C at a depth of up to 10 m, and 8-11°C at 12-30 m. The salinity was almost everywhere 16-17‰, the most difficult oxygen regime was in 2005. Having annual collections of material in the summer period, we could conclude that the maximum abundance of Foraminifera in this period was typical for 2005-2006 (Figure 6). The long-term average population abundance of Foraminifera was 33,355.6±6,377.7 ind·m^{-2}, the maximum indicator was 835,000 ind·m^{-2}.

In autumn, 58 stations were examined during the research period. If the occurrence of foraminifers was high in spring and summer, it was on the average 41.4 % in autumn. They were especially rare in 2007, their share in the total number of meiobenthos averaged 19%. In autumn in some years, the abundance of settlements varied significantly in different parts of the OSR and averaged 32,168.9±16,134.9 ind·m^{-2}. The maximum accumulations of Foraminifera were recorded in the fall of 2008, on silty soil with a salinity of 17.2‰ as 766,000 ind·m^{-2}.

In winter, materials were collected only once (27 stations) at the end of December 2005. In addition to low water temperatures in the bottom layer (7-

9°C) and relatively low salinity of 14-15‰, almost 50% of the stations showed very low levels of oxygen dissolved in water (0-3 O_2 mg/l). The average density of foraminifer settlements was 361,194 ind·m^{-2}. The average abundance for the water area was 45,219.1±19,406 ind·m^{-2}, the maximum indicator was 390,000 ind·m^{-2}. During this period, the total number of meiobenthos was formed by 81% Nematoda, the proportion of Foraminifera in the total number was 11.6%.

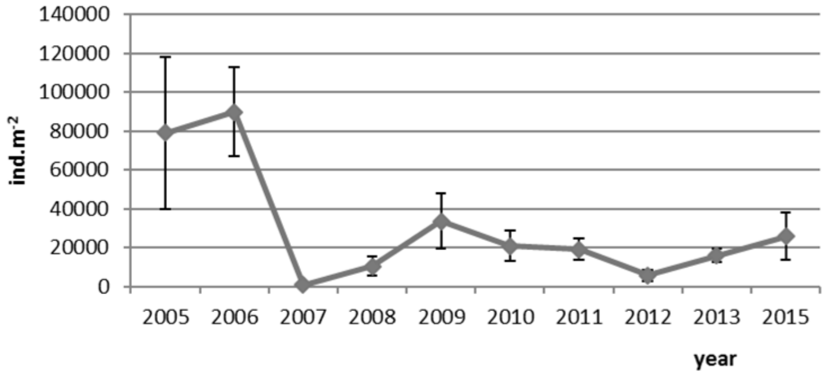

Figure 6. Interannual dynamics of average annual abundance indices (ind·m^{-2}) of Foraminifera in the Odessa Sea Region in summer

Thus, an analysis of the obtained material indicates that the average long-term maximum Foraminifera densities were confined to the spring period, often being the dominant group in the total number of meiobenthos (Figure 7).

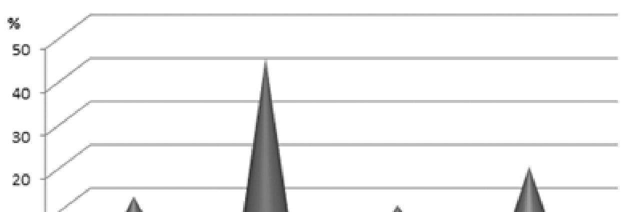

Figure 7. Average long-term indicators of fractions (%) of foraminifera in the total number of meiobenthos

The development of Foraminifera and the formation of their population density was affected by the oxygen regime at the bottom. Studies in the northwestern part of the Black Sea (Vorobyova 1999) showed that with repeated extensive zones of hypoxia and anoxia, the species diversity of Foraminifera sharply decreases, but their population density can reach up to 1-2 million. ind. ·m^{-2}. It has been known for a long time that many bottom foraminifers can live in anoxic conditions. In 2005 unusually high nitrate content in the cytoplasm of Glubobulimina (Foraminifera) was discovered, which lived in anoxic conditions at the bottom of the Swedish fjords (Risgaard-Petersen *et al.* 2006). The authors hypothesized the nitrate respiration of foraminifers, which accumulate a large amount of nitrates in their body. Many benthic foraminifers associated with oppressed oxygen environments retain chloroplasts. They provide a metabolic advantage that allows foraminifers to inhabit these habitats. Thus, it has been suggested that many benthic foraminifers are facultative anaerobes (Bernhardt 1996). It has now been established that foraminifers can dwell in soil to a depth of 12-15 cm and periodically transfer oxygen-free conditions (Basov and Chusid 1983; Moodley and Hess 1992). When studying meiobenthos in the northwestern part of the Black Sea, live Foraminifera were found in the thickness of the soil up to 10 cm in water areas at depths of 25-90 m (Vorobyova and Kulakova 2009). The analysis of long-term data allowed to show the dynamics of the formation of average of Foraminifera abundance at various indices of dissolved oxygen in the bottom layers of water (Figure 8).

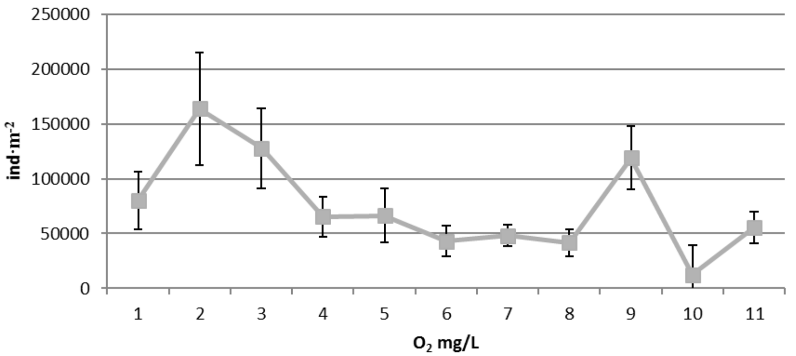

Figure 8. Average indices of the density of foraminiferal settlements (ind·m^{-2}) under different oxygen conditions

Significant concentration of Framinifera was confined to both very low and high levels of dissolved oxygen. Based on the results obtained, it can be assumed that the first peak was formed by species that continue to develop during hypoxia. The second peak should relate to oxyphilic species. A similar picture was seen in the Sea of Okhotsk (Saidova 1960), where the author described two groups of Foraminifera, one of which formed the maximum abundance at a dissolved oxygen content of 4-5 ml/l or more, and the second, forming the southern maximum, lived with less dissolved oxygen (about 2-4 O_2 mg/l).

To determine the significance of foraminifers in the formation of quantitative indicators of small bottom invertebrate animals (meiobenthos) of the OSR ecosystem, the average indices of portion of Foraminifera in the total number of meiobenthos under different oxygen conditions were calculated (Figure 9).

Foraminifers are constantly an essential component of the meiobenthic community of eutrophic water areas of the Black Sea. To some extent they can reflect the quality of the marine environment in the benthal and the formation of quantitative indicators of the rest of the meiobenthic community, which is valuable as a fodder for young fish and some species of macrozoobenthos.

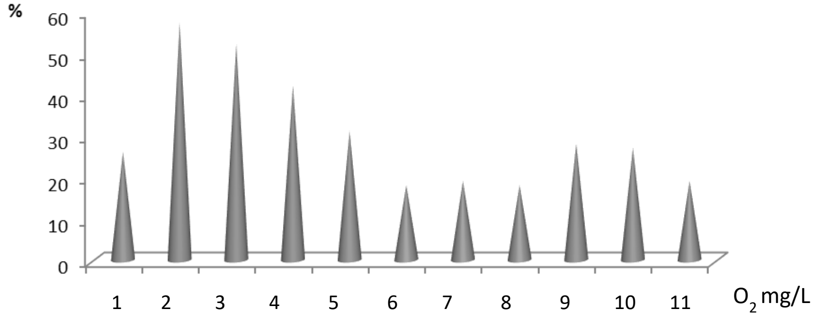

Figure 9. Proportion the numbers (%) of Foraminifera in the total abundance (ind·m^{-2}) of meiobenthos under different oxygen conditions

Conclusions

In the Odessa Sea Region, taxocene Foraminifera play a significant role in the formation of indicators of the total number of meiobenthos. The maximum values were confined to silty soil (632,000-728,000 ind·m^{-2}), as well as silted shell (650,000 ind·m^{-2}); on other types of substrates (silted shells, sand, shell) they ranged from 500 to 10,000-38,000 ind·m^{-2}. The maximum average long-term indicator of the abundance of foraminifer settlements was recorded in the depth range of 16-20 m as 133,134.5±21,745.1 ind·m^{-2}, where there was significant accumulation of organic matter. With a wide range of indicators of oxygen dissolved in water, two peaks of Foraminifera population density were observed: the first peak was formed by species that continue to develop during hypoxia, the second peak should be related to oxyphilic species.

References

Basov, I.A., Chusid, T.A. (1983) On the biomass of benthic foraminifera in the sediments of the Sea of Okhotsk. *Oceanology* 23(4): 648-655 (in Russian).

Bernhardt, I.M. (1996) Survival, ATP pool, and ultrastructural characterization of benthic foraminifera from Drammensfjord (Norway): response to anoxia. *Marine micropaleontology* 28: 5-17.

Blum, N.S., Taldenkova, E.E. (2002) Methods of paleodraphic reconstruction. In: Analysis of Marine Microfauna. Scientific publication, Moscow, Russia, pp. 213-247 (in Russian).

Bresler, Vl., Yanko, V. (1995) Acute toxicity of heavy metals for benthic epiphytic Foraminifera *Pararotaria spinigera* (Le Calvez) and influence of seaweed-derived doc. *Enviromental Toxicology and Chemistry* 14(10): 1687-1695.

Burkovskij, I.V. (1992) Structural and Functional Organization and Stability of Marine Benthic Communities. Moscow State University Press, Moscow (in Russian).

Galtsova, V.V., Kulangieva, L.V., Pavlyuk, O.N., Ryabchenko, V.N. (2001) The role of meiobenthos in the transformation of substances and energy in marine ecosystems. *Izvestiya TINRO* 1-1: 45-57 (in Russian).

Graf, G., Bengtsson, W., Diesner, U., Schulz, R., Theede, H. (1982) Benthic response to sedimentation of spring phytoplankton bloom: process and budget. *Mar Biol* 67 (2): 201-208.

Kiseleva, M.I. (1975) Food spectra of some benthic invertebrates of the Black Sea. *Zool Journal* 54(11): 1595-1601 (in Russian).

Mokievsky, V.O. (2009) Ecology of Marine Meiobenthos. Moscow: Society of Scientific Publishing KMK (in Russian).

Moodley, L., Hess, C. (1992) Tolerance of infaunal benthic foraminifera for low and high oxygen concentrations. *Biol Bull* 183(1): 94-98.

Phleger, F.D. (1960) Ecology and Distribution of Recent Foraminifera. John Hopkins University Press.

Risgaard-Petersen, N., Langezaal, A.M., Ingvardsen, S., Schmid, M.C., Jetten, M.S.M., Op den Camp, H., J., M., Derksen, J.W.M., Pin a-Ochoa, E., Eriksson, S.P., Nielsen, L.P., Revsbech, N.P., Cedhagen, T., van der Zwaan, G.J. (2006) Evidence for complete denitrification in a benthic foraminifer. *Nature* 443: 93-96.

Saidova, Kh.M. (1960) Distribution of foraminifera in bottom sediments of the Sea of Okhotsk. *Proceedings of the Institute of Oceanology* 32: 207-209 (in Russian).

Thiel, H., Pfannkuche, O., Schriever G., Lochte, K., Goodey, A, J., Hemleben, Ch., Mantoura, R.F.G., Turley, C.M., Patching, J.W., Riemann, F. (1989)

Phytodetritus on the deep-sea floor in a central oceanic region of the Northeast Atlantic. *Biol Oceanogr* 6: 203-239.

Vorobyova, L.V. (1999) Meiobenthos of the Ukrainian Shelf of the Black and Azov Seas. Naukova Dumka, Kiev (in Russian).

Vorobyova, L.V., Bondarenko, A.S. (2008) Meiobenths polychaetes in northwestern Black Sea. *Oceanological and Hydrobiological Studies* 37: 1-13.

Vorobyova, L.V, Kulakova, I.I. (2009) Contemporary State of the Meiobenthos in the Western Black Sea. Astroprint, Odessa, Ukraine.

Yanko, V., Anmand, M., Kaminski, M. (1998) Morphological deformities of benthic Foraminiferal test in response to polunion by heavy metals: implications for pollution monitoring. *Journal of Foraminiferal Research* 28(3): 177-200.

Yanko, V.V., Troitskaya, T.S. (1987) Late Quaternary foraminifera of the Black Sea. Science, Moscow, Russia (in Russian).