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MEIOBENTHOS OF THE BLACK SEA UNDER ANOMALOUS CLIMATIC CONDITIONS

Vorobyova L.V. – D.Sc., Prof., Senior Researcher
Institute of Marine Biology of the NAS of Ukraine
vorobyova.meio@gmail.com

Bolshakov V.M. – PhD, Senior Researcher
Institute of Marine Biology of the NAS of Ukraine
vbolshakov@ua.fm

The results of the analysis of long-term studies of the meiobenthos of the northwestern shelf of the Black Sea (1994–1999 and 2005–1015) are presented. It has been shown that the formation of the meiobenthic community depends not only on such environmental factors as the type of substrate, salinity, oxygen regime, and depth. The formation of its qualitative and quantitative characteristics is also influenced by periodic changes in climatic conditions. These changes are associated with changes in the processes that take place in the near-surface layers of marine areas. The article considers the dynamics of meiobenthos indicators that came for 15 years in the northwestern part of the Black Sea (Odessa Sea Region). The temperature of the surface layers of water, the dynamics of precipitation, and the runoff of the Dnieper River were taken into account. The interannual dynamics of the total abundance of meiobenthos and some of its large taxa (Foraminifera, Harpacticoida, Polychaeta) is described. The data obtained show that in the period of anomalous climatic conditions the maximum indicators of the nematode-copepod ratio and the total abundance of meiobenthos increases, whereas biomass decreases. The purpose of this article is to describe the formation of quantitative indicators of the meiobenthic community in anomalous climatic conditions. Our long-term observation of the formation of the meiobenthic community of organisms showed that under chronic constant anthropogenic impact, the species diversity of meiobenthos in the NWBS is sharply reduced, the dominance of the main groups (foraminifera and nematodes). The present data obtained show that for during years with anomalous climatic conditions, the maximum indicators of the N_{nem}/N_{harp} index nematode-copepod ratio are characteristic, it increases and, the total number of meiobenthos increases, and whereas the biomass decreases.

Key words: Black Sea, northwestern shelf, meiobenthos, dynamics of indicators, climatic anomalies.

Introduction

Meiobenthos is a community of marine organisms that is able to quickly respond to both acute and chronic environmental stresses. In addition, the formation of its qualitative and quantitative characteristics is influenced by periodic changes in climatic conditions and related changes in the aquatic ecosystem. The development and functioning of meiobenthic animals are closely dependent on the biological processes that occur in the surface layers of the pelagial. Changes in the abiotic parameters of the marine environment lead to a significant restructuring of the entire benthic community. Shifts in the structure of eutrophic pelagic communities are mirrored in the benthal zone.

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Shifts in the abiotic parameters of the marine environment entail significant changes in the structure and functioning of the entire benthic community of organisms. Their influence enhances the growth of abiotic parameters in a negative direction. This is especially pronounced in the northwestern part of the Black Sea (NWBS), where there are extensive fields of hypoxia with periodically recurring anoxia.

Meiobenthos, having a high fecundity, as a rule, a short life cycle and a fast growth rate, is capable of restructuring its composition and functional indicators. It is believed that abnormal climatic conditions were observed in 1994, 1998, 2005–2006 and 2009–2010. The purpose of this article is to describe the formation of quantitative indicators of the meiobenthic community in anomalous climatic conditions.

Materials and Methods

The paper is based on the materials of observations of 1994–1999 and 2005–2015. Sampling during all years of research was carried out at constant set of sites (Vorobyova, 1999) to the standard grid of stations in northwestern part of the Black Sea. Dislocation of sampling stations and methods processing meiobenthos samples are given in several scientific publications (Vorobyova 1999, 2021; 2021a; Vorobyova et al. 2017). The data that fell on the summer period (June, July, August) were analyzed (about 200 samples).

Using the data of long-term observations, we have identified the indicators (total number, number of some taxa and their ratio) that best reflect the main trends in the development of meiobenthos in modern conditions. Among these indicators: the total abundance of meiobenthos, foraminifera and harpacticids, the indices of the ratio of the numbers of nematodes and harpacticids, as well as the ratio of total abundance of meiobenthos to its biomass.

Results and discussion

It is known that the NWBS is a highly eutrophic water area influenced by the flows of three large rivers (Danube, Dnieper and Dniester). Their waters flow through highly urbanized areas and countries with highly developed agriculture. Studies in 1983–1998 showed that in this highly eutrophic water area, the meiobenthos in terms of its ecological characteristics differs significantly from the meiobenthos of the Romanian and Bulgarian shelves (Vorobyova 1999; Vorobyova, and Kulakova 2009). Recent publications (Vorobyova et al. 2016; Vorobyova et al. 2017; Vorobyova et al. 2021) reflect the main environmental factors (substrate type, depth, spatial distribution, etc.) that affect the formation of biodiversity, indicators of the total abundance and biomass of meiobenthos.

In this paper, we paid attention to the influence of anomalous external abiotic factors (water temperature, precipitation, runoff volume of the Dnieper River) on meiobenthos. As mentioned, our data refer to 15 years of observations (1994–1999 and 2005–2015). Climatic conditions during this period underwent significant fluctuations. It is believed that they were anomalous in their characteristics in 1998, 2005–2006 and 2009–2010. This is evidenced by indicators of external abiotic factors. Water temperature, precipitation and River Dnieper runoff. They are given according to the measurements of State weather service Odessa-port (Fig. 1). The water temperature during the period of this study varied significantly and its maximum values were noted in the years indicated above. Prolongated summer water temperature anomalies were in 2010. For example, in 2010 the anomaly was 22%. In addition, this year was a record year in terms of precipitation (709 mm).

It is known that the summer significant development of diatoms algae indicates the development of copepods, followed by oligochaetes, nematodes, ostracods and others (Gerlach 1978). At the same time, shifts in the structure of pelagic groups caused by eutrophication are mirrored in the benthal zone.

The concentrations of various compounds in the upper sediment layer change, that lead to a change of the oxygen regime and the rate of chemical exchange between sediments and water. The ecosystem of the Odessa Sea Region is also affected by the runoff of the Dnieper River. The transformed waters of the Dnieper River carry million tons of organic matter out of the Dnieper-Bug Estuary. Such amount of organic substances in the NWBS leads to a deterioration in the oxygen regime at the bottom, hypoxia and anoxia. The given graph testifies the dynamism of Dnieper River runoff (Fig. 2).

A significant impact of freshwater runoff influence – the ecological structure of phytoplankton. Together with marine and brackish species, there are numerous freshwater species of unicellular algae (42.2%) (Nesterova 2017). D.A. Nesterova (2017) pointed out that the highest phytoplankton abundances were in 2005 during a strong water “bloom” caused by an outbreak of freshwater Cyanobacteria. At the same time, diatoms and dinoflagellates intensively developed in the composition of phytoplankton. An increased abundance of freshwater green algae was noted in 2006, 2010 and 2013 in the summer. This is due to the runoff of brackish water from the Dnieper-Bug Estuary. There are increased indicators of the total annual runoff of the Dnieper River in the considered anomalous years. So, in 1998–1999 the annual runoff amounted to 58.41–57.27 km^{-3}, respectively. This is one third higher than was assessed for 1994–2000. In 2006, the annual runoff (49.29 km^{-3}) exceeded the established pattern by 8 km^{3}, which also happened in 2010.

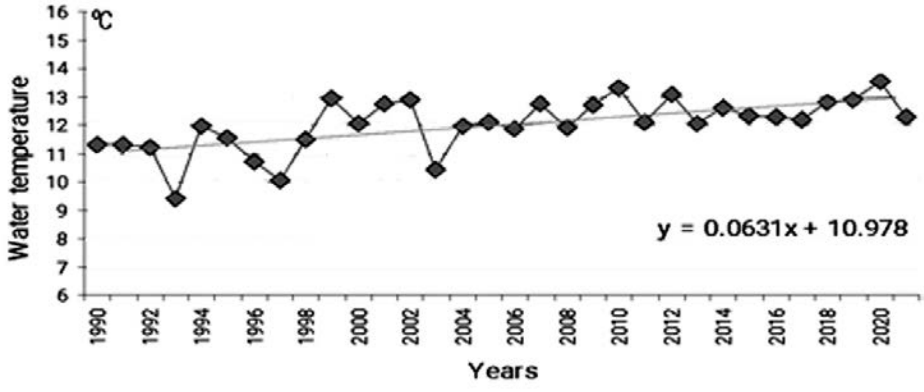

Fig. 1. Average annual water temperatures in the Odessa region

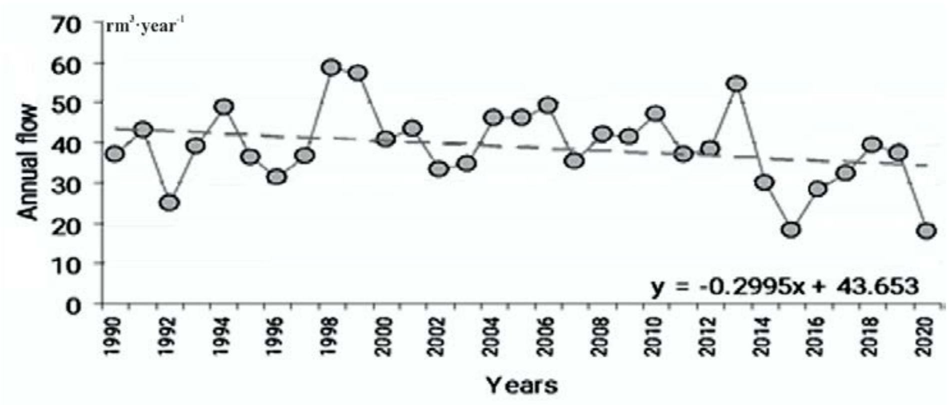

Fig. 2. Average annual flow of the Dnieper River

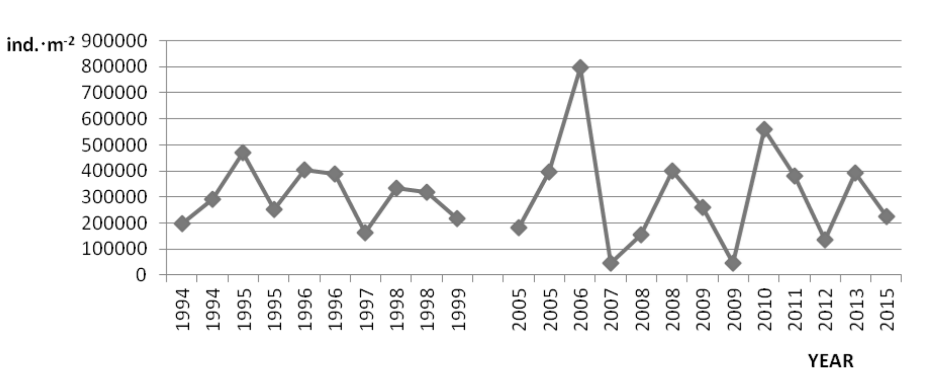

Fig. 3. Interannual dynamics of the total abundance (ind. m^{-2}) of meiobenthos in the Northwestern part of the Black Sea

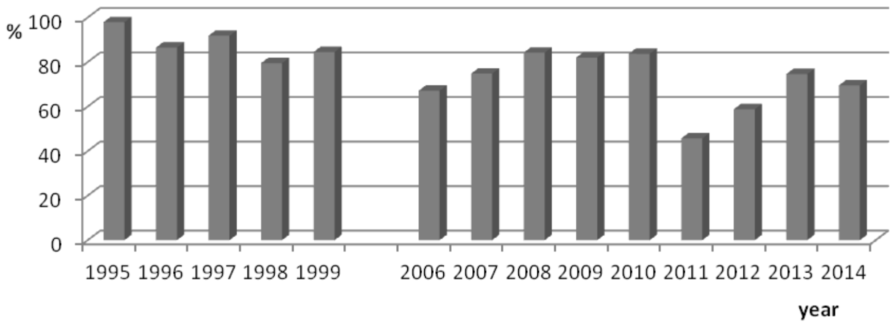

Fig. 4. Proportion (%) of organisms of the foraminiferal-nematode complex in the total abundance of meiobenthos in different years in the Northwestern part of the Black Sea

During these years the abundance of meiobenthos was the highest due to the mass development of small organisms with a short development cycle (Fig. 3).

As indicated, the analysis of long-term data showed that in these years the protozoa (foraminifera) and nematodes had the greatest development. It should be noted that, for example, in 2006, these two groups of eumeiobenthos accounted for 76.2% of the total number of meiobenthos. Among the representatives of temporary component of the meiobenthos only oligochaetes and polychaetes achieved insignificant development.

Over 16 years of research, abnormal climatic conditions in our region have been observed several times, which reflected on the composition of higher taxa of meiobenthos (Fig. 4).

In 1994–1998, the transformed waters of the Dnieper River and the Southern Bug River had a significant impact on the development of biological processes in the near-surface layers of the NWBS, including the Odessa

Sea Region. The increased temperature of sea water and the runoff of the Dnieper River during this period (Fig. 2), contributed to the saturation of water with suspended and dissolved organic substances. The accumulation in the near-bottom layers (at the bottom) of a large amount of allochthonous and autochthonous organic substances led to the development of hypoxia (Garkavaya, and Bogatova 2006).

An analysis of the ecological situation and the quality of the marine environment in the bottom layers by meiobenthic indicators showed that the anthropogenic press led to an extremely high eutrophication of the considered water area. The scientific literature provides evidence that, under extremely unfavorable conditions in the bottom layers of eutrophic waters, foraminifera can be the dominant group of meiobenthos in terms of abundance. For several decades, monitoring studies of the quality of the marine environment in the NWBS have indicated the dominance of the population density of representatives of the nematode-foraminiferal or foraminiferal-nematode complexes of meiobenthic organisms (Vorobyova 1999; Vorobyova, and Kulakova 2009).

At the end of the last century the formation of quantitative indicators of meiobenthos achieved their maximum in 1995–1996 and 1998. The meiobenthos was dominated by a foraminifera-nematode complex of organisms with a small amount of harpacticoids (Fig. 5, 6).

The average abundance of foraminifers ranged from 40,469.6 ind. m^{-2} to 178,926.3 ind. m^{-2}; the maximum indicators, as can be seen in the figure, are dated for 1995–1996 and 1998. The dominance of foraminifers in the meiobenthos indicates a high concentration of organic matter near the bottom and a very poor oxygen regime (hypoxia).

During the same three years, the maximum abundance of nematodes was typical (Fig. 7). Harpacticoids formed 0.7–9.1% in the Northwestern part of the Black Sea (1994–1996), and – 11–12% of the total number of meiobenthos in 1998–1999. The share of these three groups in the period of 1994–1999 was 92.3–98.9%. Other representatives of the meiobenthos were noted in the samples as single specimens.

As the analysis of the material showed at the end of the last century and in the first decade of the present,

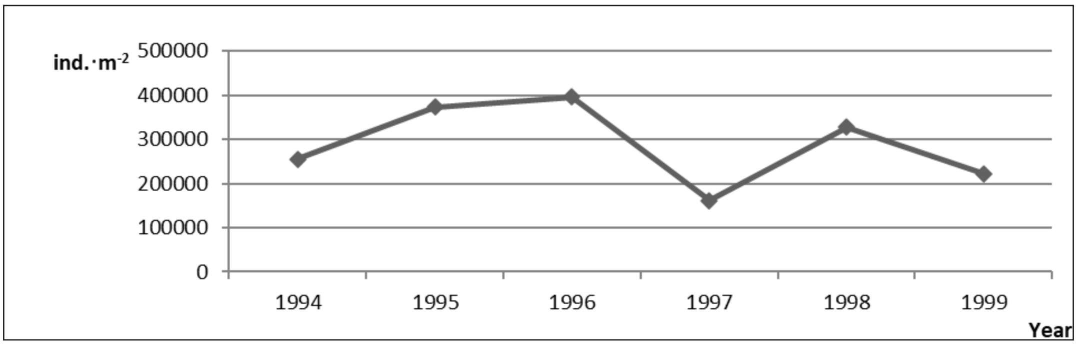

Fig. 5. Long-term dynamics of the total abundance (ind.m^{-2}) of meiobenthos in the Northwestern part of the Black Sea

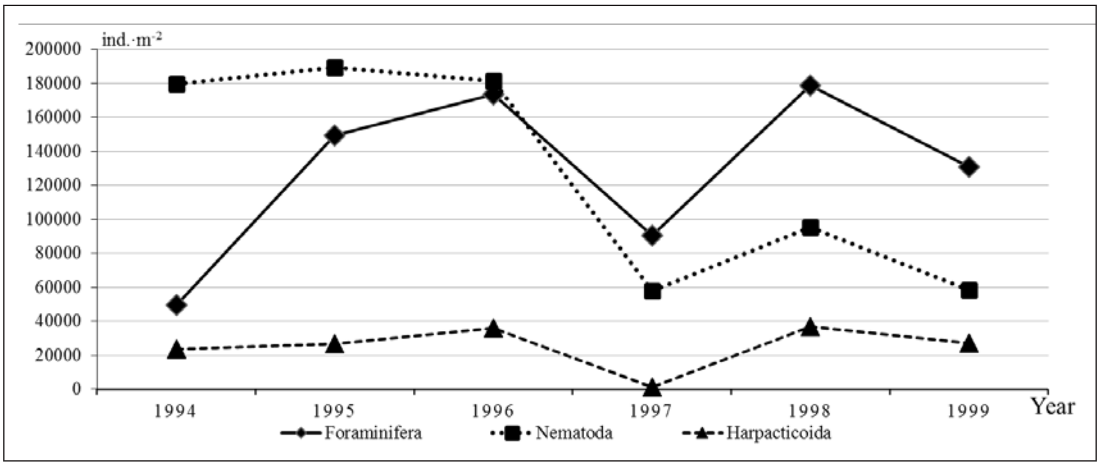

Fig. 6. Long-term dynamics of the abundance (ind.m^{-2}) of Foraminifera, Nematoda and Harpacticoida the Northwestern part of the Black Sea

the nematode-foraminiferal complex of organisms prevailed in the meiobenthos. However, it can be stated that in 2005–2015 the state of the environment in the bottom layer improved somewhat compared to the end of the last century.

As we can see, in 2005–2006, foraminifers played the greatest role in the formation of the total abundance of meiobenthos, accounting for 59% of its total abundance. In the remaining ten years, the proportion of foraminifers in the total abundance of meiobenthos was low (up to 5%); in 2009 and 2015 it was 11% and 12%, respectively. It can be assumed that in 2005–2006 the mass development of unicellular algae in the near-surface water layers was the strongest, and in the bottom layer the accumulation of organic matter was higher than in 2009–2010. And this contributed to the massive development of protozoa in the meiobenthic community of organisms. Thus, the foraminiferal-nematode complex of organisms prevailed in 2005–2006, whereas the nematode-harpacticoid complex took place in 2009–2010.

Having compared the foraminifers' proposition during summer periods in other years, we could conclude that the maximum abundance of foraminifera in this period was typical only for 2005–2006 (Fig. 9).

Nematodes dominated in abundance during 2005–2015, making up most of the total abundance (55.5–80%) of meiobenthos and only in 2011 it was 48% of the total abundance. Most species are characterized by a mixed diet. For this, in the NWBS, hypereutrophication creates favorable conditions for the mass development of free-living marine nematodes. The density of nematode settlements reached its maximum values precisely in anomalous years. In 2006 it was 447.086.4±86.885.7 ind. m^{-2}. In 2010 it was the same as in 2006 – 445.762.5±63.305.3 ind. m^{-2}. In all other years, it was many times lower (Fig. 10).

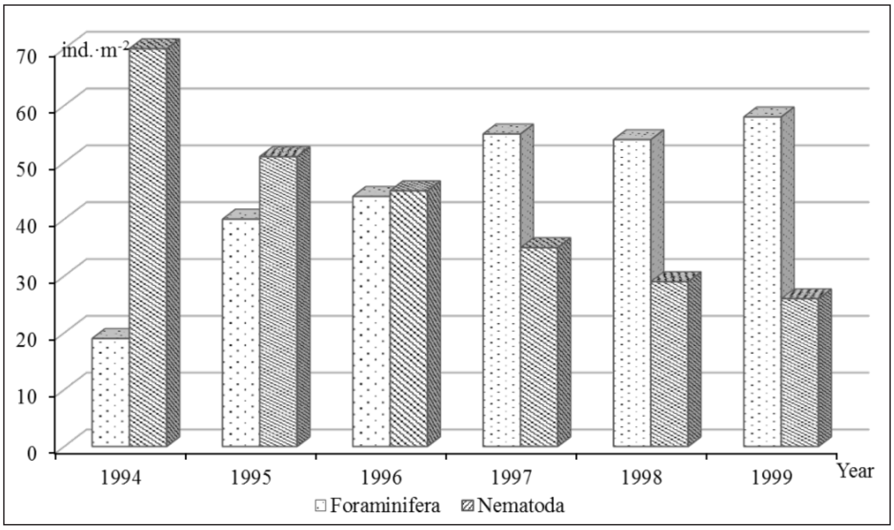

Fig. 7. The proportion of foraminifera and nematodes in the total abundance of meiobenthos the Northwestern part of the Black Sea

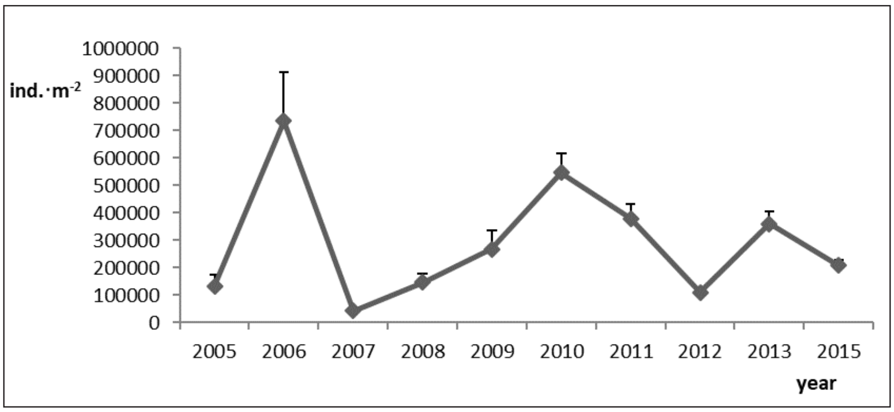

Fig. 8. Long-term dynamics of the abundance (ind.m^{-2}) of permanent meiofauna the Northwestern part of the Black Sea

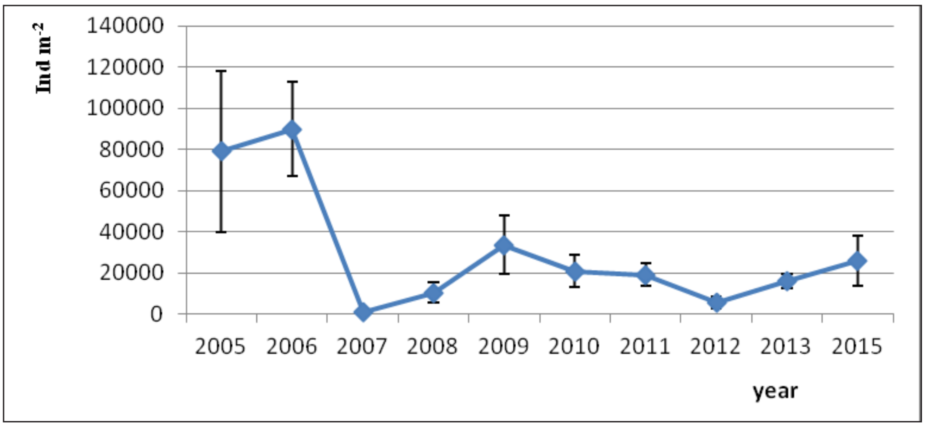

Fig. 9. Long-term dynamics of the abundance (ind.m^{-2}) of foraminifera in different years the Northwestern part of the Black Sea

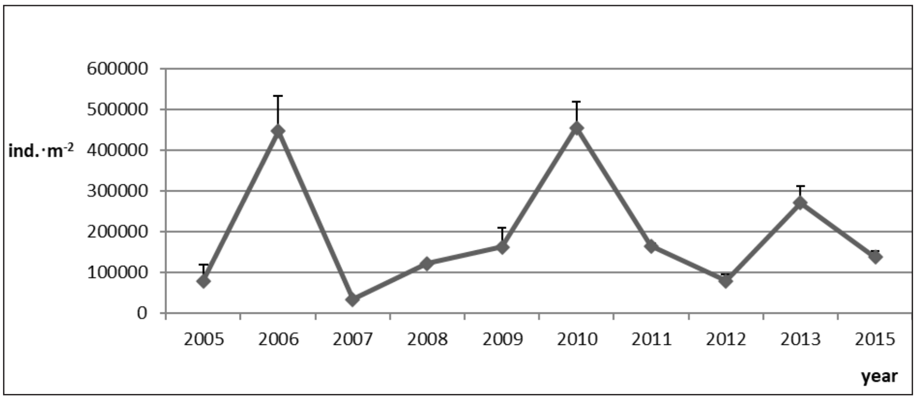

Fig. 10. Long-term dynamics of the abundance (ind.m^{-2}) Nematoda in different years in the Northwestern part of the Black Sea

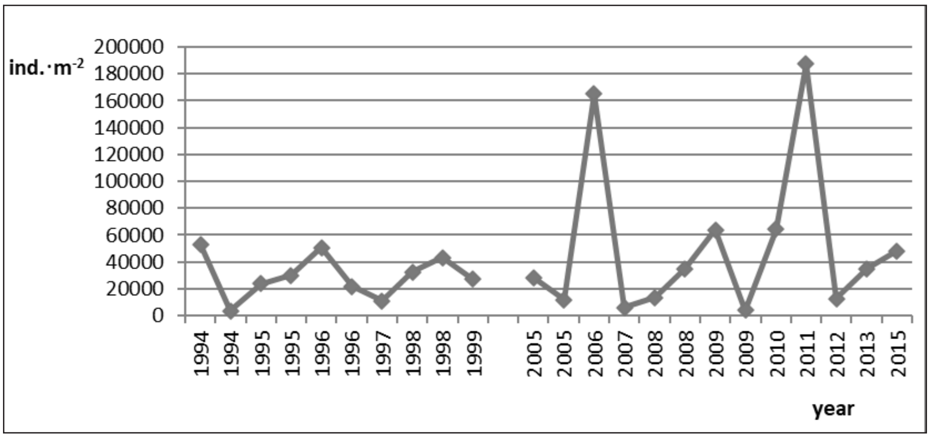

Fig. 11. Long-term dynamics of the abundance (ind.m^{-2}) Harpacticoida in different years in the Northwestern part of the Black Sea

Representatives of the taxocene Harpacticoida are a subdominant group of meiobenthos in terms of abundance. Their maximum numbers are typical for years associated with abnormal climatic conditions (Fig. 11). Their indicators in these years were sometimes 5–9 times higher than in all other years.

In anomalous years, mass sedimentation of microalgae (mainly diatoms) occurs from

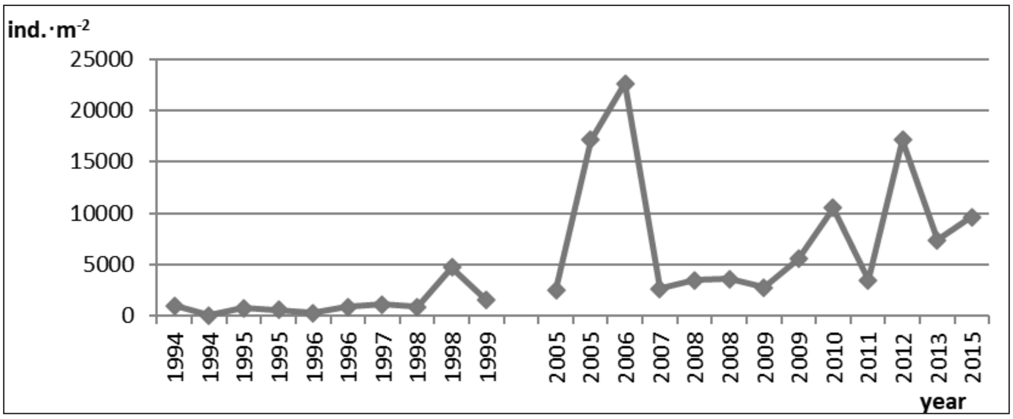

Fig. 12. Long-term dynamics of the abundance of Polychaeta (ind. m^{-2}) the Northwestern part of the Black Sea

the near-surface layers of the sea and their further decomposition. At the bottom, this process occurs with a high consumption of oxygen, the creation of hypoxia and the massive development of bacteria and protozoa. Harpacticoids are known to feed mainly on bacteria, protozoa, and diatoms. They collect them from detritus or nibble off algae from sand grains (Coull 1999; De Troch et al. 2005). It is indicated that under certain conditions, harpacticoid copepods can eat from 68% to 100% of the biomass of microphytobenthos (Carman et al. 1997). A favorable condition for copepods is the presence of a mixture (Lee et al. 1985) of microalgae (green and diatoms) and cyanobacteria. As the experiments have shown, the highest survival rate of harpacticoid copepods up to 100% is observed on diatom microalgae due to their high nutritional value for crustaceans (Coull 1999). In 2011 their dominated in the meiobenthic community (average abundance 178.130.5±42.484.7 ind. m^{-2}).

However, it can be stated that in 2005–2015 the quality of the environment in the bottom improved compared to the end of the last century. All other representatives of large taxa (Ostracoda, Halacaridae, Kinorhyncha, Turbellaria, Gastropoda) played a very small role in the formation of the total abundance of meiobenthos. The extremely low abundances of crustaceans and juvenile mollusks or their absence indicate a sharp deterioration of environmental conditions and indicators of the food supply for juvenile fish in the bottom layers of water. This situation may affect the conditions of survival and further development of larvae and juveniles of the ichthyofauna.

The density of settlements of benthic foraminifers in the years with anomalous climatic characteristics was higher than in all other years. For example, in 2005 and 2006 their abundance was 78.994.5±39.006.1 ind. m^{-2} and 89.830.0±22.723.4 ind. m^{-2}, respectively, whereas in 2008 and 2009 their abundance decreased to 10.450.0±4.854.0 ind. m^{-2} and 32.642.9±14.153.6 ind. m^{-2}, respectively. Foraminifera played the greatest role in the formation of the total abundance of meiobenthos in 2005–2006 and 2009–2010.

The analysis of the material showed the nematode-foraminiferal complex of organisms prevailed in the meiobenthos at the end of the last century and in the first decade of the present. It can be stated, that in 2005–2015 the quality of the environment in the benthal zone improved partly compared to the end of the last century.

As can be seen from the Figure 11, the maximum density of harpacticoids is confined to the years of the highest temperatures of the surface layers of water and the runoff of the Dnieper River. Under these abiotic factors, a massive development of unicellular algae occurred, which, after dying off, settled to the bottom. This leads to the enriching of the bottom substrate with organic matter. The same is typical for long-term indicators of the abundance of juvenile polychaetes, which belong to the temporary meiobenthos, or pseudomeiobenthos (Fig. 12).

To assess the quality of the marine environment we used the ratio of nematodes to harpacticoids (N_{nem}/N_{harp} index). It is known from literature that N_{nem}/N_{harp} index can be an indicator of organic pollution, at which it greatly increases (Warwick 1981; Raffaelli, and Mason 1981). It is shown that in water areas with strong anthropogenic pollution, this indicator is very high. Our long-term studies in the waters of the northwestern shelf have shown that with a large amount of organic matter in the bottom layers of water and sediments, the concentration of dissolved oxygen is sharply reduced. The processes of hypoxia are developing. When the content of dissolved oxygen is below 4 mg/l, harpacticoids are found in small quantities (Vorobyova 1999). However, the development of nematodes remains at a high level. They become the abundance

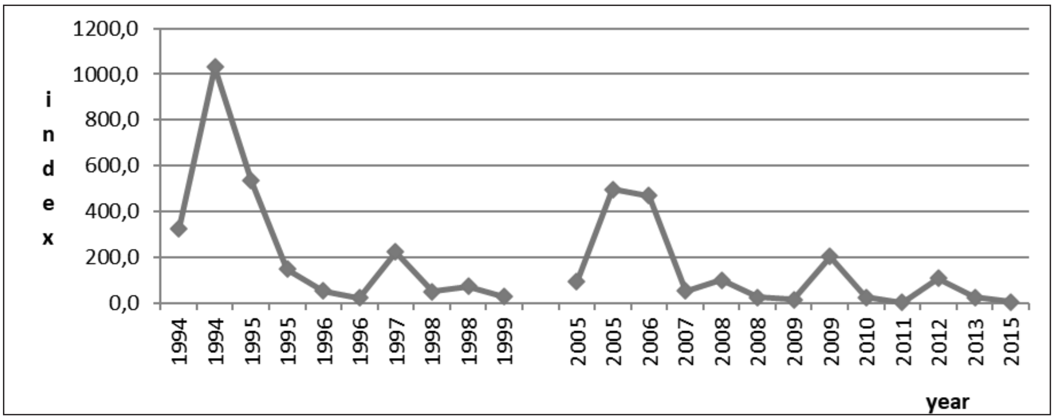

Fig. 13. Ratio of nematodes to harpacticoids (N_{nem}/N_{harp} index) in the Northwestern part of the Black Sea in 1994–2015

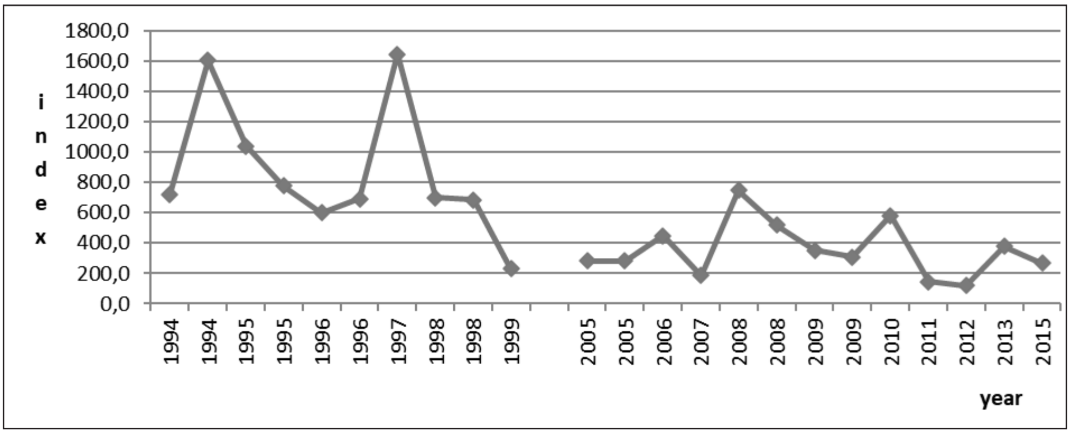

Fig. 14. Ratio of total abundance (ind m^{-2}) and biomass (mg m^{-2}) (N_{tot}/B_{tot}) of meiobenthos in the Northwestern part of the Black Sea

group of meiobenthos. Thus, in 1994, the average index of the N_{nem}/N_{harp} index was 748.7. At the same time, the average abundance of nematodes (180.310 ind. m^{-2}) and foraminifers (146.500.0 ind. m^{-2}) totaled for 89.3% of the total abundance of meiobenthos. In 1998, the abundance of nematodes (996.014) and foraminifers (183.386.0 ind. m^{-2}) were 85% of the total abundance of meiobenthos. In 2005–2006, the values of N_{nem}/N_{harp} index were 497 and 469, respectively, in 2009 – 2004, and in 2015 under normal climatic conditions the index was only 6 (Fig. 13).

When comparing the N_{nem}/N_{harp} index values with the abundance of harpacticoids and the total abundance to the total biomass of meiobenthos over 15 years we can say that the ecological situation of the marine environment in the NWBS in the current century has slightly improved compared to the end of the last century. This is also evidenced by a significant increase in the density of harpacticids settlements. During unfavorable period, the total abundance of meiobenthos increases sharply, and its biomass indicators decrease. The ratio of total abundance and biomass (N_{tot}/B_{tot}) indicates the mass development of small, short-cycle taxa which are represented by foraminifera and nematodes in our case. Thus, in 1994 this index was 1252.1, in 1997 – 1644.6; and it was reduced to 229.3 in 1998. In 2006, this index was 446.5, in 2010 – 583, in 2012 – 118.2 (Fig. 14).

Conclusions

The study of the ecological state of the water column and bottom layers of water in the NWBS for 15 years made it possible to focus on changes in the meiobenthos parameters under abnormal climatic conditions. An analysis of the indicators of meiobenthos showed that at the ecological situation in the considered water area slightly improved in 2005–2015 compared to the late 1990-s. At the same time, this water area remains to be a eutrophic zone. This is especially true for the bottom area. Our long-term observation of the formation of the meiobenthic community of organisms showed that under constant anthropogenic impact, the species diversity of meiobenthos in the NWBS is sharply reduced, the dominance of the main groups (foraminifera and nematodes) (Vorobyova 1999). Previously, in the poligon Odessa sea region, it was shown that at a depth of more than 10 m, nematodes dominate on all types of bottom sediments (Vorobyeva et al. 2017). The present data show that during years with anomalous climatic conditions, the N_{nem}/N_{harp} index and the total number of meiobenthos increases, whereas the biomass decreases. These trends are typical for many marine ecosystems (Odum 1986). Biological processes that occures under anomalous climatic conditions in the water areas increase the negative consequences for the state of the marine environment and the development of benthic communities of invertebrates. It will take more than one year with normal climatic indicators to improve the situation. Over time, transformation of organic matter will occur due to the work of bacteria and benthic invertebrate animals. In addition, organic matter coming from the pelagic zone will be partially buried in bottom sediments.

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МЕЙОБЕНТОС ЧОРНОГО МОРЯ В АНОМАЛЬНИХ КЛІМАТИЧНИХ УМОВАХ

Воробйова Л.В., д.б.н., проф.

ДУ «Інститут морської біології Національної академії наук України»

Большаков В.М., к.геогр.н., с.н.с.

ДУ «Інститут морської біології Національної академії наук України»

Наведено результати аналізу багаторічних досліджень мейобентосу північно-західного шельфу Чорного моря (1994–1999 та 2005–2015 рр.). Показано, що формування мейобентосного угруповання залежить не тільки від таких факторів середовища, як тип субстрату, солоність, кисневий режим і глибина. На формування його якісних і кількісних характеристик впливають також періодичні зміни кліматичних умов. Ці зміни пов'язані зі зміною процесів, що відбуваються в приповерхневих шарах морських акваторій. У статті розглянуто динаміку показників мейобентосу за 15 років у північно-західній частині Чорного моря (Одеський район). Враховано температуру поверхневих шарів води, динаміку опадів, стік р. Дніпро. Описана міжрічна динаміка загальної чисельності мейобентосу та окремих його великих таксонів (Foraminifera, Harpacticoida, Polychaeta). Отримані дані свідчать, що для років з аномальними кліматичними умовами характерні максимальні показники, співвідношення нематода-копепод зростає, при цьому загальна кількість мейобентосу зростає, а біомаса зменшується. Метою цієї статті є опис формування кількісних показників мейобентосного угруповання в аномальних кліматичних умовах. Проведені нами багаторічні спостереження за формуванням мейобентосу показали, що в умовах хронічного постійного антропогенного впливу видове різноманіття мейобентосу ПЗЧМ різко скорочується, спостерігається домінування основних груп (форамініфер і нематод).

Ключові слова: Чорне море, північно-західний шельф, мейобентос, кліматичні аномалії.