Microphytobenthos Diatoms of the Black Sea: Biodiversity and Ecology

LARISA I. RYABUSHKO, DARIA S. BALYCHEVA, VITALY I. RYABUSHKO

Kovalevsky Institute of Marine Biological Research RAS, Sevastopol, Russia
*Corresponding author: email: larisa.ryabushko@yandex.ru

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Abstract
The results of original studies (1987–2016) of the floristic composition of diatoms of natural and anthropogenic substrates in different regions of the Black Sea at depths of 0–53 m are summarized. 350 taxa of Bacillariophyta were identified, 77% from them are benthic, 57%–marine, 29%–boreal and 25%–boreal-tropical. In the epilithon, 140 taxa were found, in the epiphyton of macrophytes–254, the epizoon of the mussel Mytilus galloprovincialis Lam.–154, on the skin of dolphins–10 and in the periphyton of anthropogenic substrates–194. The Сzekonowsky-Sörensen coefficient of species similarity depending on the ecotope varied from 54 to 64%.

In both ecotopes of epizoon and periphyton 28 species were common. The maximum values of abundance (N), biomass (B) and the Shannon index of species diversity (H) of diatoms in all ecotopes were observed in the winter-spring season: epilithon – N=416•10³ cells•cm⁻², B=0.4 mg•cm⁻², H=1.89; epiphyton – N=366.3•10³ cells•cm⁻², B=0.82 mg•cm⁻², H=3.03; epizoon – N=179.3•10³ cells•cm⁻², B=0.54 mg•cm⁻², H=3.81; periphyton at exposure of experimental plates from 1 to 13 months – N=2180.8•10³ cells•cm⁻², B=0.543 mg•cm⁻², H=0.97–3.67 and with monthly exposure – N=1229•10³ cells•cm⁻², B=0.35 mg•cm⁻², H=1.1–3.5. The questions of similarity and dissimilarity of qualitative and quantitative characteristics of microphytobenthos diatoms in different ecotopes and areas of the Black Sea are discussed.

Key words: diatoms, microphytobenthos, epilithon, epiphyton, epizoon and periphyton ecotopes, the Black Sea, Crimean coastal waters.

Introduction
Diatoms play an important role in the balance of matter and energy in functioning marine ecosystems. They are the first to react to changes in ecological conditions of the environment, being in constant interaction and mutual influence, maintaining the balance of matter and energy in marine ecosystems. The benthic diatoms as taxonomic group of microalgae are the most widely represented in all of the Black Sea and of the seas the World Ocean as a whole (Ryabushko 2013). They have a wide adaptive potential for changes in environmental conditions, including temperature, salinity, eutrophication and pollution of coastal waters by various toxicants. Considering that diatoms are bioindicators of the ecological state of the water quality of marine areas, a wide study of the species diversity and quantitative characteristics of microphytobenthos is of particular interest.

Diatoms were found on almost all types of natural ecotopes (stones, sand, mud, shell rock, macrophytes, bivalves and gastropod mollusks, crustaceans, skin surfaces of dolphins) and anthropogenic
substrates in the sea (Proskina-Lavrenko 1963; Kucherova 1975; Ryabushko 2013; Balycheva 2014a, b; Balychev & Ryabushko, 2016; Ryabushko & Begun, 2015). The analysis of the species diversity of microphytobenthos diatoms of the Black Sea showed that their study on natural substrates was given to a greater extent than on anthropogenic substrates introduced into the sea by humans.

Species composition of microphytobenthos diatoms were most studied in the Black Sea (Proskina-Lavrenko 1963; Kucherova 1975; Bodeanu 1988-1989; Chepurnov, 1988; Guslyakov et al. 1992; Ryabushko 1991, 1993; 1994a, b, 2013; Petrova-Karadzhova & Temniskova-Topalova 1994; Ryabushko & Ryabushko, 2001; Guslyakov 2002; Balycheva 2014a, b; Nevrova 2015). However, data on the seasonal dynamics of quantitative characteristics of benthic diatoms in different ecotopes of the sea, their ecological and production role in the microphytobenthos of the Black Sea are still not enough investigated (Bodeanu 1988-1989; Ryabushko 2013; Ryabushko et al. 2013a-c, 2014; Balycheva 2014a, b). Therefore, the synthesis of own results and published data is important for revealing general patterns in the distribution of benthic diatoms in different ecological conditions and ecotopes of the sea, using a single methodological approach and similar methods of research.

The aim of the work is to generalize and compare the results of the study of species diversity and seasonal dynamics of qualitative and quantitative characteristics of the diatom communities on natural and anthropogenic substrates of the Black Sea.

Material and Methods

The essence of the methodology of the study is using of unified sampling methods, processing and analysis of material, including the study of the floristic and quantitative distribution of populations and communities of diatoms on different substrates and depths in different areas of the Black Sea. Sampling of microphytobenthos was carried out in the northwest (Zernov's Phyllophora Field, Karkinitsky Gulf and Cape Tarkhankut), northeastern (Caucasian coastal area) and Crimean coastal waters of the Black Sea for the period 1987–2016 at depths of 0 to 53 m (Fig. 1A-C).

![Sampling map on the Zernov’s Phyllophora Field (A), of the Gelendzhik and Kruglaya bays (B), of the Crimean coastal waters (C) of the Black Sea.](image-url)
The water temperature varied from 4 (February) to 28°C (August) in the different regions of study of the microphytobenthos diatoms of the Black Sea.

Ecological, floristic and quantitative indices of diatoms were studied in different ecotopes in the Crimean coastal waters. The seasonal dynamics of species richness (S), abundance (N), biomass (B) and Shannon index of species diversity (H) of diatoms of epilithon were studied in the Karantinnaya Bay in 1988–1989, 2000–2001 and 2007–2008. In the Kazach’ya Bay, similar studies were carried out for Gracillaria verrucosa (Hudson) Papenf. epiphyton in during 1988–1989 at depths of 1–3 and 5–7 m, as well as the for the mussel Mytilus galloprovincialis Lam. epizoon at a depth of 0.5: 2.5 and 4.5 m and near the Karantinnaya Bay at 6 m in 2015–2016 (Fig. 1c), as in periphyton of glass plates exposed to the sea at different terms (from day to 13 months) near the Karantinnaya Bay for the periods 2007–2008 and 2011–2012. In addition, floristic study of the species composition of diatoms on of bottlenose dolphins skin, molluscs, of macrophytes epiphyton, epilithon and periphyton of anthropogenic substrates were carried out in the Crimean and Caucasian coastal waters.

For a comparative analysis of the species lists that were found in these ecotopes of the Black Sea, the coefficient of floristic similarity of Czekanovský-Sørensen (Ks) was used. Quantitative counting of diatoms cells was carried out in the Goryaev chamber, 0.9 mm² in light microscopes BIOLAM L-212 and Axioskop 40 with AxioVision Rel. 4.6 with magnification from 400 to 2500 times. Also oil immersion lenses (90x and 100x) were used. The classification system of diatoms was used according to (Round et al., 1990) and others authors. Photo and microphotographs of diatoms were made with light and electron scanning microscopes. The calculation of abundance, biomass and richness of species, that is the number of species obtained in the counting of diatom cells in the chamber, as well as the Shannon species diversity index were carried out according to the procedure described in the work (Ryabushko et al. 2003; Ryabushko 2009, 2013).

Results and Discussion

Long-term studies of microalgae in different regions and ecotopes of the Black Sea showed that benthic diatoms are the most studied and predominant group of the microphytobenthos. According to our own and literature data, 832 microalgae taxa were listed in the benthos of the Black Sea, belonging to 3 classes, 32 orders, 64 families, 138 genera, 650 species (Ryabushko, 2009). Including 350 taxa of diatoms belonging to the 3 classes of the Bacillariophyta, that were found during the period of our investigations, 77% from them were benthic forms, 16% – benthoplankton and 7% – planktonic that occur periodically in benthic communities (Ryabushko, 2013; Balycheva, 2014a, b; Balycheva, Ryabushko, 2016).

The main mass species are colonial diatoms: Achnanthas brevipes C. Agardh, A. longipes C. Agardh, Ardissonoea crystallina (C. Agardh) Grun., Berkeleya rutilans (Trent.) Grun., Liciophora abbreviata C. Agardh, L. dalmatica (Kütz.) Grun., L. flabellata C. Agardh, Navicula ramosissima (Agardh) P. Cleve, Neosynedra provincialis (Grun.) Will. et Round, Parlibellus delognei (V.H.) E.J. Cox, Striatella unipunctata Lyngb.) C. Agardh, Tabularia fasciculata (C. Agardh) Will. et Round, Undatella quadrata (Breb.) Paddock and single-living species: Amphora hyalina Kütz., A. proteus Greg., Cocconeis costata Greg., C. scutellum Ehrenb., Cylindrotheca closterium (Ehrenb.) Reim. et Lewin, Halamphora coffeiformis (C. Agardh) Levkov, Navicula ammophila var. intermedia Grun., N. pennata var. pontica Mereschk., Nitzschia hybrida f. hyalina Proschk.-Lavrenko, N. tenerostris Mereschk., Pleurosigma elongatum W. Smith, Seminavis ventricosa (Greg.) M. Garscia-Baptista, Trachyneis aspera (Ehrenb.) P. Cleve and others.

In addition to floristic composition, the analysis of ecological and geographical characteristics of diatoms as well as seasonal dynamics of abundance and biomass in different ecotopes of the Crimean coastal waters of the Black Sea has been carried out. With respect diatoms species to the salinity of the water, 57% were marine, 24% – brackishwater-marine, 10% – brackishwater, 6% – fresh-brackishwater and 3% – fresh. By phytogeography boreal species made up 29%, boreal-tropical – 25%, arctic-boreal-tropical – 19%, cosmopolites – 18% and arcto-boreal – 10%.

Let us consider the composition and the quantitative distribution of diatoms by their ecotopes.

Epilithon. 140 taxa of diatoms were found, 90% from them were benthic forms. In the winter-spring season colonial forms predominated in the community of diatoms epilithon. These were genera: Liciophora C. Agardh, Gomphonemopsis Medlin, Tabularia (Kütz.) Will. et Round, Achnanthas Bory, Melosira C. Agardh and species of B. rutilans, Berkeleya micans (Lyngb.) Grun., N. hybridra f. hyalina, P. delognei, N. provincialis, N. ramosissima, N. ammophila var. intermedia, St. unipunctata, T. fasciculata. In the summer, single-living
species of genera *Cocconeis* Ehrenb., *Amphora* Ehrenb., *Halamphora* (Cleve) Levkov, *Navicula* Bory emend. E.J. Cox, *Undatella* Paddock et Sims, *Carinasigma* G. Reid, *Pleurosigma* W. Smith, *Cylindrotheca* Rabenh. emend. Reim. et Lewin and *Nitzschia* Hass, were more common.

29 taxa of diatoms were found in Karantinnaya Bay during the period 1988–1989. 24% of them were araphales, living attached and 76% were raphales single-living species capable to move along the substrate. The richness of species (*S*) varied from 13 to 18. 12 species occurred year-round. 10 dominant species by abundance and biomass were noted. The index of the species diversity (*H*) varied from 1.5 to 1.89. From April to the middle of May at close to the winter months water temperature (from 9 to 13°C), the maximum abundance of diatoms was $4 \times 10^3$ cells•cm$^{-2}$ with biomass of 0.4 mg•cm$^{-2}$ (Fig. 2A).

The main contribution to the overall biomass of the epilithon diatoms community in the Karantinnaya Bay was made by the genera *Nitzschia*, *Amphora* and *Navicula*, which account for 63% of their total annual biomass. The abundance of dominant species was: *N. ramosissima* – 38.4•10$^3$ cells•cm$^{-2}$, *N. tenuirostris* – 22.0•10$^3$, *L. abbreviata* – 8.8•10$^3$ and *N. hybrida* f. *hyalina* – 5.2•10$^3$. In the summer the abundance was 18 times and biomass 9 times lower than in spring. At the same time, the number of dominant species decreased, which can be explained by the influence of high temperature and water illumination on the life cycles of some benthic diatoms.

For comparison with the quantitative data of previous years, a study of the epilithon diatoms from September 2000 to September 2001 was carried out similarly (Fig. 2B) in the closed part of the Karantinnaya Bay, separated by a pier from the sea. The water temperature in this part of the bay varied from 5 to 27°C (Fig. 3). A peculiarity of the coastal waters of the Black Sea is that the biological summer season here is the longest due to the warming up from May to October.

105 taxa of microalgae were found, including diatoms, 64 species during this period. During the annual dynamics, the contribution of diatoms is high enough (Fig. 4).

![Figure 2](image-url)  
**Figure 2.** Seasonal dynamics of abundance (**N**, cells•cm$^{-2}$) and biomass (**B**, mg•cm$^{-2}$) of epilithon diatoms and other microalgae in Karantinnaya Bay at 0.5 m, 1988–1989 and 2000–2001.

![Figure 3](image-url)  
**Figure 3.** Dynamics of water temperature in the Karantinnaya Bay of the Black Sea.
Figure 4. Ratio (%) of taxonomic groups of microalgae by biomass (B) and abundance (N) in epilithon of the Karantinnaya Bay of the Black Sea.

The abundance of microalgae in the epilithon of the Karantinnaya Bay varied from $40 \times 10^3$ to $250 \times 10^3$ cells cm$^{-2}$ and the biomass from 0.02 to 0.015 mg cm$^{-2}$ with an autumn maximum (Fig. 2B), caused by water temperature decreasing, and also by the greatest elimination of macrophytes at this time of the year, which stimulates microalgae development in the sea.

82 species of diatoms were found in 2007–2008 (Lee, Ryabyshko, 2010). The greatest contribution to the total abundance and biomass of diatoms was in spring (April) with 8 dominated species: *L. abbreviata*, *L. flabellata*, *Licmophora gracilis* (Ehrenb.) Grun., *N. ramosissima*, *N. provincialis*, *N. tenuirostris*, *St. unipunctata*, *T. fasciculata*. Their abundance varied from $(3.2–38.3) \times 10^3$ cells cm$^{-2}$, accounting for 80% of the total community. The maximum diatoms abundance ($92.0 \times 10^3$ cells cm$^{-2}$) was recorded in June at a sea water temperature of 17°C due to the benthoplanktonic species *N. tenuirostris* (62%). In April biomass peak (0.19 mg cm$^{-2}$) was recorded at water temperature of 12°C.

A comparative analysis of the data was made to determine the general patterns in the distribution of epilithon diatom communities at the depth of 0.5 the Black Sea (Karantinnaya Bay) and the Sea of Japan (Vostok Gulf) at the same geographical latitude (Ryabushko 2013, Ryabushko et al. 2013; Ryabushko Begun, 2015). It was found that in winter low water temperatures, a sufficient number of nutrient elements, a long day, increasing from month to month, the activity of invertebrates at this time of the year created favorable conditions for the development of many species of diatoms microphytobenthos of the Black Sea and Sea of Japan. At this time, diatoms cells were characterized by the best conditions for their vegetation, a high content of photosynthetic pigments and an almost complete absence of dead cells compared to other seasons of the year. Colonial fouling species of the genera *Berkeleya*, *Licmophora*, *Tabularia* and others predominated.

In spring, the average annual abundance of microphytobenthos in 12 times, and biomass in 5 times were higher in the Karantinnaya Bay than in the Vostok Gulf. This is determined by the wide range of variation of the quantitative values associated with fluctuations in the water temperature in shallow water. However, the maximum values of abundance and biomass of the benthic diatoms in both water areas, marked in spring. In the Vostok Gulf abundance in 5 times was lower and biomass in 2 times was higher ($N = 83 \times 10^3$ cells cm$^{-2}$ in March and $B = 0.8$ mg cm$^{-2}$ in May) than in the Karantinnaya Bay ($N = 416 \times 10^3$ cells cm$^{-2}$ in May and $B = 0.4$ mg cm$^{-2}$ in April).

In summer, in both areas, the number of fouling species decreased. In the Black Sea from spring to autumn, the proportion of small cells increased and the quantity of diatoms decreased, which is typical for coastal eutrophic waters of the Karantinnaya Bay. In the warm seasons of the year, the number of single (attached and mobile) forms increased, and the microphytes colonies decay. From spring to summer, the illumination and temperature of water in the sea increased, which affects the characteristics of the photosynthetic apparatus in the cells of microalgae. Under experimental conditions, it was shown that when the illumination increased from 2 to 10 kilolyuks and the water temperature from 10 to 30°C, the number of living microphyte cells decreased (Kurayshevich & Kozitskaya, 1992). The intensity of the illumination of water affects both the general biomass (Round 1971) and the density of epibenthic diatoms (McLachlan & Lewin 1981). However, not all species of algae react to this environmental factor in the same way.
In summer, the hydrological and hydrochemical situation in the sea is characterized by instability, which also affects the structure of microphytobenthos communities and its individual components. Therefore, depending on the combinations of environmental factors, structural indicators of benthic communities the species composition of dominants changed. During this period, the number of dead individuals increases, which is associated with both high insolation in shallow water and with the elimination of diatoms by invertebrates (Ryabushko 1993). Reduction in total numbers of species and an increasing of amount of dead diatoms during this period are also noted for freshwater epilithon and epiphytic littoral communities (Huang & Boney, 1985).

In autumn, the difference in water temperature in the coastal part of the two seas (lower in the Sea of Japan), the average values of the diatoms in the Vostok Gulf were higher than in the Karantinnaya Bay and the highest indicators in these regions were observed in December. In the summer-autumn period, competition for the substrate between diatoms, green microalgae and cyanobacteria, as well as macrophytes, intensifies in comparable water areas. Macrophytes seedlings replace diatoms on the stones and later themselves become a substrate for diatoms fouling. This trend is also characterizes of fresh periphyton, where diatoms, cyanobacteria and green microalgae in the first half of summer predominated (Stanislavskaya, 1987). Probably, for epilithic fresh and marine algae communities, there are similar seasonal changes in the composition and quantitative distribution of species. In general, diatoms species diversity in the Karantinnaya Bay in 2 times and abundance in 6.5 times higher than the Vostok Gulf.

The common features of the similarity of the diatom flora of the two seas are manifested in a pronounced of abundance and biomass increasing in the winter-spring period and competition for the substrate between diatoms and other algal groups in the summer season. According to the trophicity, the investigated water areas differ among themselves: the Vostok Gulf belongs to the mesotrophic reservoir, and the Karantinnaya Bay – to the eutrophic one. Differences in the salinity of the two compared water areas determine the ecological characteristics of the microalgae species composition. Mesogalob species prevail in the Karantinnaya Bay, and polygalob are found in the Vostok Gulf.

**Epiphyton.** 254 taxa of diatoms were registered in the epiphyton of 48 macrophytes species. From them, 69 diatoms species were found on the red algae, including 60 species in the epiphyton of 4 species of *Phyllophora*; 53 species of diatoms were found in epiphyton of the green algae; 67 species – on the brown algae, 50 diatoms taxa – on 2 species of *Cystoseira* C. Agardh and also 34 – in the epiphyton of the sea grass *Zostera marina* L. (Ryabushko 2013; Ryabushko et al. 2013).

157 taxa of diatoms were found in the epiphyton of macrophytes in the region of the Zernov’s Phyllophora Field (Ryabushko 1991, 2013). 15 common species of benthic diatoms were identified in the epiphyton of all macrophytes.

In the Kazach’ya Bay, studies of the species composition and seasonal dynamics of the quantitative characteristics of diatoms were carried out in the epiphyton of *Gr. verrucosa* during the annual cycle in 1988–1989 at various depths of 1–3 and 5–7 m. 94 taxa of Bacillariophyta were found, including 26 dominant species. Depending on the season, the number of species varied from 43 to 55.

In the winter-spring period colonies of diatoms abundantly occurred, the maximum quantitative indices were recorded in the spring at $N = 366.3\times10^3$ cells$\cdot$cm$^{-2}$, $B = 0.82$ mg$\cdot$cm$^{-2}$ (Fig. 5). The Shannon index of the species diversity ($H$) varied from 2.65 to 3.03. *N. hybrida* f. *hyalina* reaches mass development. The species *B. rutilans*, *Gyrosigma prolongatum* var. *closterioides* (Grun.) P. Cleve, *L. abbreviata* and *Navicula directa* (W. Smith) Ralfs prevail by biomass and abundance.

In the summer, the quantitative indices of diatoms were unstable due to the variety of environmental conditions typical for the extended warm season. In the autumn, increasing of the richness of diatom species was observed with the sea water temperature decreasing.

**Epizoony.** 154 taxa of diatoms were found on the surface of marine animals, including the shells of the *M. galloprovincialis* and the bottlenose dolphins skin. In the winter-spring period (6–16°C) the colonial species *L. flabellata*, *L. abbreviata*, *T. fasciculata*, *Tabularia tabulata* (C. Agardh) Snoeijis, *Ar. crystallina*, *St. unipunctata* and others prevailed. In summer, as the temperature grows to 25°C single-living species were noted in mass. These were the genera *Amphora* and *Nitzschia*. On the skin of bottlenose dolphins 10 species were recorded: *Halamphora granulata* (Greg.) Levkov, *Grammatophora serpentina* Ehrenb., *L. abbreviata*, *N. hybrida* f. *hyalina*, *N. teniurostris*, *T. fasciculata*, *Pl. elongatum*, *Rhabdonema arcuatum* (Lyngb.) Kütz., *Fragilaria* sp. and *Navicula* sp.
39 taxa of diatoms were found on the surface of the mollusk of Rapana venosa Valenciennes and mussel shells in the Zernov’ field. The quantitative indices of diatoms on mussels shells of different ages (0.5 to 10 years) were received in Kazach’ya Bay. S varied from 18 to 21, \( N = (6.0\text{–}830.0) \times 10^3 \text{cells} \cdot \text{cm}^{-2} \), \( B = 0.3\text{–}2.56 \text{mg} \cdot \text{cm}^{-2} \) (Fig. 6) and \( H \) varied from 3.28 to 3.57.

During February 2015 – February 2016 in the area of the cultivation farm of mussel Mytilus galloprovincialis near the Karantinnaya Bay at 6 m S ranged from 4 to 24, \( N = (5.8\text{–}73.8) \times 10^3 \text{cells} \cdot \text{cm}^{-2} \), \( B = 0.001\text{–}0.049 \text{mg} \cdot \text{cm}^{-2} \) with the maximum in February 2015 at water temperature of 9.7°C and \( H \) varied from 1.49 to 3.81.

Periphyton. 194 taxa of diatoms were found on the anthropogenic substrates (Ryabushko 2013, Balycheva 2014a). The experimental study of the species composition, dynamics of species richness, abundance and biomass of diatoms in the periphyton of glass plates in different seasons and exposure from 1 to 13 months were carried out for the periods 2007–2008 and 2011–2012 (Fig. 7, 8).

The annual means of diatoms abundance were 1.5 times higher at long exposure than at monthly. The maximum values were recorded in March 2007 \( (t=9.0°C) \) and January 2011 \( (t=11°C) \), mainly due to the massive development of colonial species of B. rutilans, A. longipes, St. unipuctata and L. abbreviata. In April and May, the abundance of diatoms declined regardless of the terms of substrates exposure. In the summer, fouling of glass plates with diatoms is less pronounced than in the winter-spring season, which is typical for other coastal ecotopes of the sea.
Figure 7. Periphyton of glass plates with exposure from 1 to 13 months in different seasons of 2007–2008 near the Karantinnaya Bay
The obtained results have shown that the substrates exposed in the sea can be studied in different seasons of the annual cycle of algae development – short or long-term, depending on the goals and objectives of the study. It has been experimentally established that the first settlers on an artificial substrate were the diatoms *L. abbreviata* and *N. ramosissima* (Castenholz 1963).

It was noted that the glass plates that stayed in the sea for 4 days were populated mainly by solitary and colonial diatoms, bacterial cells appeared on 12 days. In this case, the type of substrate and the season of the year play a decisive role.

The Czekanovsky-Sörensen coefficient of species similarity for all ecotopes varies from 54 to 64%. In both ecotopes of epizoon and periphyton 28 species were common with a predominance of benthic and benthoplankton forms.

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The Czekanovsky-Sörensen coefficient of species similarity for all ecotopes varies from 54 to 64%. In both ecotopes of epizoon and periphyton 28 species were common with a predominance of benthic and benthoplankton forms.

In the benthos of the Black Sea, more than 20 potentially harmful diatoms species, including toxic ones, have been found (Ryabushko 2003). Thus, a toxic species of *Pseudo-nitzschia calliantha* Lundholm, Moestrup et Hasle was found in the coastal waters of Sevastopol. From this species phytotoxin of domoic acid was isolated with a maximum value of 0.43 ng•cell$^{-1}$ (Besiktepe et al. 2008; Ryabushko et al. 2008), which is dangerous to humans, causing amnesiac mollusc poisoning (Maranda et al. 1990; Potentially … 2001).

Thus, studies have shown that the species composition of diatoms independently of the type of substrate is mainly formed by benthic species with a maximum of abundance and biomass in the winter-spring season at a water temperature 7.7–10°C with the massive growth of the colonial forms of diatoms.
Despite similar trends in the development of benthic diatoms in different ecotopes and regions of the Black Sea, there are differences due to the species composition, which forms communities under the influence of changes in hydrological and hydrochemical factors of the environment.

Conclusions

1. It has been established that the most studied and predominant group of the microphytobenthos of the Black Sea are Bacillariophyta.

2. In the microphytobenthos of the Black Sea 350 taxa of Bacillariophyta were found, 77 % from them were benthic forms, 16 % – benthoplanktonic and 7 % – planktonic. Marine species (57 %) were predominated. By geographical characteristics 29 % of species were boreal, 44 % – boreal-tropical and arcto-boreal-tropical and 18 % – cosmopolites.

3. 140 taxa were found in epilithon, in epiphyton of different macrophytes – 254, in epizoon of the mussel Mytilus galloprovincialis Lam. – 154, on the dolphin’s skin – 10, in periphyton of anthropogenic substrates – 194. In both ecotopes of epizoan and periphyton 28 species were common with a predominance of benthic and benthoplanktonic forms, some of them are mass colonial species A. longipes, B. paxillifera, L. abbreviata, L. flabellata, St. unipunctata, and single-living species of A. hyalina, C. costata, C. scutellum, C. closterium, H. coffeiformis and N. hybrida f. hyalina.

4. For all ecotopes of the sea the Czekanowsky-Sörensen coefficient of species similarity (Ks) varied from 54 to 64%.

5. The maximum values of abundance (N), biomass (B) and Shannon index (H) of diatoms amount in different ecotopes reached in epilithon – N = 416•10^3 cells•cm^-2, B=0.4 mg•cm^-2, H = 1.89; epiphyton – N = 366.3•10^2 cells•cm^-2, B = 0.82 mg•cm^-2, H = 3.03; epizoon – N = 179.3•10^3 cells•cm^-2, B = 0.54 mg•cm^-2, H = 3.81; periphyton at exposure of experimental plates from 1 to 13 months – N = 2180.8•10^3 cells•cm^-2, B = 0.543 mg•cm^-2, H = 0.97–3.67 and with monthly exposure – N = 1229•10^3 cells•cm^-2, B = 0.35 mg•cm^-2, H = 1.1 – 3.5.

6. In the microphytobenthos of the coastal waters of the Black Sea, the seasonal distribution of diatoms was established: increasing of abundance and biomass in the winter-spring season due to the predominance of colonial forms and their decrease in the summer-autumn.

References

Balycheva, D.S. (2014a) Species composition, structural and functional characteristics of microalgae periphyton of anthropogenic substrates in the Crimean coastal region of the Black Sea: Author's abstract. Dis. ... Cand. Biol. Sci., Sevastopol, 24 pp. (In Russ.)

Balycheva, D.S. (2014b) Seasonal quantitative dynamic of periphyton Bacillariophyta on the experimental glass slides monthly exposed in a coastal seawater area of the Crimea (the Black sea). J. on Algae, 24 (3), 229–236.

Balycheva, D.S. & Ryabyskho, L.I. (2016) Diatoms of anthropogenic and natural substrates in the Black Sea. Marine biological research: achievements and prospects, All-Russian Scientific-practical. Conf. Sevastopol’: ECOSI-Gidrofizica, 2, 18–21. (In Russ.).

Besiktepe, S., Ryabushko L., Ediger, D., Yilmaz, D., Zenginer, A., Ryabushko, V. & Lee, R. (2008) Domoic acid production by Pseudo-nitzschia calliantha Lundholm, Moestrup et Hasle (Bacillariophyta) isolated from the Black Sea. J. Harmful Algae, 7, 438–442.

Bodeanu, N. (1987–1988) Structure et dynamique de l’ algoflore unicellulaire dans les eaux du littoral Roumain de la mer Noire. Cercetări marine, no. 20/21, 250 pp.

Castenholz, R.W. (1963) On experimental study of the vertical distribution of littoral marine diatoms. Limnol. & Oceanogr., 8(4), 450–462.

Chepurnov, V.A. (1988) Benthic diatoms and harpactoids of the Black Sea stony shoal of the Karadag region and their food relations: Author's abstract. Dis. ... Cand. Biol. Sciences. Sevastopol, 25 pp. (In Russ.).
Guslakov, N.E., Zakordonets, O.A. & Gerasimyuk, V.P. (1992) Atlas of benthos diatoms of the north-western part of the Black Sea and adjoining reservoirs. Kiev: Naukova Dumka. 109 pp. (In Russ.).

Huang, R. & Boney, A.D. (1985) Huang Seasonal ecology of littoral epiphytic diatoms on Great Cumbrae Island. Trans. Bot. Soc. Edinburgh, 44(4), 309–322.

Lee, R.I. & Ryabyshko, L.I. (2010) Seasonal dynamics of the species composition and quantitative characteristics of epilithon diatoms of the Karantinnaya Bay as a function of the water temperature in the Black Sea. Monitoring and Environmental Systems. Sevastopol: MGI NASU, 215–221. (In Russ.).

Kucherova, Z.S. (1975) Dynamics of the number and biomass of diatoms in the cenosis of fouling. Biology of the Sea, 35, 67–73. (In Russ.).

Kurayshevich, A.V. & Kozitskaya, V.N. (1992) Effect of light and temperature regimes on the content of chlorophyll a in the biomass of algae. Algologia, 2(3), 37–41. (In Russ.).

Nevrova, E.L. (2015) Benthic diatoms (Bacillariophyta) of the Black Sea: diversity and structure of taxocenes of different biotopes: Author's abstract. Dis. ... Dr. Biol. Sci., Moskow, 46 pp. (In Russ.).

McLachlan, A. & Lewin, J. (1981) Observations on Surf phytoplankton blooms along the coasts of South Africa. Bot. Mar., 24(10), 553–557.

Maranda, L., Wang, R., Masuda, K. & Shimuzu, Y. (1990) Investigation of the source of domnic acid in mussels. Toxic marine phytoplankton. New York: Elsevier, pp. 300–304.

Petrova-Karadzhova, V.I. & Temniskova-Topalova, D. (1994) Dynamics of the number of benthic Bacillariophyta of the Bulgarian shelf of the Black Sea. Algologia, 4(4), 36–40. (In Russ.).

Potentially Harmful Microalgae of the Western Indian Ocean (2001). A Guide based on a preliminary survey, IOC, Manuals and Guides. № 41. UNESCO, 105 pp.

Proshkina, L.I. (1963) Diatoms of the benthos of the Black Sea, Moscow, Leningrad: AN SSSR, 243 pp. (In Russ.).

Round, F.E. (1971) Benthic marine diatoms. Oceanogr. Mar. Biol. Ann. Rev., 9, 83–139.

Round, F.E., Crawford, R.M., Mann, D.G. (1990) The Diatoms. Biology and morphology of the genera. Cambridge: Cambridge University. 747 pp.

Ryabushko, L.I. (1991). Diatoms are epiphytes of Gracilaria verrucosa (Huds.) Papenf. from the Black Sea. Algologia, 1(3), 53–60. (In Russ.).

Ryabushko, L.I. (1993) Structure of the Bacillariophyta community of the epiphyton Gracilaria verrucosa (Huds.) Papenf. from the Black Sea. Algologia, 3(3), 42–49. (In Russ.).

Ryabushko, L.I. (1994). Diatoms of the microphytobenthos of hard substrates of coastal regions of Sevastopol Bay (the Black Sea). Algologia, 4(2), 15–21. (In Russ.).

Ryabushko, L.I. (1996). Fouling diatoms on the benthic plants of the Black Sea by cape Omega. Hydrobiol. Journ., 32(2), pp. 15–22.

Ryabushko, L.I. (2003). Potentially harmful microalgae of the Black and Azov seas, Sevastopol: EKOSI-Gidrofizika (ECOSY-Hydrophysics), 288 pp. (In Russ.).

Ryabushko, L.I. (2009) Microphytobenthos of the Black Sea: Author's abstract. Dis. ... Dr. Biol. Sci., Sevastopol, 44 pp. (In Russ.).

Ryabushko, L.I. (2013) Microphytobenthos of the Black Sea, Sevastopol: ECOSI-Gidrofizica, 416 pp. (In Russ.).

Ryabushko, L.I., Begun, A.A., Lokhova, D.S. (2013a) Comparison of the species composition, ecological and phytoecographic characteristics of the diatom algae of periphyton of anthropogenic substrates from the Black and Japanese Seas. Izvestiya TINRO, 174, 234–246. (In Russ.).

Ryabushko, L.I., Firsov, Yu., Lokhova, D.S. & Eremin, O.Yu. (2013b) Composition, quantitative and production characteristics of phytoperiphyton glass plates for different periods of exposure in the Black Sea. Algologia, 23 (1), 69–81. (In Russ.).

Ryabushko, L.I. & Begun, A.A. (2015) Diatoms of the microphytobenthos of the Sea of Japan. In 1-2 volumes. Vol. 1, Simferopol': N. Orianda, 288 pp. (In Russ.).

Ryabushko, L.I. & Ryabushko, V.I. (2001). Microphytobenthos of Kazach'ya Bay of the Black Sea. Algologia, 11 (1), 70–82. (In Russ.).

Ryabushko, L.I., Balycheva, D.S. & Strizhak, A.V. (2013c) Diatoms epiphyton of some species of green macrophytes and periphyton of anthropogenic substrates of the Crimean coastal waters of the Black Sea. Algologia, 23 (4), 419–437. (In Russ.).
Ryabushko, L.I., Balycheva, D.S. Popovichev, V.N., Firsov Yu. & Ryabyshko, V.I. (2014) Production characteristics of phytoperiphyton of experimental glass plates and phytoplankton in the Karantinnaya Bay (the Crimean coastal area of the Black Sea). Algologia, 24 (4), 504–517. (In Russ.).

Ryabushko, L.I., Besiktepe, S., Ediger, D., Yilmaz, D., Zenginer, A., Ryabushko, V.I. & Lee, R.I. (2008) Toxic diatom *Pseudo-nitzschia calliantha* Lundholm, Moestrup et Hasle from the Black Sea: morphology, taxonomy, ecology. Marine Ecological Journal, 7(3), 51–60. (In Russ.).

Ryabushko, V.I., Aleev, M.Yu., Radchenko, V.N., Ryabyshko, L.I. & Chubchikova, I.N. (2003) The use of some bioindicators for assessing the state of impact marine ecosystems. Ecological safety of coastal and shelf zones and integrated use of shelf resources. Sevastopol, 2(7), 144–154. (In Russ.).

Stanislavskaya, E.V. (1987) Floristic composition of periphyton algae of different-type lakes of the Latgalsky upland: Tez. I All-Union Conf. «Actual problems of modern algology» (Cherkassy, Sept. 23-25, 1987). Kiev: Nauk. dumka, pp. 78–79. (In Russ.).