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BENTHIC MICROALGAE UNDER THE INFLUENCE OF BEACH NOURISHMENT IN THE GULF OF ODESSA (THE BLACK SEA)

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Abstract

Snigirova A., 2013: Benthic microalgae under the influence of beach nourishment in the Gulf of Odessa (the Black Sea) [Paplūdimių papildymo smėliu poveikis bentosinių dumblių bendrijoms Odesos įlankoje (Juodoji jūra)]. – Bot. Lith., 19(2): 120–128.

The coast of the Gulf of Odessa (Odessa Bay) in the north-western part of the Black Sea is exposed to abrasive processes, which lead to its destruction. One of the measures for landslides stabilization is sand nourishment, which was held on the beach of the gulf in October 2007. As a result of shore protection works, the sand grain size on the beaches of Odessa has decreased by 53% on average. The influence of sand grain size on the abundance and biomass of benthic microalgae was investigated. Benthic microalgae were presented mostly by Bacillariophyta and Dinophyta. Other groups of Chlorophyta, Cyanophyta and Cryptophyta were less presented. The abundance and biomass of algae increased threefold and fourfold, accordingly, as a result of sand nourishment. Significant influence of fine sand particles on the biomass and abundance of microalgae was revealed. However, the structure of algological assemblages changed because of the increase of mixotrophic groups of algae contribution.

Keywords: microphytobenthos, epipsammon, sand grain size, the Black Sea.

INTRODUCTION

Studies on microscopic algae are very relevant because of their role in the formation of primary production, nutrient cycle and energy. The benthic algae are the feed base for invertebrates and benthic fish. Most of them are indicators of ecological state of the water body (McCormick & Cairns, 1994) and take part in the processes of natural purification, which is significant on sandy beaches (Frantsev & Lebedeva, 1963; Wotton, 2002). Sand is known to represent one of the most effective agents of water purification, particularly from the polluting organic matter (Shimek, *2001*).

For more than 20 years the productivity and composition of benthic microalgal communities on tidal flats have been thoroughly investigated (Underwood & Kromkamp, 1999). However, there is still little information about microphytobenthic communities from non-tidal basins (Vilbaste et al., 2000).

The coastline in the western and northwestern parts of the Black Sea consists mainly of sand (Shuisky & Vyhovanets, 1989). Sandy beaches are mostly areas for recreation, so the anthropogenic impact on hydrobionts of sand is very high in these areas (Cahoon et al., 2012).

Among the organisms living in the interstices of sand, great attention has been paid to the investigations on meiofauna (Vorob'ëva, 1999). The study of algal communities that live on sand was begun in the second half of the 20th century (Round, 1965). There were a number of ecological fundamental studies describing problems of algae attachment to sand particles, production and co-existence in marine sands (Meadows & Anderson, 1968; Steele & Baird, 1968; Jewson et al., 2006).

Studies on the ecology of algae living on sand in the Black Sea region have been recently started by GUSLYAKOV & KOVTUN (2000), who proposed the term *mezophytopsammon* as a group of microscopic algae living in the water of interstitial spaces. It includes algae attached to grains or moving on their surface (epipsammic algae) and unattached ones living in the water of interstitial spaces (epipelic algae). The investigation of mezophytopsammon was continued by GUSLYAKOV (2002), who revealed 88 species from this habitat. Further researches of algae that live on sand were organized on the coast of Tiligul Liman (KOVTUN, 2012) and Odessa Bay (GERASIMYUK & TARASOVA, 2000) and were devoted to ecological and geographical characteristics of detected species. One new species of epipsammon for the Black Sea region *Attheya decora* West was described in the work by TARASENKO & TERENJKO (2008).

The coast of Odessa is characterized by abrasion processes that lead to its destruction. During the 1960s, the system of coast-protecting structures was applied in order to save the shore from wave activity (ZIZAK & KONOVALOVA, 2007). Nourishment of sand as one of the measures for landslides stabilization was held on the coast of the Gulf of Odessa in October 2007. As a result, the width of the beaches was extended by 10–15 m.

Environmental control is usually considered to be the main mechanism that structures ecological communities, whereas biological factors have much less of an influence (SCHLACHER & HARTWIG, 2013). In this context, the ecological significance of benthic microalgae in sandy beach ecosystems remains poorly resolved. There are very few studies devoted to the analysis of impact of sand nourishment on beach habitats (CAHOON et al., 2012). Some its effects have associated to the differences in sediment grain-size distribution between native and imported materials (PETERSON et al., 2006).

It is widely known that the existence of any organisms depends on complex of environmental conditions. The inhabitants of the sand are under the influence of nutrient compound, light availability, temperature, salinity, re-suspension, wave action, grazing, and desiccation wave action (CARTAXANA et al., 2006). Several studies on the influence of sand grain composition on meiobenthic organisms (VOROB'ËVA, 1999) and microphytobenthos (TARASENKO & ALEXANDROV, 2008) have been carried out in the northwestern part of the Black Sea.

To the best of our knowledge there is no information about direct influence of sand nourishment on benthic microalgae for the Black Sea coast. The analysis of changes in taxonomic composition and biodiversity of microalgae on sand beaches, paying special attention to Bacillariophyta, has been made in our previous paper (SNIGIROVA & KOVALËVA, 2012). The aim of this study was to understand the influence of sand nourishment on benthic microalgal community, specifying the impact of sand grain-size change on the quantitative characteristics of microalgae in the Gulf of Odessa.

MATERIALS AND METHODS

The investigation was carried out at 13 sampling sites, where the nourishment took place, and at 3 control sites without it in September 2007 and 2008 (Fig. 1). The samples of phytopsammon were collected using a tube (cross-section area 5.3 cm^2) in 2 cm surface layer of sand at 1 m distance from the water edge. As the water edge we consider the line to which the water comes in calm weather (SAKHAROVA, 1963).

The samples were preserved with 4% formaldehyde and separated from sand at the laboratory. About 50 mg of the sample was added into 100–150 ml of distilled water and shaken for 3 minutes. The procedure was repeated three times. Then the sample was filtered from sand and thickened up by means of sedimentation during two weeks (ALEXANDROV & TARASENKO, 2006). As a result, 50–100 ml of the samples was obtained. Quantitative procedures were made under light microscope (Hund Wetzlar H 600) with magnification ×160 and ×640 in counting chamber 0.05 ml. The abundance of algae cells was determined per 1 cm^3. To count biomass of algae, the biovolume of cells was determined on the base of geometric shapes (OLENINA et al., 2006). Species of microalgae were identified according to the following guides and checklists: ROUND et al. (1990), WITKOWSKI et al. (2000), Diversity of algae of Ukraine (2000).

Sediment granulometry was performed using the sieves of 2, 1, 0.5, 0.25 mm in diameter. To represent

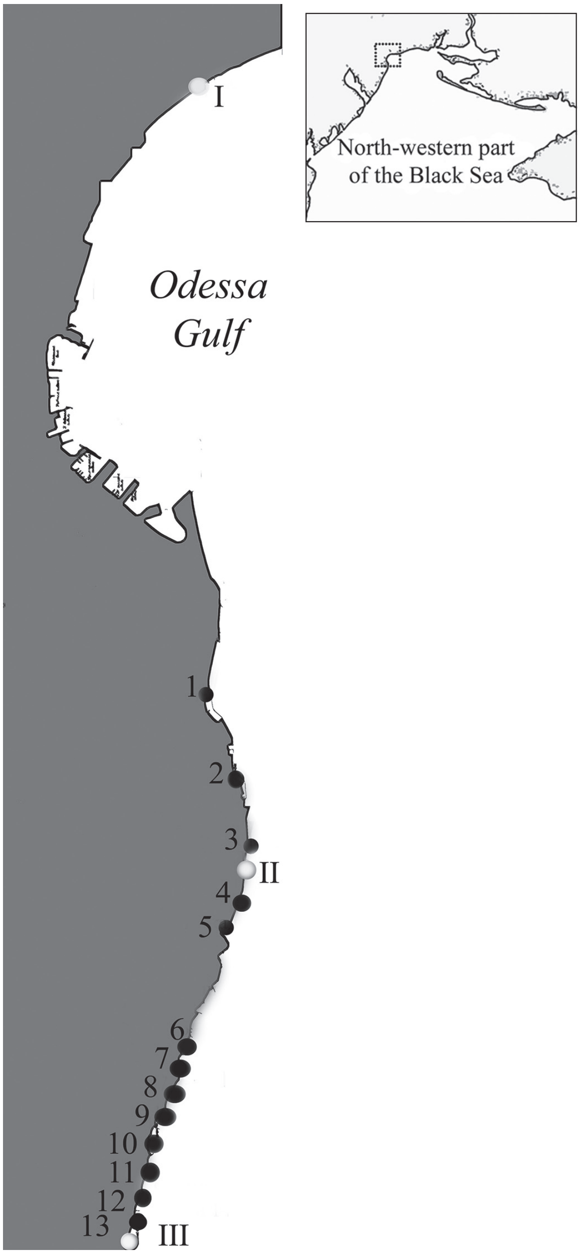

Fig. 1. Study area and sampling stations

the sand grain size, a gradation factor (Mdk) was calculated, which shows the compound of predominant sediment fraction (Vorob'ëva et al., 1992). Sand for nourishment was taken from the beach land (Zizak & Konovalova, 2007), the size of grains considerably finer than on the Odessa Gulf coast.

Average values of the data on nutrients for the Gulf of Odessa in the investigated period were obtained from the Laboratory of Water Quality of Odessa Branch of the Institute of Biology of Southern Seas.

Statistical analysis of the material was performed using the software package Microsoft Excel 2003. The relationship between microphytobenthos and environmental parameters were evaluated on the base of one-way ANOVA (Fisher's ratio test) and correlation analysis.

RESULTS

The size of sand grains used for the coast protection works was much smaller than naturally accumulated on the coast of Odessa. As a result, the size of sand grains on the beaches has decreased by 53% on average after nourishment. The grain size of sediments changed significantly at the sites where nourishment took place ($F = 20.09$ at $p < 0.001$). The range of Mdk values varied as follows: in 2007 – from 2.3 to 5.3 and in 2008 – from 1.4 to 2.0 at sites with infused sand (Fig. 2). Differences at control sites were not found ($F = 0.06$, $p > 0.05$). The range of several environmental variables is shown in Table 1. Temperature and salinity didn't change notably in 2007 and 2008.

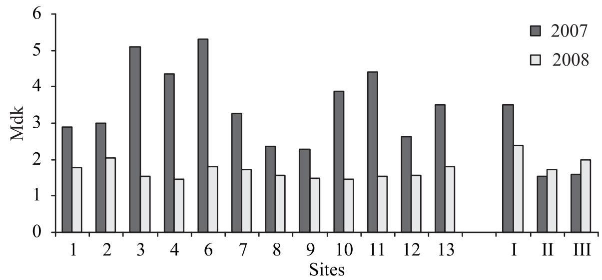

Fig. 2. Sand grain size on the coast of Odessa in 2007–2008 (1–13 – nourished sites; I–III – control sites)

Based on the data on nutrient content in the Gulf of Odessa in 2007–2008, we state that it increased (Table 2). It was mostly reflected in nitrogen (ammonium, total nitrogen) and mineral phosphorus concentrations. Contents of nitrogen oxides, total phosphorus didn't show considerable changes.

In 2007, algae abundance was in similar range in both the control sites and the sites of sand nourishment, whereas in 2008 it was threefold lower at the control sites. Microalgae biomass was almost twofold lower at the control sites both in 2007 and 2008 (Fig. 3). After the organization of the shore protection works, the average abundance of phytopsammon increased by 1.5 times at the sites of sand nourishment,

Table 1. Range of environmental parameters at the investigated sites in 2007–2008

Parameters	Nourished sites		Control sites	
	2007	2008	2007	2008
Temperature of water, C °	15.0–25.5	15.5–21.0	14.5–27.0	17.0–25.5
Temperature of sand, C °	16.5–26.5	18.5–22.5	14.0–25.0	15.0–17.5
Salinity, ‰	16.2–16.8	15.67–15.53	–	15.02–15.67
Sand grains size, Mdk	2.3–5.3	1.4–2.0	1.5–3.5	1.7–2.4

Table 2. Change of nutrient concentrations (μg L^{-1}) (average ± SD) in the coastal seawaters of the Gulf of Odessa in 2007–2008

	NH_4	NO_2	NO_3	TN	PO_4	TP
2007	41.55 ± 1.13	2.20 ± 0.50	31.85 ± 6.07	842.00 ± 62.19	1.95 ± 0.15	18.50 ± 1.15
2008	207.50 ± 1.15	6.55 ± 2.60	30.65 ± 7.07	1598.50 ± 244.23	3.40 ± 0.30	19.95 ± 0.15

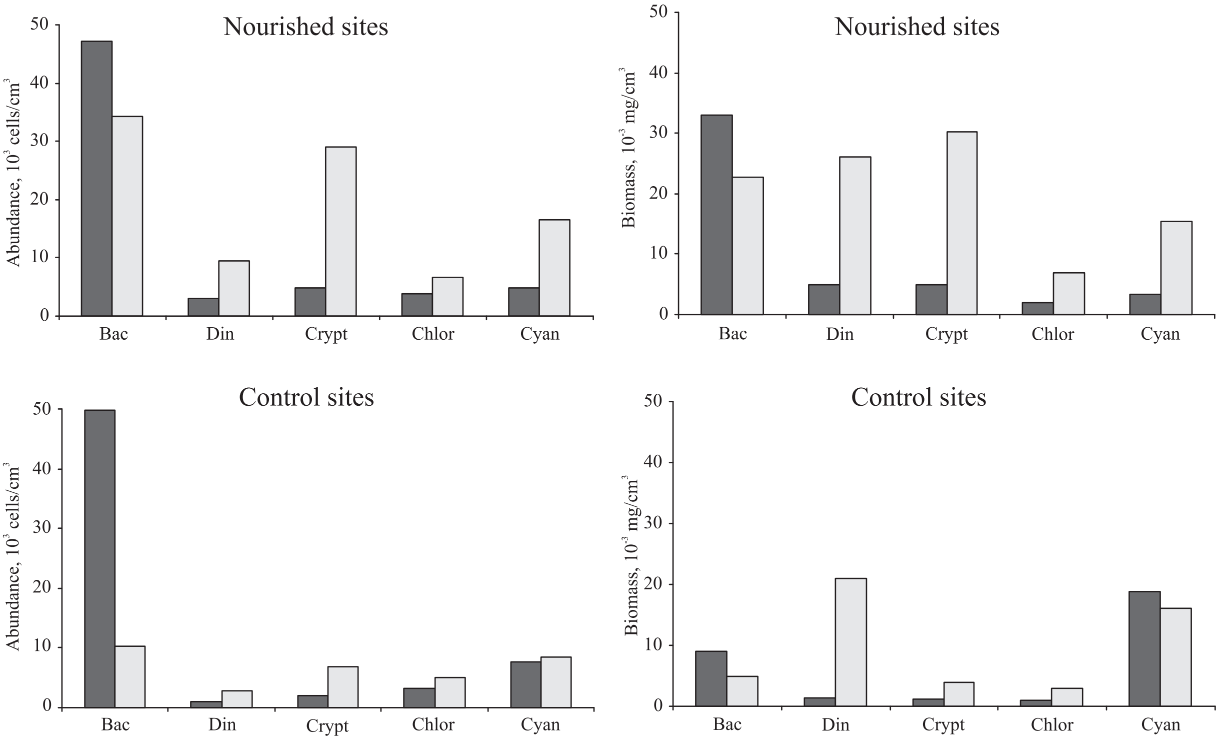

Fig. 3. Abundance (× 10^3 cells cm^{-3}) and biomass (× 10^{-3} mg cm^{-3}) of different groups of microalgae in 2007–2008 (Bac – Bacillariophyta, Din – Dinophyta, Crypt – Cryptophyta, Chlor – Chlorophyta, Cyan – Cyanophyta)

whereas at the control sites it decreased by two times. Biomass increased about twice both at the sites of sand nourishment and at the control sites (Fig. 3).

Table 3. Results of the one-way analysis of variance (ANOVA) of microalgae abundance and biomass in 2007–2008

Variable	Nourished sites		Control sites	
	F	P	F	P
Abundance	2.70	0.030	1.46	0.240
Biomass	3.60	0.008	1.04	0.410

F – Fisher's statistics, P – significant level

ANOVA showed statistically significant changes in algal community structure at the nourished sites (Table 3–4), whereas it wasn't confirmed for control sites.

When analysing the structure of mezophytopsammon at the control sites, especially of Bacillariophyta and Dinophyta groups, it was revealed that for diatoms the abundance was higher than biomass and for Dinophyta opposite situation was observed. This could be explained by smaller sizes of diatom cells that are abundant on sand substrates, the cell length varied from 7.5 to 37.5 μm in our samples. Thus, despite of fivefold decrease of diatom abundance, their biomass changed insignificantly, whereas minor decrease of Dinophyta abundance resulted rise of their biomass by 20 times (Fig. 3). For control sites, no statistically significant differences in abundance and biomass in 2007–2008 were revealed ($F = 1.04$ at $P = 0.409$).

The taxonomic composition of microalgal community has changed. The abundance and biomass of representatives of Dinophyta and Cryptophyta have increased. The impact of Dinophyta ranged from 1×10^3 to 4×10^3 cells cm^{-3} in 2007 and from 1×10^3 to 36×10^3 cells cm^{-3} in 2008 (Table 4). Total biomass at some sites before nourishment reached 30×10^{-3} mg cm^{-3}, and as a result of shore protection, it increased up to 75×10^{-3} mg cm^{-3}. The level of Cryptophyta abundance ranged from 1×10^3 to 31×10^3 cells cm^{-3} in 2007 and from 7×10^3 to 50×10^3 cells cm^{-3} in 2008, the biomass ranged from 1×10^3 to 40×10^{-3} mg cm^{-3} in 2007 and from 6×10^3 to 113×10^{-3} mg cm^{-3} in 2008 (Table 4).

The average value of blue-green algae abundance increased 3 times at the sites where the shore protective works took place and made 4.9×10^3 in 2007 and 16.6×10^3 cells cm^{-3} in 2008. The average biomass amounted to 3.3×10^3 in 2007 and 15.4×10^{-3} mg cm^{-3} in 2008. These parameters at the control sites didn't change significantly (Table 4).

Table 4. Results of the one-way analysis of variance (ANOVA) for the abundance and biomass of different groups of microalgae in 2007–2008

Variables	Nourished sites		Control sites	
	F	P	F	P
Bacillariophyta	1.03 / 0.44	0.31 / 0.51	0.91 / 0.75	0.39 / 0.43
Dinophyta	2.61 / **6.7**	0.11 / **0.01**	0.58 / 1.51	0.48 / 0.28
Cryptophyta	24.67 / **9.14**	4.51 / **0.005**	0.73 / 1.20	0.43 / 0.33
Chlorophyta	1.45 / 2.00	0.23 / 0.16	0.63 / 2.40	0.46 / 0.19
Cyanophyta	4.11 / 2.78	0.05 / 0.10	0.01 / 0.01	0.93 / 0.91

Note: abundance / biomass. F – Fisher's criterion, P – significant level

Abundance of diatoms was lower in the nourished beach area than in other regions, and made on average 30.0%, and at the control sites – 45.0%. The changes in diatom biomass at the sites where shore protection works were carried out were more considerable than at the control sites and made 33.0×10^{-3} and 22.8×10^{-3} mg cm^{-3} in 2007 and 2008, accordingly.

Based on the correlation analysis, it was concluded that different groups of microalgae were influenced by sand grain size in different ways. The abundance of mixotrophic (Dinophyta and Cryptophyta) and blue-green algae had an inverse relationship with sand grain size ($r = -0.6$ and -0.4, respectively). Other taxonomic groups of microalgae (Bacillariophyta and Chlorophyta) were characterized by direct relationship ($r = 0.6$). However, statistically significant changes were observed only for Dinophyta and Cryptophyta biomass (Table 4).

More evident relations were revealed in effect of the sand grain size on the cell length of different groups of algae (Fig. 4). The average cell length of Dinophyta ($F = 5.16$ at $P = 0.03$), Cryptophyta ($F = 5.59$ at $P = 0.03$) and Cyanophyta ($F = 4.93$ at $P = 0.04$) significantly increased after the shore protection works. The average length of diatom cells remained almost unchanged. At the control sites, where there was no effect of sand nourishment, for all groups of microflora, except Cyanophyta, we observed a positive correlation between the average cell length and sand grain size.

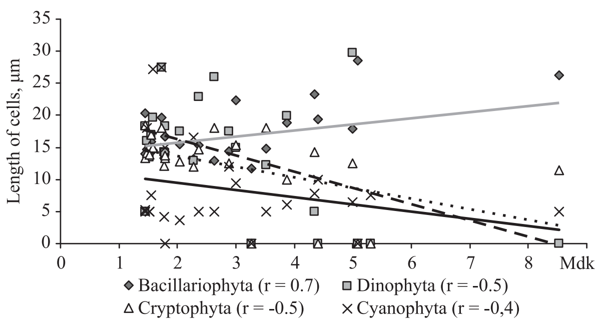

Fig. 4. Dependence of microalgae cell length on granulometric structure of sand (Mdk)

DISCUSSION

Sand nourishment works on the coast of the Gulf of Odessa let us to investigate the response of algae community to changed physical and chemical habitat parameters. In this paper, the importance of sand grain size on the benthic microalgae ecology was confirmed. This lies in accordance with the results on other investigations of sand beaches (Cahoon et al., 2012; Facca &

Sfriso, 2007). Sediment composition being one of environmental factors, which determines the community organization on sandy shores, is an important driver of biomass, community composition and production in the microphytobenthos (Schlacher & Hartwig, 2013).

Microalgae of sand substrate of the Gulf of Odessa were represented by diatom (Bacillariophyta), green (Chlorophyta) and blue-green (Cyanophyta) algae and flagellates (Dinophyta and Cryptophyta) (Snigirova & Kovalëva, 2012). Benthic microalgal biomass ($5.0 \times 10^3 - 1.2 \times 10^6$ cells cm^{-3}) and abundance ($0.5 \times 10^{-3} - 141.0 \times 10^{-3}$ mg cm^{-3}) on the coast of Odessa were at the same order of magnitude of values as reported from previous investigations on microphytobenthos of the Black Sea (Tarasenko & Alexandrov, 2008). Most data concern the revision of microphytobenthos of bottom soft sediments, with depth beginning from 40 m, where values of abundance range from 10.9×10^3 to 1.6×10^6 cells cm^{-2} (Revkov & Nevrova, 2004).

In literature the data on biomass is mostly estimated as chlorophyll *a* (Cibic et al., 2007 and references there in). We are not aware of benthic microalgal biomass values reported for the Black Sea coast based on chlorophyll *a* analysis. This creates a difficulty in comparison of our data with the information from other regions, where the main characteristics of benthic microalgae is chlorophyll *a*.

A few reports on microphytobenthos cell abundances in different marine habitats were reviewed by Cibic et al. (2007). The abundance of benthic microalgae for intertidal and coastal habitats (sampling to the 10 m depth) in different coasts of Europe varied in the range $4.0 \times 10^4 - 4.3 \times 10^6$ cells cm^{-3}, and are comparable with our data. There is a lack of standard unit for calculation of abundance, which is often expressed either per area or volume. Moreover, a comparison is difficult due to the different sampling and analysis methods employed.

Taking into account the decrease of microalgae abundance at the control sites, we resumed that the year 2008 was probably characterized by low trophic level. Having compared the abundance and biomass of microalgae at the nourished sites with the control ones, we determined the threefold and fourfold increase of their abundance and biomass as a result of shore protection, accordingly.

The present investigation showed that mixotrophic algae were the first ones that adapted to the changes. As we can see, the increase in abundance and biomass of Dinophyta (predominantly genus *Prorocentrum*, *Gymnodinium*) and Cryptophyta (genus *Cryptomonas*) indicates the reorganization in algological community.

The content of nutrients is an important factor for sandy beaches. Sandy littoral of the Gulf of Odessa is suggested to be a eutrophic habitat due to large amounts of phosphate, nitrate, sulphate and iron in coastal sands (Vorob'ëva, 1999). Fine particles of sediments adsorb significant amounts of phosphate concentration, which are proportional to the content of mud particles on the beaches. The beaches are often an important source of nutrients, in particular in the form of fine particles $FePO_4$ washed out by waves.

Increase in nutrients is known to strongly influence benthic food webs through the stimulation of primary productivity (Schlacher & Hartwig, 2013). Dinophyta and Cyanophyta are disposed to mixotrophy and can be considered as indicators of organic outbreak (Agatz et al., 1999). Therefore, the appearance of these groups of algae in the benthic assemblages is possibly connected with changes in water parameters.

As we know from literature, in some cases sand nourishment resulted in quite negative effects on beach communities (Peterson et al., 2006). After the change in the habitat of the coastal zone of the Gulf of Odessa as a result of shore protection, all the components of the food chain from algae to fish have suffered. The structure of the whole benthic biocoenoses of Odessa Bay has changed (Chernikova & Zamorov, 2011).

The nourishment of sand on the coast of Odessa led to the death of both the inhabitants of sand and hydrobionts removed from the sand, taken from the Odessa beach land. This was the factor that caused the dramatic increase of nutrients and dissolved organic matter. The average data on nutrient change for the Gulf of Odessa (Table 2) are the evidence of the trend in changing of organic matter in the coastal water area of Odessa in 2007–2008. It is also confirmed by the increase of nutrients in pore water of sand beaches (Garkusha, 2009). On the other hand, the differences in quantitative characters of benthic microalgae within samples and years indicate that factors other than grain size regulated distribution of phytopsammon (Cahoon et al., 2012). Besides, the predominance on the sandy beaches of finer fractions contributes to the accumulation of organic matter (Garkusha, 2009; Harriague et al., 2006). Therefore, we hypothesize that the microalgal communities were directly influenced by diminution of sand grain size and indirectly by nutrients of sandy beaches that were enriched as a result of sand nourishment. These processes led to the increase in total abundance of algae and finally have a positive effect on their community.

In the investigation on the effect of beach nourishment, Cahoon et al. (2012) indicate that sources of sand taken for nourishment, dredging and placement of techniques (length of pipe) may have temporary differential effects. But in our study we couldn't observe such relationship, because the sand was taken from one source and the process of nourishment was the same on all beaches.

Thus, in the Gulf of Odessa, rearrangement of benthic microalgal community was observed as a result of shore protection. Significant influence of fine sand particles on biomass and abundance of microalgae were revealed. The taxonomic composition of algal community of sand changed: the contribution of mixotrophic algae Dinophyta and Cryptophyta increased. The predominance on the sandy beaches of smaller fractions of the sand (1.4–2.0 Mdk) represents more favourable environment for the development of Dinophyta and Cryptophyta.

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PAPLŪDIMIŲ PAPILDYMO SMĖLIU POVEIKIS BENTOSINIŲ DUMBLIŲ BENDRIJOMS ODESOS ĮLANKOJE (JUODOJI JŪRA)

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Santrauka

Abraziniai procesai lėmė pakrantės zonos suardymą Juodosios jūros šiaurės vakarinėje dalyje esančioje Odesos įlankoje. Viena iš pakrantės stabilizavimo priemonių yra jos papildymas smėliu, kuris buvo atliktas Odesos įlankoje 2007 m. spalio mėn. Dėl šių pakrantės apsaugos darbų smėlio dalelių dydis Odesos įlankos paplūdimiuose vidutiniškai sumažėjo 53%. Buvo tirtas smėlio dalelių dydžio poveikis bentoso mikrodumblių gausumui ir biomasei. Bentosinių dumblių bendrijoje dominavo Bacillariophyta ir Dinophyta, ženkliai mažiau buvo Chlorophyta, Cyanophyta ir Cryptophyta rūšių. Smėlio dalelių sumažėjimas statistiškai reikšmingai paveikė dumblių gausumo ir biomasės rodiklius. Dumblių gausumas ir biomasė smėliu papildytame paplūdimyje išaugo atitinkamai tris ir keturis kartus. Miksotrofinių dumblių kiekio padidėjimas lėmė reikšmingus pokyčius bentoso dumblių bendrijoje.