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Article

The ecological structure of the macroalgal community in western Crimea

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Abstract. A study of the macrophytobenthos off the western coast of Crimea in the area from Cape Tyubek to Yazykovaya Balka showed the presence of 12 ecological groups of algae. The marine, dominant, annual and oligosaprobic groups are characterized by the highest species diversity, which is typical of the Black Sea phytobenthos. Chlorophyta is an ecologically distinct group dominated by brackish-marine, mesosaprobic and rare species that rank second in other divisions. The extreme values of numbers of species in the ecogroups occur in areas of the coastal zone with varying activity of abrasion and landslide processes and anthropogenic interference. Species diversity and floristic composition of ecogroups are subject to spatial transformation even though their ratio is stable. The observed dominance of oligosaprobionts, the abundance of mesosaprobionts and the low number of polysaprobionts correspond to their proportions in the pristine marine areas. However, the values of the floristic and saprobiological coefficients show that the quality of the environment in the study area is close to mesotrophic.

Key words: macrophytobenthos, ecological groups, occurrence rate, floristic composition, spatial variability, Black Sea

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Научная статья

Экологическая структура сообщества макроводорослей на западе Крыма

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Аннотация. Исследование макрофитобентоса у западного берега Крыма на участке от мыса Тюбек до Языковой балки показало, что в его состав входят водоросли 12 экологических групп. Наибольшим видовым разнообразием характеризуются морская, ведущая, однолетняя и олигосапробная группы, что типично для черноморского фитобентоса. Экологическим своеобразием отличается Chlorophyta, в котором доминируют солоноватоводно-морские, редкие и мезосапробные виды, занимающие в других отделах вторую позицию. Крайние значения числа видов в экогруппах приходятся на участки прибрежной зоны с разной активностью абразионно-оползневых процессов и антропогенного вмешательства. Видовое разнообразие и флористический состав экогрупп подвержены пространственной трансформации, но их соотношение стабильно. Выявленное доминирование олигосапробионтов, многочисленность мезосапробионтов и малая доля полисапробионтов соответствует их пропорции на чистых морских участках. Однако величины флористического и сапробиологического коэффициентов показывают, что качество среды в районе исследований приближается к мезотрофному.

Ключевые слова: макрофитобентос, экологические группы, встречаемость, флористический состав, пространственная изменчивость, Черное море

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Introduction

The structural and functional differentiation of its species is an important characteristic of a phytocenosis, along with its species composition and the biomass formed by plants. In 1924, L.G. Ramensky noted that every species is ecologically unique, characterized by its ability to live only within certain limits and combinations of effects of environmental factors (Rabotnov, 1983). Therefore, phytocenoses are systems of ecologically and biologically different plant species. Of existing approaches to differentiation of Black Sea macroalgal assemblages, we consider one that takes into account the relationship of the plants with the salinity and saprobity of the habitat, their occurrence rate in the Black Sea, and the genetically fixed duration of the growing season. The ecological scale proposed by A.A. Kalugina-Gutnik, has been used widely for decades in hydrobotanical research (Belich et al., 2019; Berezina, 2011; Evstigneeva and Tankovskaya, 2020; Kalugina-Gutnik, 1975; Maslov, 2004). Information on ecological composition is important both for assessing another aspect of the bio-

diversity of marine ecosystems and for expanding the possibilities of phytoindication of their habitat (Archinoa and Piazzi, 2021; Borja et al., 2011; Kang et al., 2011; Kapkov et al., 2021; Wells et al., 2007). Unfortunately, poor knowledge about macrophytes in some Black Sea regions prevents broad generalizations regarding the ecosystem, landscape, economic potential and distribution patterns of coastal communities (García, 2021). The natural benthic associations of the western regions of the Crimean Peninsula are also no exception. Meanwhile, they are characterized by abundant macrophytobenthos and its key producers (Pankeeva and Mironova, 2021). The purpose of this work is to characterize the ecological features of macrophytobenthos and the contribution of representatives of various divisions to the formation of the spectra of ecological groups in different parts of the Black Sea coastal zone from Cape Tyubek to Yazykovaya Balka.

Materials and methods

The work is based on the results of the summer hydrobotanical survey (July–August) 2020 at six sites on the western coast of Crimea, including capes Tyubek, Lukull, Vai-Vai, Margopulo, Nemetskaya and Yazykovaya gullies (Fig. 1).

The length of the coastline of the study area is 17.1 km. Based on the available data, the coast is of abrasion and landslide type, composed of limestone beds overlain by alluvial proluvial-clay-pebble deposits and red-brown clays (Pankeeva et al., 2021). The coast shows high energy of abrasion, abrasion-gravity, and abrasion-landslide processes. The coastline is poorly indented, and its evenness is disturbed due to the formation of capes. In the coastal area from the shoreline to a depth of 10 m, bottom rises and individual banks are formed due to the accumulation of slabs and blocks of conglomerate. The dynamics of the coastline and topography is determined by the alongshore movement of coastal marine sediments, which depends on the wind-wave regime in the adjacent water area.

Sampling was carried out by a diver at depths of 0.5, 1, 3, 5, and 10 m (to the phytal boundary) in four repetitions using 25×25 cm sampling quadrates (Kalugina, 1969). A total of 120 quantitative samples were collected. They were first processed in a laboratory, where the species composition of algae was determined using an Armed XS-90 microscope. Species were identified taking into account the latest nomenclature changes (Guiry and Guiry, 2022; Zinova, 1967;). The information obtained on species composition, taxonomic structure of the macrophytobenthos of the Western Coast of Crimea and the parameters of its spatial variability are discussed in a previous paper (Evstigneeva and Tankovskaya, 2021). It has been established that the macrophytobenthos near the western coast of Crimea includes 74 species of macroalgae representing four classes, 19 orders, 28 families, 50 genera. The species belong to three divisions: 17 species belong to Chlorophyta, 16 to Ochrophyta, and 41 to Rhodophyta. The identified species were divided into ecological groups according to Kalugina-Gutnik's scale (1975). Data on the occurrence of ecogroups and their constituent species were used to describe macrophytobenthos (Dajo, 1975). Cheney's saprobiological indices (Cheney, 1977), as well as Drescher and Mark's indices (Kalugina-Gutnik, 1989) were used io phytoindicate the environment and assess the degree of eutrophication of various areas. To describe the spatial variability of the characteristics of the cenosis, the limits, the range of their variation, and the average value with a confidence interval were determined (Zhukova and Minets, 2019). Based on the coefficient of variation (C_v, %), the type of character variability was assessed on a seven-point scale (small variation, upper and lower normal, significant, large, very large, abnormally high) (Zaitsev, 1990).

Results and discussion

General characteristics of the ecological composition of macrophytobenthos in the west of the Crimean Peninsula

Macroalgae occurring along the western coast of the Crimean Peninsula, in accordance with the existing classification of Black Sea species, belong to 12 out of the 13 recognized ecological groups (Fig. 2).

The study area had no representatives of the freshwater-brackish water assemblage, which are rare in the Black Sea and are more typical for river estuaries with a salinity of 5–8‰. A zone with such a salinity range is referred to as a "species minimum" zone (Khlebovich, 1974). The brackish group is represented by a single species (*Cladophora liniformis* Kützing), which belongs to a group of taxa rarely found in the Black Sea (Kalugina-Gutnik, 1975). The brackish-marine assemblage includes 17 species of Chlorophyta (Ch) and Rhodophyta (Rh). Species of this group are widely distributed in the coastal zone of the sea, but prefer desalinated areas, where salinity is 8–16‰. The absence of such species among Ochrophyta (Och) in the study area can be explained not only by their low representation in the Black Sea, but also by the fact that they are mainly seasonal-winter forms, while our sampling was in summer, during the period of mass vegetation of annual and perennial species. As in the entire Black Sea, a group of typical marine algae predominates in the study area. It consists of 55 species, which is 75% of the total species diversity of the phytocenosis. The dominance of marine species is consistent with the conclusion that

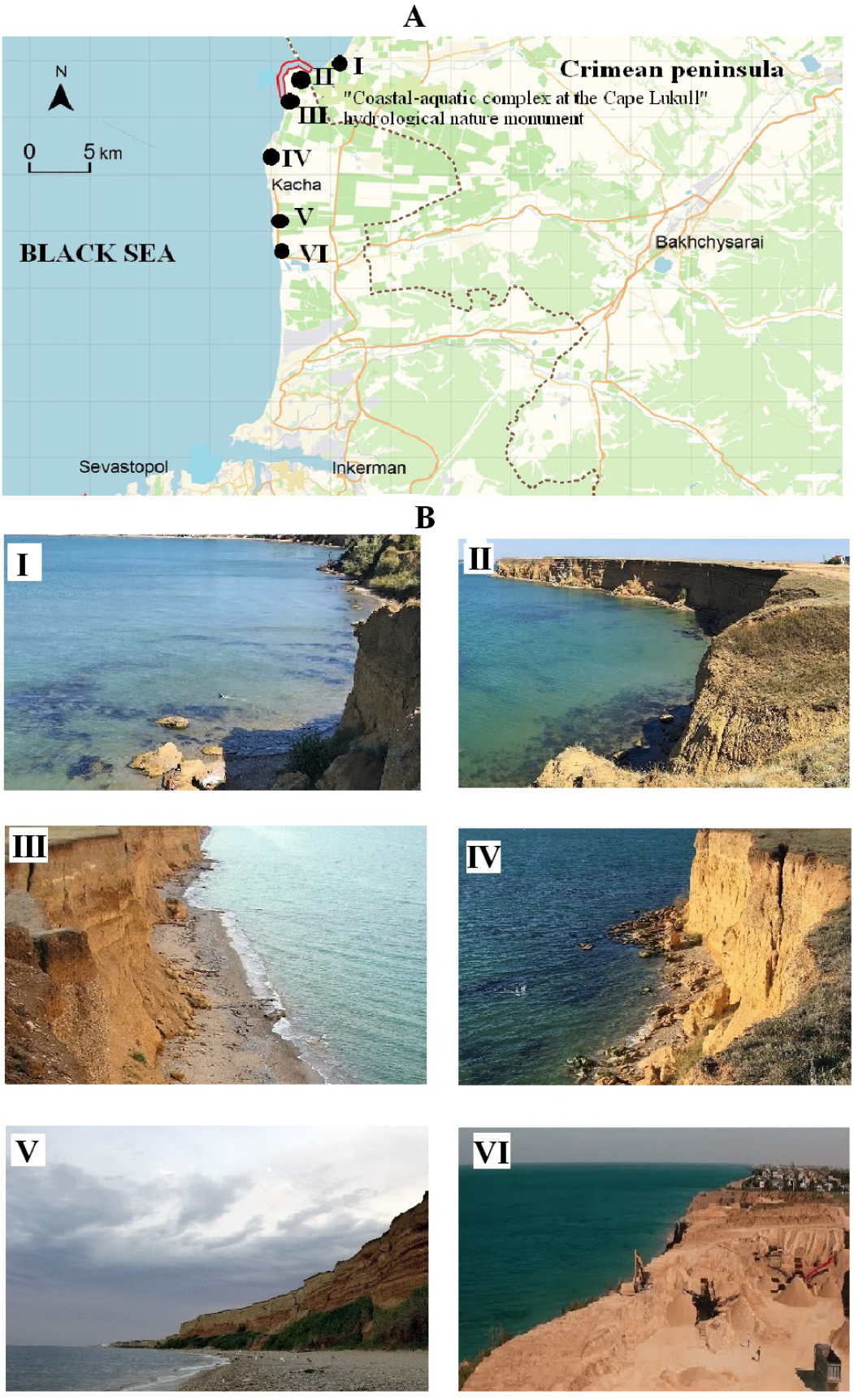

Fig. 1. A – Map of algological survey area off the Crimean Peninsula western coast (Sevastopol region). **B** – Study areas: I – Cape Tubek (N 44°50.483′ E 033°33.642′); II – Cape Lukull (N 44°50.411′ E 033°33.274′); III – Cape Vai-Vai (N 44°50.061′ E 033°32. 996′); IV – Cape Margopulo (N 44°42.878′ E 033°32.665′); V – Nemetskaya Balka (N 44°45.225′ E 033°32.758′), VI –Yazykovaya Balka (N 44°47.383′ E 033°32.115′).

the Black Sea algoflora is predominantly marine and euryhaline (Kalugina-Gutnik, 1975). The dominance and high diversity of red algae in terms of species diversity, frequently found across the marine basin and in local coastal areas indicate that these euryhaline species can inhabit and prosper in the marine and brackish-water environment.

Depending on the frequency of occurrence in the Black Sea, macroalgae are divided into dominant, subdominant and rare species. Six sites along the western coast are dominated by dominant species, followed by subdominant and rare species. The species ratio of these groups in the divisions testifies to a leading role of dominant and rare groups among brown algae (1 sd : 11 d : 4 r); in greens and reds, these same groups correlate as 2 d : 2 r and 1 d : 2 r, and across the entire phytocenosis as 3 d : 1.5 r. The share of subdominant species occupying the last position in the divisions is from 6% (in green algae) to 24% (in red algae) (Table 1).

Macroalgae differ from each other in terms of vegetation, and among them are perennial, dominant annual and seasonal species. Half of the species from the west of Crimea are annual, a third are perennial, and the rest are seasonal (Fig. 2). Their ratio is shown in Table 1. The annuals are dominated by green algae, while perennials are dominated by red algae.

In the studied water area, the most characteristic seasonal species belong to the brown algae division, and their contribution to the overall structure is comparable to that of perennials. Participation of seasonal forms from other divisions is limited to 10 and 13%. In the 1970s, the role of green and red algae in the composition of this group in the Black Sea was equally higher than that of brown algae (Kalugina-Gutnik, 1975). During our work, the contribution of green algae to the composition of the seasonal group was noticeably lower than that of red algae (Table 1). The proportion of seasonal brown algae remains unchanged. The distribution of divisions in the perennial group differs from that in the annual group. In the perennial group, Och ranks second in relative quantity, and third in the annual group. The percentage of this division in the Black Sea perennials, known previously and in this study are the same.

In sanitary hydrobiology, saprobity is understood as the ability of aquatic organisms to live with a high content of organic substances in the environment. Recently, this term has been used to characterize the degree of general water pollution, including organic pollution (Gerasimov, 2014). It has been established that in the series oligosaprobionts – mesosaprobionts – polysaprobionts, not only the resistance of hydrobionts to the influence of excessive content of

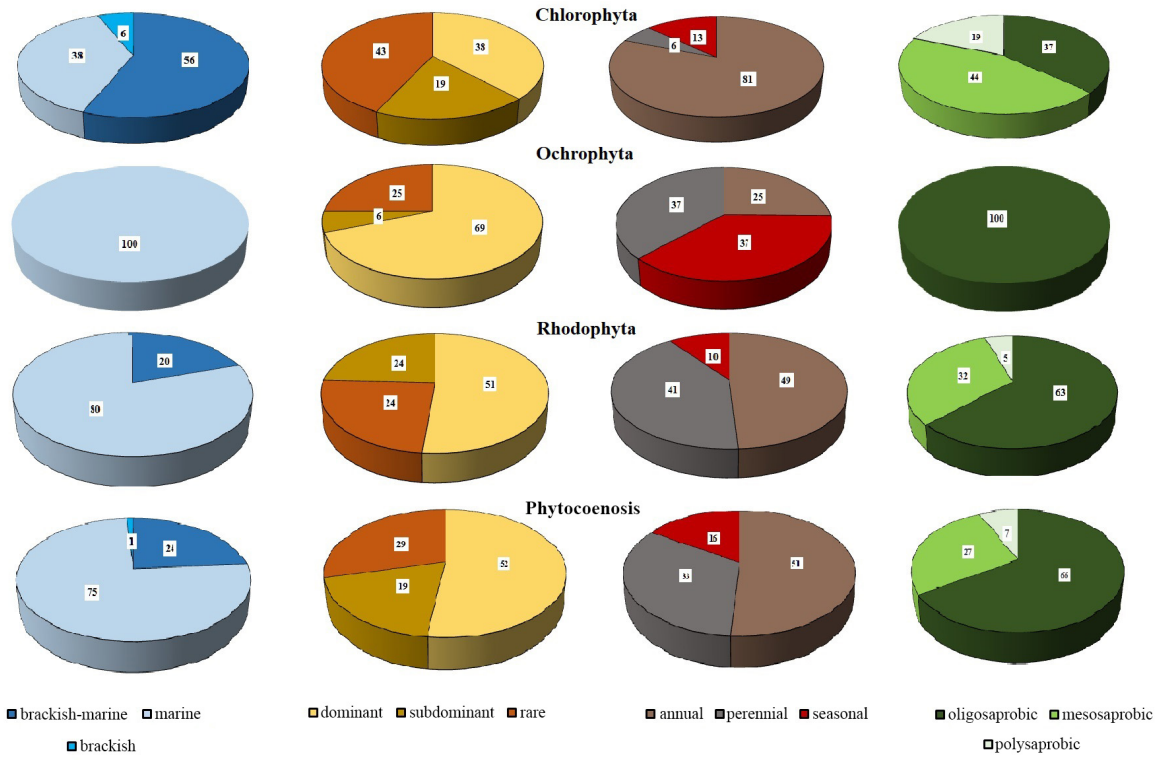

Fig. 2. Ecological composition of macroalgae divisions (**A**) and phytocenosis (**B**) along the western coast of Crimea. **A** – the numbers indicate the percentage of species quantity in the division in the study area; **B** – the percentage of the total number of identified species.

Table 1. Species ratio of ecogroups and divisions in each of them. Before the line, the ratio of divisions is indicated; after it, the absolute number of species in the group. Designations: b, bm, m – brackish, brackish-marine, marine groups; sb, d, r – subdominant, dominant, rare groups; s, per, an – seasonal, perennial, annual groups; ps, ms, os – poly-, meso-, oligosaprobic groups.

Ecogroup	Species ratio of divisions (Ch : Och : Rh)		Species ratio of ecogroups	
	Black Sea (according to Kalugina-Gutnik, 1975)	West Coast	Black Sea (according to Kalugina-Gutnik, 1975)	West Coast
brackish	7 : 0 : 1	1 : 0 : 0 / 1		
brackish-marine	3 : 1 : 1.5	1 : 0 : 1 / 17	1 b : 10 bm : 25 m	1 b : 17 bm : 55 m
marine	1 : 2 : 3	1 : 3 : 5.5 / 55		
subdominant	1 : 1 : 2	3 : 1 : 10 / 14		
dominant	1 : 2 : 4	1 : 2 : 4 / 38	1 sb : 4 d : 4 r	1 sb : 3 d : 2 r
rare	1 : 1 : 2	2 : 1 : 2.5 / 21		
annual	5 : 1 : 5	3 : 1 : 5 / 37		
seasonal	1 : 4 : 2	1 : 3 : 2 / 12	2 s : 1 per : 1 an	3 s : 2 per : 1 an
perennial	1 : 8 : 28	1 : 6 : 17 / 24		
polysaprobic	2 : 0 : 1	2 : 0 : 1 / 5		
mesosaprobic	4 : 1 : 3	1 : 0 : 2 / 20	1 ps : 4 ms : 8 os	1 ps : 4 ms : 10 os
oligosaprobic	1 : 3 : 4	1 : 3 : 4 /48		

organic pollutants, but also to the long-term consequences of their impact increases, which makes it possible to assess the degree of biotic tolerance of a particular species. Saprobiological analysis has shown that oligosaprobic species prevail in western Crimea and throughout the Black Sea (Kalugina-Gutnik, 1975). Relatively numerous mesosaprobionts are indicators of the average degree of organic pollution of the marine environment. This group includes α-mesosaprobic and β-mesosaprobic species represented equally. It is known that the sensitivity of the species to environmental pollution in different habitats may differ (Wells et al., 2007). The proportion of polysaprobic species in the study area is 5%, which is typical of clean areas of the Black Sea. To assess the quality of the environment in the study area, Drescher and Mark's saprobic index (Kalugina-Gutnik, 1989) was used. The obtained value of the coefficient (1.8) suggests that the coastal waters in the study area are close to mesotrophic in quality, which was confirmed by the calculated value of Cheney's floristic index (3.6) corresponding to that for the flora of areas with an average degree of eutrophication. To a certain extent, the results of comparing the values of Cheney's index for one of the surveyed western sites near Cape Lukull also suggest a trend in changes in the quality of the environment. The value of the coefficient obtained by us is more than twice the similar value (1.92) calculated based on the list of species summarized for the period from 1964 to 1998 (Milchakova, 2003). The species ratio of the saprobic groups of the macrophytobenthos of the Black Sea and the areas of the western coast is generally the same (see Table 1). Approximately the same proportion of saprobic groups is typical of macroalgae in the area of the Sotera River in southeastern Crimea (Belich et al., 2019). The rank positions of saprobic groups (the first position for oligo-, the second for meso-, the third for polysaprobic) were previously established for macrophytobenthos in the bay located at the mouth of the Kanaka Gully, as well as near the Cape of the Holy Trinity on the southern coast of Crimea (Sadogursky, 2009, 2014). As in the case of groups of species with different life spans, the ratio of saprobic groups and their ranking positions did not change over time. Obviously, the spatio-temporal preservation of these relationships provides the ecosystem with the ability to maintain a relatively unchanged state and resist changes in environments and biotic relationships in the community. Such facts clearly demonstrate the manifestation of such properties of aquatic ecosystems as stability and resilience (Alimov, 2017). The

proportions of divisions in the groups of poly- and oligosaprobionts in the Black Sea and in the study area are shown to be similar, while the proportion of mesosaprobic group is different. This is because while brown algae in this group were recorded, albeit in low quantity, across the entire sea basin, on its western coast during the study period it was reduced to zero. The structure-forming role of Rh of the mesosaprobic affiliation increased with time.

The ecological composition of the three divisions shows similarities and differences at the level of such characteristics as its completeness and the assemblage of basic groups. The composition of Ch includes species of all identified groups, among Rh there are no brackish-water elements, and among Och there are brackish-marine, polysaprobic and mesosaprobic elements. The latter fact indicates the low ecological diversity of brown algae and the significant ecological diversity of green algae. Rh is close to Ch in terms of the completeness of the ecospectrum. Perhaps this is due to ecological preferences and ecological valence of representatives of different divisions. It is known that brown algae demand a high-quality marine environment (Evstigneeva and Tankovskaya, 2020; Kalugina-Gutnik, 1975), therefore, among them there are no indicator species for a high degree of desalination (brackish-water group) or organic pollution (polysaprobic group) of water; the participation of indicators of an average degree of disturbance is also small (brackish-water-marine and mesosaprobic groups). Green and mostly red algae are more environmentally tolerant, which are favorable for settling in the coastal zone (Berezina, 2011; Evstigneeva and Tankovskaya, 2010; Kalugina-Gutnik, 1975; Maksimova, 2013; Prazukin et al., 2019).

Each division is characterized by its own set of ecogroups, which are dominant in terms of the number of species. Such an assemblage is most specific in Ch, since the brackish-marine (nine species), rare and mesosaprobic (seven species each) groups are predominantly developed here. The second position is occupied by marine, dominant and oligosaprobic species. Och and Rh are equally characterized by high species diversity, primarily of those groups that are in a subordinate position in Ch. The second place of perennials among Rh makes the composition of the basic groups of brown and red algae even more similar.

Despite the absence of absolute coincidence of the ecospectra of the divisions, the assemblage of dominant groups in each of them is typical for the macrophytobenthos of the entire Black Sea. The ecological differences between the divisions can be considered as a complementary phenomenon that ensures the normal functioning of the marine coastal ecosystem.

Of particular interest, in our opinion, is a comparative analysis of the organization of phytocenoses at the level of the quantitative ratio of divisions in each ecogroup in the study area and in total for the Black Sea. The results of such a comparison, carried out with some temporal assumptions, are presented in Table 1. Brown algae, in the groups where they are present, occupy the second position. The contribution of green algae, as a rule, is small, and only in the polysaprobic, brackish-marine, and rare groups is it comparable and even higher than that of red algae. Comparison of the proportions of divisions in the ecogroups of the Black Sea phytobenthos and along the western coast of Crimea in some cases shows their absolute or close similarity. Exactly the same floristic proportion in the local and regional flora is characteristic of only two groups: oligosaprobic and dominant. Much more groups were noted where the ratio of the participation shares of division is close to the same (polysaprobic and all groups with different periods of vegetation). In half of the ecogroups in the local and regional flora, there is a difference in the positions of divisions and their participation in certain groups. Thus, in the composition of the Black Sea macrophytobenthos, the mesosaprobic group is mainly composed of green algae, and in the phytocenoses in the west of the peninsula during the study period, mainly of red algae. The brackish-water group in the local flora is smaller and consists exclusively of the Ch group. In the marine group, the positions of the divisions are the same, but in the local flora, the structural role of Rh is higher.

The species ratio of saprobic and halobic groups in the phytobenthos of the Black Sea and in the studied area of the western coast of Crimea is approximately the same. In this case, oligosaprobionts and marine species remain dominant, followed by brackish-marine and mesosaprobic groups, and then by brackish-water and polysaprobic algae. The order of quantitative subordination of groups, the species of which have different duration of vegetation and the degree of occurrence, does not coincide in the Black Sea and on the western coast of Crimea: in the study area, the role of perennials is somewhat higher, while those of the dominant and rare species are lower.

As a result, the data obtained indicate that the proportions of divisions within ecogroups of local and regional flora often coincide or are close to this state. Differences are manifested at the level of the share of participation of each division in the formation of one or another part of the ecospectrum of the community. The presence of similarities and differences in the proportions of divisions in ecogroups illustrates the principle of “congeneric homotaxis”. In accordance with its mechanism, individual elements of the system can vary in changing environmental conditions, while maintaining their ratios (Evstigneeva and Tankovskaya, 2020; Whittaker, 1980).

Spatial variability of the ecological composition of three divisions of macroalgae

The organization of phytocenoses with their characteristic composition and structure is dynamic as it changes within various limits and in relation to environmental factors. The array of data obtained during the research makes it possible to estimate some parameters of the spatial variability of the ecological composition of phytobenthos along the western coast of Crimea (Fig. 3).

It has been established that the ecospectrum of Ch in all the studied areas, except for Yazykovaya Balka, is complete, and most of its groups show 100% occurrence. There are no perennial species of green algae in Yazykovaya Balka. In each of the surveyed plots, among Ch, the brackish-marine, dominant, annual, oligo- and mesosaprobic groups differ in the largest number of species; the second position is occupied by rare species. The maximum absolute number of species in ecogroups of green algae is more often observed in the area of Lukull and Margopulo capes, the minimum occurrence of most groups was observed in Nemetskaya Balka and Yazykovaya Balka, the territories of which are subject to active recreational and economic development. At present, soil collapses have become more frequent in Nemetskaya Balka. To prevent dangerous situations here, the coastal slopes are artificially collapsed. The range of the extreme values of the number of Ch species in the groups is not great, changes in this indicator from site to site are slight. According to the scale of variability of features of biological objects, spatial variations in the number of green algal species in ecogroups correspond to the norm (C_v = 10–39%).

The distribution of species by groups in Och looks different in the studied areas of the coast. Previously, it was noted that the ecospectrum of the division is reduced due to the absence of brackish-water, brackish-marine, meso- and polysaprobic groups. This should be supplemented by the presence of a subdominant group only in the area of Tyubek and Vai-Vai capes (R = 33%) and the absence of seasonal taxa in the water area of the first of these sites (R = 83%). The spatial homogeneity of the ecological composition of the species complex of brown algae is ensured by the high species saturation of the basic groups (60–100% of the total number of species in the division). The maximum absolute number of Och species was recorded in the coastal area between Cape Tyubek and Yazykovaya Balka. In areas of the basin with pronounced activity of landslide and abrasion processes, and in sites of spontaneous recreation, the number of species remains at a minimum level. In contrast to Ch, the spatial distribution in the Och ecogroups is characterized not only by the “normal”, but also by the “significant” type of variability. The latter type was recorded in rare and one-year-old groups (C_v is 45 and 61%, respectively).

Like Ch and Och, in Rh the qualitative composition of the dominant groups in the plots is the same (marine, dominant, annual, and oligosaprobic species). However, perennials and mesosaprobionts consistently occupy the second position at almost all stations. The highest number of species in the composition of most groups included in Rh was recorded at Cape Vai-Vai, the smallest is in the water areas of Yazykovaya Balka and Cape Tyubek, close to ecologically critical habitats due to natural processes and anthropogenic intervention. The difference between the extreme values of the analyzed parameter is small, its spatial variability in most groups in terms of the strength of manifestation does not exceed the “lower” norm (C_v in the range from 14 to 22%). Only in small groups, such as rare and seasonal, does the variability in the number of species in space correspond to the “significant” type (C_v is 61 and 45%, respectively).

In summary, the data obtained for the three divisions indicate a low intensity spatial transformation of the absolute number of species in the groups. “Significant” according to G.N. Zaitsev’s scale of the type of changes, is characteristic of a limited number of groups: rare and annual in Och, rare and seasonal in Rh. The extreme values of the analyzed parameter are usually observed in coastal areas with contrasting environmental conditions. The types of spatial variability of the relative number of species in groups are supplemented by the so-called “small” variation. It is observed in the dominant group in the composition of Rh, and marine and dominant in the phytocenosis as a whole. The proportions of brackish-marine, marine, and oligosaprobic species included in the Och ecospectrum remain unchanged in the studied coastal areas.

Conclusions

1. Macrophytobenthos near the western coast of the Crimean Peninsula consists of 74 species from 12 ecological groups. It does not include representatives of the freshwater-brackish-water assemblage, and the marine, dominant, annual, and oligosaprobic groups, uniting 51–75% of the total number of identified species, are most developed.

2. Each division is characterized by its own set of key ecogroups and a certain degree of completeness of the ecospectrum. Chlorophyta is the most distinctive, dominated by brackish-marine, rare and mesosaprobic species, which occupy the second position in other divisions. The quantitative distribution of ecogroups by divisions is typical for the Black Sea phytobenthos.

3. The extreme values of the number of species in ecogroups fall on areas of the coastal zone with different activity of abrasion-landslide processes and

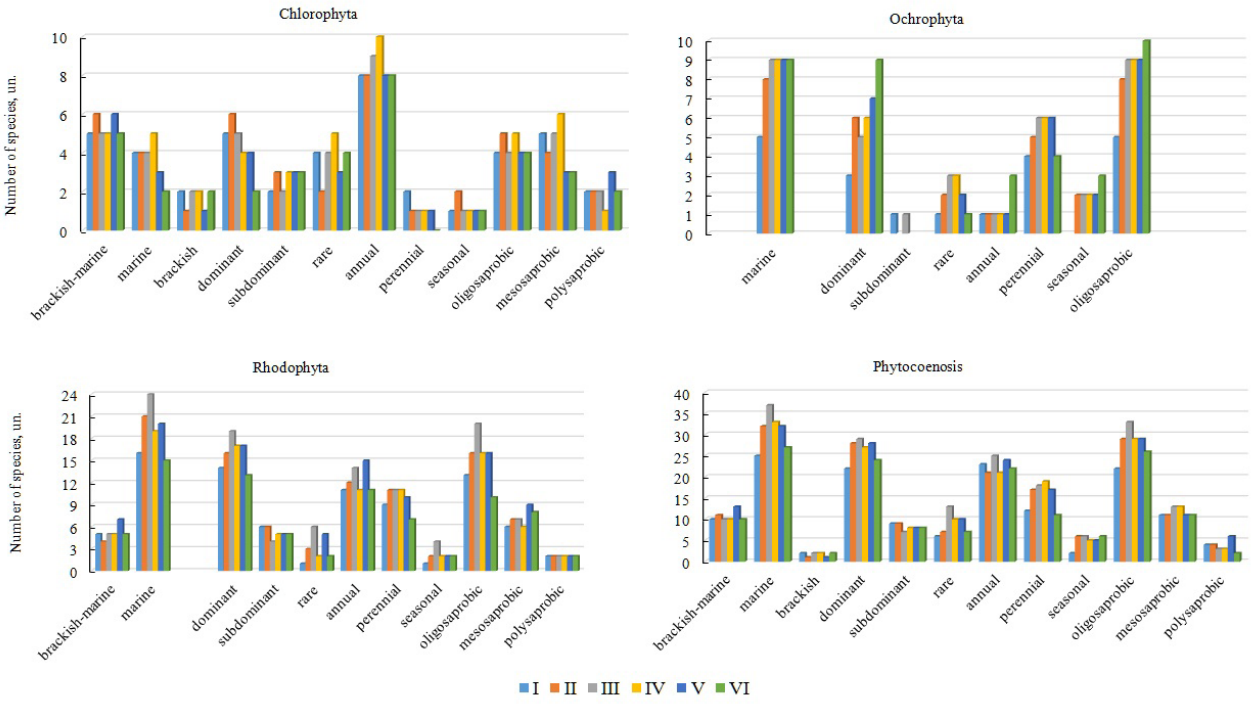

Fig. 3. Spatial distribution of the ecological composition of phytobenthos along the western coast of Crimea. Roman numerals indicate study areas (see Fig. 1).

anthropogenic interference: for most ecogroups, the maximum number of species was recorded in the water area of Cape Vai-Vai, and the minimum was recorded in the area of Yazykovaya Balka and Cape Tyubek.

4. The species diversity and floristic composition of ecogroups are subject to spatial transformation, but their ratio remains stable.

5. The results of phytoindication show the widespread dominance of oligosaprobic species, the abundance of mesosaprobic species, and a small proportion of polysaprobic species, which corresponds to the ratio of saprobic groups in clean areas of the sea. Nevertheless, the values of the floristic and saprobiological indices indicate that the coastal waters in the study area are close to mesotrophic in quality.

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