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Article

Current state of macrozoobenthos of the rocky marine environment of Karadag Nature Reserve (Black Sea, Crimea)

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Abstract. In 2021–2022, 106 macrozoobenthos species were found in the fouling communities of the rocky marine environment of Karadag Nature Reserve at a 0–5-m depth. In the reserve, several rocks (Kuzmichev Kamen', Ivan Razboynik, Zolotye Vorota, Lev, and Mayak) and two bays, the Barakhta Bay and Serdolikovaya Bay, were studied. The average macrozoobenthos abundance ranged as 35355 ± 9958 ind./m^2, biomass, 2678.38 ± 909.73 g/m^2. The highest abundance was recorded in the periphyton communities at Mayak Rock (54878 ind./m^2), the highest biomass, in the periphyton at Lev Rock (5712.62 g/m^2). In fouling communities of the Serdolikovaya Bay, crustaceans made a significant contribution to the total abundance (54%), while in other areas, these were mollusks (from 49 to 86%). Based on the functional abundance index, community of *Mytilaster lineatus* (Gmelin, 1790) was identified in the study area. Onmivorous species predominated by the species number, sestonophagous species, by abundance and biomass. Sestonophagous bivalve mollusk *M. lineatus* contributed significantly to total abundance and biomass (98% and 86% respectively).

Keywords: community, abundance, biomass, frequency of occurrence, trophic structure, rocky biotope, Karadag Nature Reserve

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Научная статья

Современное состояние макрозообентоса скальных субстратов Карадагского природного заповедника (Черное море, Крым)

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Аннотация. В обрастаниях естественных твердых субстратов Карадага (на скалах Кузьмичёв камень, Иван Разбойник, Золотые ворота, Лев, Маяк, в бухтах Барахты и Сердоликовая) на глубине 0–5 м в 2021–2022 гг. обнаружено 106 видов макрозообентоса. Средняя плотность и биомасса макрозообентоса составила 35355 ± 9958 экз./м^2 и 2678.38 ± 909.73 г/м^2 соответственно. Наибольшая плотность зарегистрирована в перифитоне скалы Маяк (54878 экз./м^2), наибольшая биомасса – в перифитоне скалы Лев (5712.62 г/м^2). В обрастаниях бухты Сердоликовая значительный вклад в общую плотность внесли ракообразные (54%), на остальных участках – моллюски (от 49 до 86%). На всем исследуемом полигоне на основании индекса функционального обилия выделено сообщество *Mytilaster lineatus* (Gmelin, 1790). По количеству видов преобладали полифаги, по плотности и биомассе – сестонофаги. Среди сестонофагов в общую плотность и биомассу значительный вклад вносил двустворчатый моллюск *M. lineatus* (98 и 86% соответственно).

Ключевые слова: сообщество, плотность, биомасса, встречаемость, трофика, биотоп скал, Карадаг

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Introduction

Karadag Nature Reserve consists of three arcuate ridges composed of terrigenous-volcanic and terrigenous-carbonate complexes of Mesozoic age. Kuzmichev Kamen' is a large rock formation jutting out into the sea to the depths of 4–5 m. The coastline frequently changes its outline due to landslides and scree. Ivan Razboynik Rock is a small 100-m volcanic vent with multiple magma outpourings. Zolotye Vorota Rock is a recumbent volcanic vent composed of concentric andesite-basalt lavas with columnar jointing. Lev Rock is a neck between two dikes split at the base; the main fissure vent is located beneath the rock below sea level. Mayak Rock is composed of igneous liparite-dacite rocks. The small Barakhta Bay is located in the middle of the coastline belonging to Karadag Nature Reserve, southwest of Serdolikovaya Bay. At the Serdolikovaya Bay (Yuzhnaya, Srednyaya, and Severnaya inlets), the steep southeastern slope of the ridge is protected by lava flows with pronounced “pillows” (Kupchenko, 1976; Yudin, 2023).

The Karadag Nature Reserve was established by Resolution no. 386 of the Council of Ministers of the Ukrainian Soviet Socialist Republic on August 9, 1979. Subsequently, in accordance with Decree no. 1091 of the Government of the Russian Federation dated September 13, 2018, it was transferred to the jurisdiction of the Ministry of Science and Higher Education of the Russian Federation. The reserve is located in the eastern part of the Crimean Peninsula, between the villages of Koktebel' and Kurortnoye; it is one of the centers for the biological diversity conservation of the marine flora and fauna (Kopiy, 2024).

For over a hundred years, studies of macrobenthic communities of various biotopes, including that on hard substrates, have been conducted in the reserve (Boltacheva et al., 2010, 2015; Grintsov, 2018; Grintsov et al., 2005; Kopiy, 2019, 2024; Kovaleva et al., 2014; Makarov, 2006; Murina et al., 2004; Sharonov, 1952; Sinegub, 2004).

Benthic organisms are a highly taxonomically diverse group; they represent one of the most important links in marine food webs and inhabit virtually all benthic biotopes. In the Black Sea, most of the shelf (90%) is occupied by soft soils (Kiseleva, 1981). Hard substrates, including rocky surfaces, are less common. At the Black Sea coast of Crimea, they form a narrow strip near Cape Tarkhankut in the northwest and then from the city of Sevastopol in the southwest along the southern coast to the igneous massif of Karadag Nature Reserve in the southeast; these are the areas exposed to intensive surf. Sampling the biota on hard substrates is a difficult task. Considering these peculiarities, the fouling

fauna of natural rocky environment remains insufficiently studied. In 2021–2022, the studies of the macrozoobenthos of natural hard substrates in this area have been continued.

The study aims to assess the current state of macrozoobenthos in the marine rocky environment of Karadag Nature Reserve.

Materials and methods

The work is based on the materials of benthic surveys carried out in the summer of 2021 and 2022 at the marine rocky environment of Karadag Nature Reserve (Southeastern Crimea): Kuzmichev Kamen', Ivan Razboynik, Zolotye Vorota, Lev, Mayak, and in the bays of Barakhta and Serdolikovaya (Fig. 1).

Periphyton samples were collected at depths of 0, 1, 2, and 5 m using a frame lined with fine mesh and a capture area of 0.04 m^2 (Kopiy, 2024). At each sampling point, the material was collected in two replicates. A total of 66 samples were collected in the study area (26 samples in 2021, 40 samples in 2022). Decapod crustaceans were collected manually and treated with the highest precaution to avoid any damage. After visual taxonomic identification with minimal chance of harm, the decapods were returned back alive to their natural habitat.

The collected material was preserved in 4% neutralized formaldehyde solution and then washed through a sieve (0.5-mm mesh size) in the laboratory. Individuals of each species were counted; their wet weight was determined using a Class 3 torsion balance (weighting range of 250–1000 mg) with an accuracy of 1.0 mg. Smaller specimens were weighed using an AXIS Class 3 torsion balance (weighting range of 1–50 mg) with an accuracy of 0.5 mg (Kopiy, 2024).

Species were identified by using published taxonomic keys; the trophic characteristics were obtained in literary sources (Chukhchin, 1984; Greze, 1985; Grintsov, 2022; Grintsov and Sezgin, 2011; Kiseleva, 1981, 2004; Opredelitel'..., 1972). Species taxonomy is given in accordance with the WORMS[1] database.

When describing the quantitative development of macrozoobenthos, abundance (N, ind./m^2) and biomass (B, g/m^2) were calculated, as well as the functional abundance index (FAI) based on N and B values:

$$FAI = N^{0.25} \times B^{0.75},$$

where N is species abundance, B, species biomass (Semkin and Gorshkov, 2010).
The ranked curve of the species dominance-diversity was constructed based on the calculated values of the abundance indices (AI) of species:

$$AI = FAI \times P,$$

where P is the species frequency of occurrence.

For the average abundance and average biomass of macrozoobenthos, a confidence interval is given (Kholodov, 2016).

The species frequency of occurrence (P) was calculated as:

$$P = \frac{m}{n} 100\% \ ,$$

where *m* is the number of stations at which the species was encountered, *n,* the total number of stations (Odum, 1986).

An index approach was applied to assess species diversity. Species dominance was analyzed using the Simpson index (Simpson 1-D), biodiversity, using the Shannon index (Shannon H, Shannon (exp)H), calculated by species abundance; species richness, according to the Taxa S index. The Sørensen index (i) was applied to assess the similarity of the faunas in the two compared lists:

$$i = \frac{2a}{b+c} \ ,$$

where *a* is the number of common species, *b* and *c*, the number of species in the compared lists (Odum, 1986).

[1] WoRMS Editorial Board. 2025. World Register of Marine Species. Web page. URL: https://www.marinespecies.org/ (accessed: 22.01.2025).

Fig. 1. Sampling site map: 1 – Kuzmichev Kamen' Rock, 2 – Ivan Razboynik Rock, 3 – Zolotye Vorota Rock, 4 – Lev Rock, 5 – Mayak Rock, 6 – Barakhta Bay, 7 A – Southern Serdolikovaya Bay, 7 B – Central Serdolikovaya Bay, 7 C – Northern Serdolikovaya Bay.

In order to compare the abundance of species per unit area and the evenness of the relative distribution, a dominance-diversity curve was constructed, in which the X-axis was a ranked series from the most numerous species to the least numerous, the Y-axis, accumulated percentage of the species abundance (Whittaker, 1972).

The ABC method was applied to assess the stress experienced by the community (Warwick, 1986). The expected number of species was estimated using the Chao-2 species richness extrapolation algorithm (Chao, 1987). Data processing was performed using Microsoft Excel 16, PAST 3.5, and BioDiversity Pro software.

Results and discussion

In the coastal waters of Karadag Nature Reserve, 106 species of macrozoobenthos were identified in fouling communities, including Polychaeta (38 species), Crustacea (43), Mollusca (18), Pantopoda (2); representatives of the taxa Acari, Ascidiidae, Platyhelminthes, Nemertea and Actiniidae were found, but not identified down to species level (Table 1).

The largest number of macrozoobenthos species was recorded for the Zolotye Vorota Rock (77), the lowest, for the Kuzmichev Kamen' Rock (48).

The average abundance and biomass of macrozoobenthos in the study area was 35355 ± 9958 ind./m^2 and 2678.38 ± 909.73 g/m^2, respectively.

The highest abundance of macrozoobenthos (54878 ind./m^2) were recorded in the periphyton communities at Mayak Rock, the highest biomass, in that at Lev Rock (5712.62 g/m^2). The lowest abundance of macrozoobenthos was noted in the fouling communities at the Ivan Razboynik Rock (13297 ind./m^2), the lowest biomass, at Mayak Rock (692.84 g/m^2).

Crustaceans made a significant contribution to the total abundance (54%) in the rock fouling communities of the Serdolikovaya Bay, while in other areas these were mollusks, bringing from 49 to 86% of the total periphyton community abundance. The share of *Mytilaster lineatus* in the total mollusks' abundance ranged from 49 to 82%. Mollusks dominated by biomass in all areas (98.3–99.7% of the total biomass).

According to biodiversity indices, the highest species richness and macrozoobenthos diversity were found at Zolotye Vorota Rock, Mayak Rock, and the Serdolikovaya Bay. The lowest number of species, the lowest species abundance and biomass were observed in the periphyton communities at Ivan Razboynik Rock (Fig. 2).

Table 1. Species composition and quantitative indicators of macrozoobenthos at the marine rocky environment of the coastal waters of Karadag Nature Reserve. Values above the line are average species abundance (N), ind./m^2, below the line, average species biomass (B), g/m^2; "–" – taxon was not found.

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
PLATYHELMINTES (TURBELLARIA) gen. sp.	75 0.446	56 0.205	79 0.341	50 0.144	94 0.377	66 0.281	40 0.178
NEMERTEA gen .sp.	67 0.242	34 0.075	34 0.054	22 0.057	39 0.092	6 0.009	48 0.243
ANNELIDA							
Polychaeta							
Alitta succinea (Leuckart, 1847)	–	31 0.538	182 4.452	222 5.864	92 1.883	–	3 0.038
Amphiglena mediterranea (Leydig, 1851)	–	–	16 0.014	–	13 0.004	–	–
Capitella capitata (Fabricius, 1780)	8 0.004	–	7 0.006	3 0.001	6 0.003	–	3 0.0008
Dorvillea rubrovittata (Grube, 1855)	25 0.017	16 0.034	45 0.063	6 0.003	6 0.017	3 0.009	5 0.001
Eulalia viridis (Linnaeus, 1767)	17 0.021	22 0.022	50 0.025	33 0.024	46 0.029	16 0.021	25 0.037
Eumida sanguinea (Örsted, 1843)	–	–	16 0.007	6 0.002	29 0.039	16 0.008	10 0.006
Fabricia stellaris (Müller, 1774)	–	–	2 0.0005	–	–	–	–
Ficopomatus enigmaticus (Fauvel, 1923)	–	–	–	8 0.009	2 0.013	–	–
Genetyllis tuberculata (Bobretzky, 1868)	25 0.083	13 0.008	7 0.035	6 0.005	6 0.006	3 0.002	3 0.001
Haplosyllis spongicola (Grube, 1855)	–	3 0.006	–	–	–	–	–
Harmothoe extenuata (Grube, 1840)	17 0.033	6 0.009	–	–	–	6 0.005	–
Harmothoe imbricata (Linnaeus, 1767)	–	–	5 0.001	6 0.001	6 0.003	–	–
Harmothoe impar (Johnston, 1839)	–	–	7 0.003	3 0.011	13 0.012	–	–

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
Harmothoe reticulata (Claparède, 1870)	125 0.092	88 0.098	70 0.055	36 0.025	79 0.077	25 0.033	23 0.074
Lagis neapolitana (Claparède, 1869)	17 0.021	–	4 0.011	–	6 0.003	–	–
Leiochone leiopygos (Grube, 1860)	–	–	2 0.004	–	–	–	–
Lysidice ninetta Audouin & H. Milne Edwards, 1833	8 0.083	6 0.059	14 0.338	8 0.1	2 0.008	6 0.047	3 0.015
Nematonereis unicornis (Grube, 1840)	–	–	7 0.012	5 0.016	4 0.003	3 0.002	13 0.007
Neodexiospira pseudocorrugata (Bush, 1905)	–	–	–	–	–	–	5 0,0005
Nereididae	175 0.073	288 0.123	323 0.054	306 0.069	185 0.041	266 0.122	723 0.108
Nereis zonata Malmgren, 1867	242 3.133	275 2.484	79 1.025	6 0.22	19 0.435	222 2.477	190 2.786
Perinereis cultrifera (Grube, 1840)	–	–	2 0.743	11 0.702	2 0.071	–	–
Pholoe inornata Johnston, 1839	17 0.054	19 0.02	34 0.024	36 0.023	38 0.024	28 0.021	40 0.018
Phyllodoce maculata (Linnaeus, 1767)	8 0.021	9 0.022	11 0.046	8 0.005	–	3 0.002	–
Phyllodoce mucosa Örsted, 1843	–	3 0.016	7 0.036	3 0.018	6 0.011	19 0.006	13 0.002
Platynereis dumerilii (Audouin & Milne Edwards, 1833)	8 0.317	13 0.303	41 0.55	42 0.367	56 1.013	59 1.044	65 0.963
Polycirrus jubatus Bobretzky, 1868	8 0.175	3 0.003	–	–	–	–	–
Polyophthalmus pictus (Dujardin, 1839)	17 0.042	22 0.013	138 0.137	769 0.457	390 0.243	119 0.027	513 0.251
Prionospio cirrifera Wirén, 1883	25 0.058	–	27 0.018	11 0.003	13 0.004	–	8 0.001
Protoaricia capsulifera (Bobretzky, 1870)	–	–	–	–	–	–	3 0.0008
Salvatoria clavata (Claparède, 1863)	50 0.004	69 0.008	120 0.008	333 0.008	350 0.025	216 0.009	753 0.031

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
Schistomeringos rudolphi (Delle Chiaje, 1828)	–	–	5 0.005	–	8 0.008	–	–
Spirobranchus triqueter (Linnaeus, 1758)	–	–	23 0.04	8 0.03	–	–	3 0.005
Syllis hyalina Grube, 1863	175 0.225	84 0.115	125 0.093	189 0.114	113 0.081	106 0.067	198 0.163
Syllis gracilis Grube, 1840	83 0.071	25 0.014	107 0.124	69 0.05	152 0.093	34 0.026	25 0.008
Syllis prolifera Krohn, 1852	125 0.096	13 0.019	55 0.051	114 0.056	192 0.139	25 0.022	125 0.089
Syllis variegata Grube, 1860	–	9 0.008	2 0.001	3 0.005	2 0.002	6 0.003	35 0.029
Trypanosyllis zebra (Grube, 1860)	–	16 0.017	7 0.005	6 0.002	19 0.022	22 0.03	8 0.009
TOTAL	**1175** **4.623**	**1033** **3.939**	**1540** **7.986**	**2256** **8.19**	**1855** **4.312**	**1203** **3.983**	**2795** **4.644**
OLIGOCHAETA gen. sp.	233 0.023	78 0.009	86 0.013	39 0.004	165 0.018	163 0.016	243 0.026
MOLLUSCA							
POLYPLACOPHORA (LORICATA)							
Acanthochitona fascicularis (Linnaeus, 1767)	–	–	7 0.503	9 0.167	6 0.13	–	5 0.063
Lepidochitona cinerea (Linnaeus, 1767)	8 0.833	3 0.313	–	7 0.034	8 0.017	16 0.375	–
BIVALVIA							
Cerastoderma glaucum (Bruguière, 1789)	–	–	2 0.179	–	–	–	–
Flexopecten glaber (Linnaeus, 1758)	–	–	–	–	2 0.002	–	–
Mytilaster lineatus (Gmelin, 1790)	10 900 2508.33	7 134 1421.88	35 132 3352.79	17 098 5647.27	30 810 614.583	11 816 1 268.75	13 090 746.075
Mytilus galloprovincialis (Lamarck, 1819)	8 4.167	188 1 978.13	1716 366.161	11 40.909	69 49.708	16 12.25	15 9.525

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
			GASTROPODA				
Bittium reticulatum (da Costa, 1778)	8 0.008	–	100 2.105	102 2.427	75 1.321	–	139 0.782
Brachystomia eulimoides (Hanley, 1844)	–	–	–	5 0.02	–	–	203 0.188
Marshallora adversa (Montagu, 1803)	1633 1.633	1038 0.788	21 0.027	84 0.084	506 0.502	–	–
Parthenina indistincta (Montagu, 1808)	–	–	4 0.004	–	6 0.006	–	5 0.013
P. interstincta (J. Adams, 1797)	8 0.008	–	2 0.002	2 0.002	4 0.004	–	18 0.018
Rissoa parva (da Costa, 1779)	–	–	11 0.193	7 0.007	31 0.067	–	6 0.055
R. splendida (Eichwald, 1830)	–	3 0.125	71 1.036	39 0.384	208 2.308	–	535 1.275
R. venusta R.A. Philippi, 1844	–	–	2 0.002	–	2 0.002	–	3 0.005
Setia valvatoides Milaschewitsch, 1909	–	–	–	5 0.005	–	–	–
Steromphala adriatica (R.A. Philippi, 1844)	8 0.05	–	–	2 0.002	–	–	155 1.003
Tricolia pullus (Linnaeus, 1758)	225 4.783	1238 11.316	175 5.838	170 6.155	381 12.656	–	958 4.455
Tritia neritea (Linnaeus, 1758)	–	–	2 0.107	–	–	–	2 0.045
TOTAL	**12798** **2519.81**	**9604** **3412.55**	**37245** **3728.95**	**17541** **5697.5**	**32108** **681.31**	**11848** **1281.38**	**15134** **763.50**
			ARTHROPODA				
Acari	133 0.001	63 0.0009	52 0.0007	130 0.003	246 0.006	100 0.001	263 0.005
			PANTOPODA				
Anoplodactylus petiolatus (Krøyer, 1844)	–	–	–	–	–	–	3 0.001
Tanystylum conirostre (Dohrn, 1881)	58 0.022	50 0.022	11 0.005	70 0.029	35 0.015	97 0.065	43 0.015

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
CRUSTACEA							
Amphipoda							
Ampithoe ramondi Audouin, 1826	33 0.028	122 0.065	1014 0.33	1611 1.13	1242 0.642	516 0.214	1940 0.919
Apherusa bispinosa (Spence Bate, 1857)	–	41 0.016	64 0.023	111 0.027	165 0.039	188 0.055	773 0.22
Apohyale perieri (Lucas, 1846)	–	–	73 0.067	241 0.138	–	–	140 0.117
Biancolina algicola Della Valle, 1893	83 0.013	84 0.012	13 0.003	14 0.002	67 0.014	297 0.04	383 0.052
Caprella acanthifera Leach, 1814	42 0.007	194 0.02	216 0.027	452 0.064	5213 0.571	703 0.096	5833 0.867
Caprella liparotensis Haller, 1879	25 0.006	434 0.053	338 0.117	143 0.031	5094 0.788	4763 0.56	1330 0.146
Caprella mitis Mayer, 1890	–	–	–	–	–	9 0.002	–
Colomastix pusilla Grube, 1861	–	–	–	–	2 0.0001	–	–
Dexamine spinosa (Montagu, 1813)	25 0.003	6 0.004	54 0.032	286 0.134	206 0.124	56 0.036	218 0.073
Erichthonius difformis M.-Edwards, 1830	–	–	–	5 0.001	15 0.002	3 0.001	145 0.03
Hyale pontica Rathke, 1836	–	3 0.001	–	14 0.007	–	19 0.011	20 0.01
Microdeutopus sp.	42 0.003	13 0.002	57 0.013	11 0.002	19 0.005	47 0.008	18 0.006
Melita palmata (Montagu, 1804)	8 0.026	–	–	–	2 0.0002	3 0.0006	10 0.014
Microdeutopus gryllotalpa A. Costa, 1853	–	25 0.006	263 0.063	489 0.098	400 0.105	134 0.026	1178 0.276
Microdeutopus versiculatus (Spence Bate, 1857)	–	–	–	–	2 0.001	–	18 0.003
Monocorophium acherusicum (A. Costa, 1853)	–	–	2 0.0002	–	2 0.0002	–	3 0.0003

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
Pleonexes helleri (Karaman, 1975)	–	–	61 0.063	280 0.357	202 0.204	72 0.033	198 0.245
Plumulojassa ocia (Spence Bate, 1862)	42 0.003	397 0.059	27 0.004	148 0.023	1525 0.3	394 0.056	763 0.104
Protohyale (*Protohyale*) *schmidtii* (Heller, 1866)	192 0.336	128 0.11	71 0.054	1352 1.512	2398 2.67	625 0.466	1498 1.444
Stenothoe monoculoides (Montagu, 1813)	100 0.008	688 0.053	1154 0.082	1709 0.108	2796 0.252	2753 0.196	5488 0.374
Decapoda							
Athanas nitescens (Leach, 1814)	8 0.004	22 0.014	9 0.081	34 0.028	6 0.012	6 0.003	48 0.046
Clibanarius erythropus (Latreille, 1818)	–	–	–	–	–	3 2.781	–
Decapoda juv.	–	9 0.004	–	–	–	–	–
Diogenes pugilator (P. Roux, 1829)	–	–	–	7 0.115	–	–	–
Hippolyte leptocerus (Heller, 1863)	–	6 0.029	–	–	–	6 0.018	35 0.228
Macropodia czernjawskii (Brandt, 1880)	–	–	4 0.092	–	–	–	–
Palaemon elegans Rathke, 1836	–	–	–	2 0.008	–	–	–
Pilumnus spinulosus Kessler, 1861	17 0.733	28 2.428	43 2.739	20 0.654	–	19 0.397	13 0.966
Pisidia bluteli (Risso, 1816)	142 2.054	88 1.327	102 2.453	80 1.64	35 0.532	81 0.845	80 0.869
Processa edulis (Risso, 1816)	–	6 0.275	13 0.479	–	–	–	–
Tanaidacea (Anisopoda)							
Chondrochelia savignyi (Kroyer, 1842)	8 0.0004	41 0.007	105 0.026	114 0.023	610 0.123	41 0.005	1360 0.211
Tanais dulongii (Audouin, 1826)	–	–	2 0.0004	–	6 0.005	–	–

Taxon	Sampling site						
	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdolikovaya
			Cumacea				
Cumella (*Cumella*) *pygmaea* G.O. Sars, 1865	–	–	–	–	–	–	8 0.0008
Nannastacus euxinicus Băcescu, 1951	–	–	16 0.002	30 0.004	48 0.005	–	78 0.01
			Isopoda				
Dynamene bidentata (Adams, 1800)	42 0.099	38 0.065	48 0.071	359 0.469	169 0.257	44 0.118	333 0.47
Elaphognathia bacescoi (Kussakin, 1969)	–	–	–	–	–	–	3 0.0005
Idotea balthica (Pallas, 1772)	–	–	–	–	2 0.001	6 0.007	8 0.002
Stenosoma capito (Rathke, 1837)	–	–	2 0.0005	–	–	6 0.01	23 0.131
			Mysidacea				
Mysida gen. sp.	–	–	2 0.001	–	6 0.004	–	3 0.006
			Cirripedia				
Amphibalanus improvisus (Darwin, 1854)	–	3 0.027	2 0.015	5 0.138	–	3 0.019	38 0.792
CHIRONOMIDAE LARVAE gen. sp	–	3 0.002	–	19 0.002	25 0.003	–	43 0.008
Copepoda gen. sp.			25 0.00005	63 0.00012	103 0.00023		
Ostracoda gen. sp.				38 0.00525			
TOTAL	**809** **3.32**	**2379** **4.58**	**3780** **6.84**	**7637** **6.72**	**20360** **6.67**	**10797** **6.004**	**22029** **8.64**
Actiniidae	83 0.142	3 0.003	21 0.013	25 0.014	104 0.048	13 0.006	–
TOTAL	**15431 ± 9983** **2528.63 ± 2489**	**13300 ± 1103** **3421.38 ± 2637**	**42848 ± 31 206** **3744.2 ± 1880.86**	**27770 ± 9066** **5712.6 ± 3627.**	**55006 ± 32341** **692.84 ± 492.4**	**24293 ± 19261** **1291.74 ± 1073.8**	**40395 ± 17420** **777.067 ± 406.1**

According to FAI, a direct estimated equivalent of the energy role of aquatic organism, a community of *M. lineatus* was identified in the entire study area.

Each group of aquatic organisms contributed differently to the species composition and total abundance and biomass (Table 1).

The class Polychaeta is represented by 38 species belonging to 17 families. The most diversely represented polychaete families are Syllidae (7 species), Nereididae (5), and Phyllodocidae (5 species).

The average abundance and biomass of polychaetes in the study area are 1693 ind./m^2 and 5.38 g/m^2, respectively. *Polyophthalmus pictus* (34%) dominates by abundance in macrozoobenthos communities, large polychaete *Alitta succinea*, by biomass (71.8%). All registered polychaete species prefer to inhabit various substrates and macrophyte thickets in coastal zones (Kiseleva, 2004).

The dominant species (occurrence > 50%; according to: Vorobiev, 1949) of polychaetes are *Eulalia viridis*, *Harmothoe reticulata*, *Nereis zonata*, *Pholoe inornata*, *Phyllodoce mucosa*, *Platynereis dumerilii*, *P. pictus*, *Salvatoria clavata*, *Syllis hyalina*, *S. gracilis*, and *S. prolifera*. All these species are characterized by their habitat in the coastal zone in the algae thickets, as a component of the fouling communities, in the mussel and *Mytilaster* clusters (Kiseleva, 2004). Rarely found polychaete species (occurrence < 25%) are represented by 17 species: *Amphiglena mediterranea*, *Capitella capitata*, *Fabricia stellaris*, *Ficopomatus enigmaticus*, *Haplosyllis spongicola*, *Harmothoe extenuata*, *Harmothoe imbricata*, *H. impar*, *Lagis neapolitana*, *Leiochone leiopygos*, *Neodexiospira pseudocorrugata*, *Perinereis cultrifera*, *Phyllodoce maculata*, *Polycirrus jubatus*, *Protoaricia capsulifera*, *Schistomeringos rudolphi*, and *Spirobranchus triquetter*.

Only 13 species of polychaetes were recorded at all sampling sites. Five species of polychaetes – *F. stellaris* (1 ind., Zolotye Vorota), *L. leiopygos* (1 ind., Zolotye Vorota), *N. pseudocorrugata* (2 ind., Serdolikovaya Bay) *P. capsulifera* (1 ind., Serdolikovaya Bay), and *H. spongicola* (1 ind., Ivan Razboynik) – were recorded each in one sample only out of 66 samples in total.

Amphiglena mediterranea is a rare species recorded previously in August 2015 at a depth of 1.5 m along the coast of Romania (Surugiua and Capa, 2020). This species was not included in the list of Karadag Nature Reserve polychaete species (Murina et al., 2004). In our samples, *A. mediterranea* is found in the fouling communities at Zolotye Vorota Rock (1-m depth, 3 ind.; 5-m depth, 6 ind.) and at Mayak Rock (1-m depth, 6 ind.).

Protoaricia capsulifera is a rare species, single specimens of which were noted by N.V. Bobretsky and S.A. Zernov in the sand sediments of Sevastopol Bay (Kiseleva, 2004). This species is absent from the list of Karadag Nature Reserve polychaete species (Boltacheva et al., 2015; Mazlumyan et al., 2009; Murina et al., 2004; Revkov et al., 2015). In our samples, a single specimen of *P. capsulifera* is found in Serdolikovaya Bay at a depth of 1 m.

Crustaceans are represented by 43 species belonging to 31 families. The largest number of species is found for the Caprellidae and Hyalidae families (3 species in each), the other families are represented by two or one species.

The order Decapoda is represented by nine species. The representatives of this order are very mobile and are rarely included in benthic samples obtained by frame. Visual observations provided additional information about these animals, resulting in eight more species being added to the Decapoda list: *Palaemon adspersus* Rathke 1836, *Polybius depurator* (Linnaeus, 1758), *Polybius vernalis* (Risso, 1827), *Carcinus aestuaries* Nardo, 1847, *Brachynotus sexdentatus* Risso, 1827, *Eriphia verrucosa* (Forskål, 1775), *Pachygrapsus marmoratus* (Fabricius, 1793), and *Xantho poressa* (Olivi, 1792). Therefore, the number of Malacostraca species has increased up to 51.

The average crustacean abundance and biomass in the study area were 9646 ind./m^2 and 5.96 g/m^2, respectively. Amphipods *Stenothoe monoculoides* (21.8%) made the greatest contribution to the total abundance, decapods *Pisidia bluteli*, to the total biomass (23.3%). Amphipoda made a significant contribution to the total abundance and biomass of all Arthropoda taxa (92 and 44%, respectively). Key arthropod species were *Ampithoe ramondi*, *Apherusa bispinosa*, *Biancolina algicola*, *Caprella acanthifera*, *C. liparotensis*, *Dexamine spinosa*, *Microdeutopus gryllotalpa*, *Pleonexes helleri*, *Plumulojassa ocia*, *Protohyale schmidtii*, and *S. monoculoides* (Amphipoda); *Athanas nitescens*, *Pilumnus spinulosus*, and *P. bluteli* (Decapoda); *Chondrochelia savignyi* (Tanaidacea); and *Dynamene bidentata* (Isopoda).

Twenty rarely found crustacean species were represented by *Apohyale perieri*, *Caprella mitis*, *Colomastix pusilla*, *Hyale pontica*, *Melita palmata*, *Microdeutopus versiculatus*, and *Monocorophium acherusicum* (Amphipoda); *Clibanarius erythropus*, *Decapoda* juv., *Diogenes pugilator*, *Hippolyte leptocerus*, *Macropodia czernjawskii*, *Palaemon elegans*, and *Processa edulis*

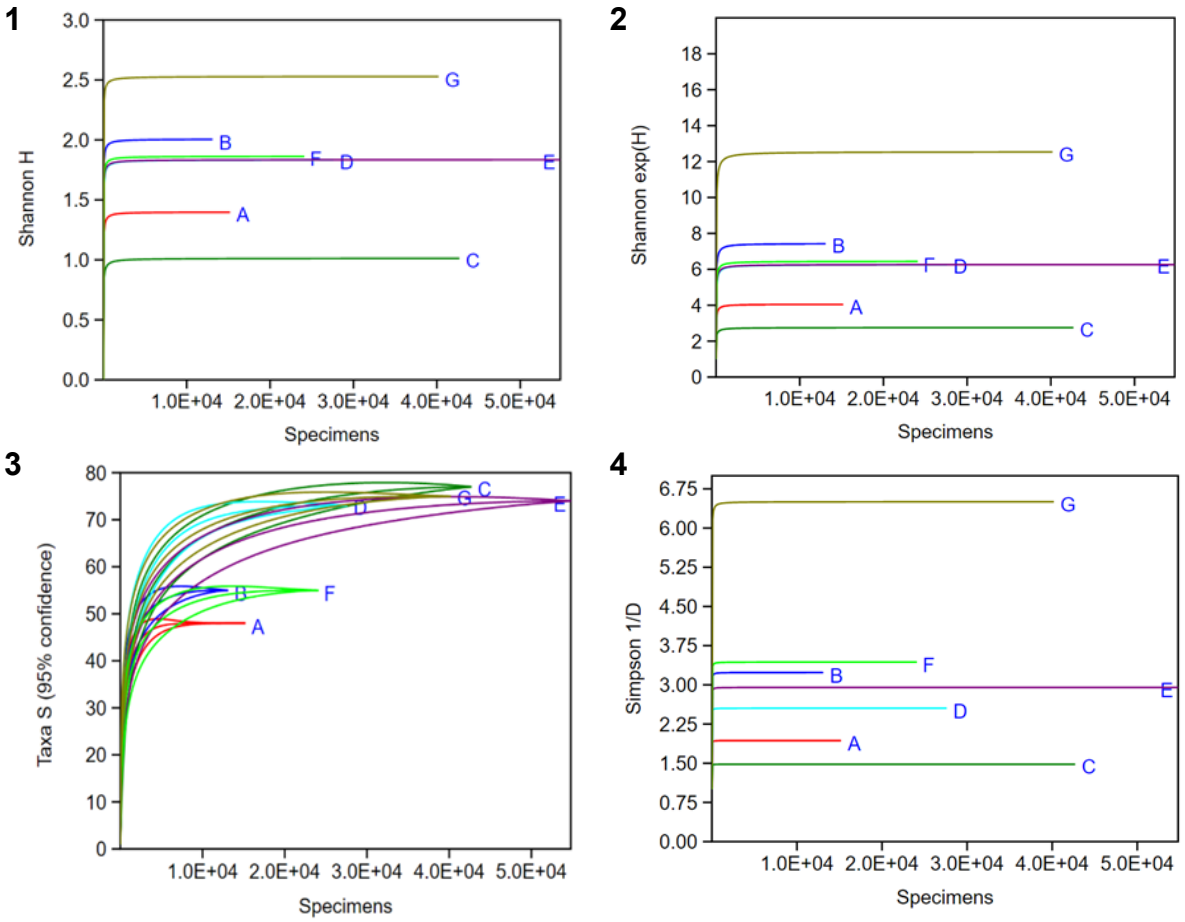

Fig. 2. Changes in diversity indices and species richness: **1** – Shannon index *H*, **2** – Shannon index (exp)H, **3** – Taxa index S, **4** – Simpson index (1-D) for benthic communities from different sampling sites. A – Kuzmichev Kamen' Rock, B – Ivan Razboynik Rock, C – Zolotye Vorota Rock, D – Lev Rock, E – Mayak Rock, F – Barakhta Bay, G – Serdolikovaya Bay.

(Decapoda); *Cumella pygmaea* (Cumacea); *Elaphognathia bacescoi*, *Idotea balthica*, and *Stenosoma capito* (Isopoda); *Mysida* gen. sp. (Mysidacea); and *Tanais dulongii* (Tanaidacea).

Thirteen crustacean species were recorded at all sampling sites (Bondarenko and Timofeev, 2023). Eight species of crustaceans, including Amphipoda (*C. mitis* in Barakhta Bay, *C. pusilla* at Mayak Rock), Decapoda (*C. erythropus* in Barakhta Bay, *D. pugilator* at Lev Rock, *M. czernjawskii* at Zolotye Vorota Rock, *P. elegans* at Lev Rock), Isopoda (*E. bacescoi*) and Cumacea (*C. pygmaea*), both in Serdolikovaya Bay, were recorded in only one sample at each site. In total, five specimens of *M. czernjawskii* were found, *C. mitis* (3), *C. pygmaea* (3), *D. pugilator* (3), *P. elegans* (3 specimens), other crustacean species, by one specimen each.

Two species of Decapoda, listed in the Red List of the Republic of Crimea (Krasnaya Kniga..., 2015) have been found at all sampling sites, *E. verrucosa* and *P. marmoratus* (Bondarenko and Timofeev, 2023).

Usually, *Eriphia verrucosa* is found from the water's edge down to a 40-m depth. During the reproduction season (May–July), the species migrates to shallow depths (up to 1 m). *E. verrucosa* prefers rocky and stony substrates with thickets of aquatic vegetation. This onmivorous species feeds on various small mollusks, fish, shrimp, and organic debris. Species fecundity is quite high, it is capable to produce a single clutch containing up to 130000 eggs. The maximum carapace size (length 61.9 mm, width 75.9 mm, height 34.8 mm) and weight (130 g) were recorded for a female caught near Lev Rock.

Pachygrapsus marmoratus is a coastal species, found from the water's edge to the 10-m depth. It is found primarily on coastal rocks and stones, preferring hard substrates with aquatic vegetation. This Onmivorous species feeds on algae, benthic invertebrates, and organic debris. The maximum carapace size (length 38.7 mm, width 42.8 mm, height 16.8 mm) and weight (38.5 g) were recorded for a male caught near Mayak Rock.

It is worth noting the appearance of three species of Amphipoda (*C. pusilla*, *M. versiculatus*, and *Monocorophium acherusicum*), one Decapoda species (*P. edulis*), and one representative of Tanaidacea (*T. dulongii*) in the benthic samples of 2021 (Bondarenko and Timofeev, 2023).

Mollusks are represented by 18 species from 12 families from the orders Polyplacophora (2 species), Bivalvia (4 species) and Gastropoda (12 species). The largest number of species is noted for the families Rissoidae (4 species) and Pyramidellidae (3 species), the other families are represented by two or one species. Mollusks of the genus *Rissoa* are widespread and eurytopic in the Black Sea (Chukhchin, 1984). Species belonging to the family Pyramidellidae (*Brachystomia eulimoides*, *Parthenina indistincta*, and *P. interstincta*) live mainly on hard substrates (Makarov, 2021).

The average values of abundance and biomass of mollusks in the study area are 19468 ind./m^2 and 2583.57 g/m^2, respectively. Representatives of Mytillidae family has the highest contribution to the total abundance and biomass, 94 and 99.6%, respectively.

Among the mollusks, three key species are noted: bivalves *Mytilaster lineatus* and *Mytilus galloprovincialis,* and gastropod *Rissoa splendida.* The latter is a widespread, eurytopic, and relatively abundant species in the Black Sea, including at hard natural substrates off the coast of Crimea (Chukhchin, 1984; Makarov and Kovaleva, 2017). The frequency of occurrence of *M. lineatus* was high (80%)*, M. galloprovincialis* and *R. splendida* were less common (51 and 54%, respectively). The maximum abundance of *M. lineatus* in the sample reached 213875 ind./m^2, that of *Tricolia pullus* was much lower (9100 ind./m^2). The other mollusk species belonged to rarely found ones, their frequency of occurrence did not exceed 25%; they were present in one or two samples of macrozoobenthos.

Mytillids *M. galloprovincialis* and *M. lineatus* were found at all sampling sites. Two mollusk species – *Setia valvatoides* (2 ind., 1-m depth, Lev Rock) and *Flexopecten glaber* (1 ind., 5-m depth, Mayak Rock) – were registered only once. *S. valvatoides* mainly prefers other biotopes and is not typical for hard substrates (Chukhchin, 1984). *F. glaber* is included in the Red Data Book of the Republic of Crimea (Krasnaya Kniga..., 2015).

According to the distribution of aquatic organisms by depth, *M. lineatus* dominated by abundance at all sampling sites. In Barakhta Bay, Ivan Razboynik Rock, and Zolotye Vorota Rock, the highest macrozoobenthos abundance was recorded at a depth of 0 m; the share of *M. lineatus* in the total abundance was 56, 68, and 87%, respectively. At Kuzmichev Kamen', Lev, and Mayak rocks and in the Serdolikovaya Bay, the highest macrozoobenthos abundance was recorded at the 1-m depth; the share of *M. lineatus* there was 54, 58, 67, and 35%, respectively.

According to the FAI graph (Fig. 3), the highest index values belong to the bivalve mollusks *M. lineatus* and *M. galloprovincialis,* which usually settle on rocks, stony and sandy soils, in the fouling communities of underwater artificial structures and stones at the 0–70-m depths. These eurybiont species stand water temperatures from +1 to +28 °C and salinity fluctuations from 3–4‰ to 30–35‰. In addition, these species, living in the coastal zone of the sea, are able to survive in conditions of temporary hypoxia and tolerate the presence of hydrogen sulfide (Karpevich, 1940; Kopiy and Bondarenko, 2020; Shcherban and Vyalova, 2001; Varigin and Rybalko, 2014). Next comes the gastropod *T. pullus,* which inhabits macrophytes at rocky biotopes. It is typically found from the water's edge down to a 20-m depth. This species may stand low oxygen content and can survive in conditions with relatively high levels of chloroform-extractable substances and petroleum hydrocarbons in the sediments (Anistratenko et al., 2007; Chukhchin, 1984; Golikov and Starobogatov, 1972; Kopiy and Bondarenko, 2020; Kovaleva et al., 2014; Tikhonova and Alemov, 2012; Opredelitel'..., 1972). Amphipod *P. schmidtii* and decapod *P. bluteli* also belong to eurybiont species. It is known that *P. schmidtii* is a phytophagous species inhabiting periphyton and macrophytes at 0–12-m depths (Grintsov, 2004, 2022). *Pisidia bluteli* is an onmivorous species found primarily in shallow waters (up to 40 m) under rocks, on sandy bottoms with algae thickets, in rock crevices, and in mussel clusters along the entire coast of the Crimean Peninsula. In the coastal waters of Crimea and the Caucasus, the plankton larvae of this crab-like crustacean are registered from late spring to early autumn at water temperatures of 10–25 °C (Kosyakina, 1936; Makarov, 2004; Zernov, 1913). *P. bluteli* makes up a large portion of the diet of some bottom-dwelling fish species (Zakutskiy, 1965).

Dominance-diversity graphs of macrozoobenthos, based on its abundance and biomass, were developed to assess the evenness of species in the community (Figs. 4**A**, 4**B**). It is known that a community is stable if it has a large number of species and high evenness (Mazlumyan et al., 2009). The graph shows that the dominance-diversity curve includes a large number of species, with only one

species of bivalve mollusks dominating in abundance and biomass (*M. lineatus*). Amphipods *Stenothoe monoculoides*, *C. acanthifera*, and *C. liparotensis* were subdominants by abundance, bivalves *M. galloprovincialis,* gastropods *T. pullus,* polychaetes *A. succinea* and *N. zonata,* by biomass.

Species evenness is low, and dominance is high, suggesting that habitat conditions for aquatic organisms were relatively unfavorable during the study period. In 2011–2012, habitat conditions were also unfavorable for the Karadag Nature Reserve communities of hard substrates (Kovaleva et al., 2014).

The Sørensen-Czekanowski index, the measure of the faunistic similarity of the species composition, varied from 0.63 to 0.84, which indicated a high degree of similarity between the studied habitats (Table 2).

The trophic structure of the periphyton community was represented by onmivorous (34 species), phytophagous (21 species), predators (17 species), detritivorous (10 species), sestonophagous taxa (5 species), and 16 species with the unknown food spectra (Figs. 5**A**, 5**B**).

In terms of the number of species (Fig. 5**A**), onmivorous taxa predominated. Among them, the largest share (47%) belonged to crustaceans, a smaller contribution (35%) was made by polychaetes. In terms of abundance (Fig. 5**B**), sestonophagous species predominated, among which bivalve mollusk *M. lineatus* made a significant contribution (98%). In terms of biomass, sestonophagous species predominated (99%), and *M. lineatus* played the first role again, its share was 86%. The contribution of other groups to the total biomass is insignificant: 0.39% of phytophagous, 0.33% of onmivorous, 0.05% are the species with an unknown feeding spectrum, predators and detritivorous species contributed 0.02% each.

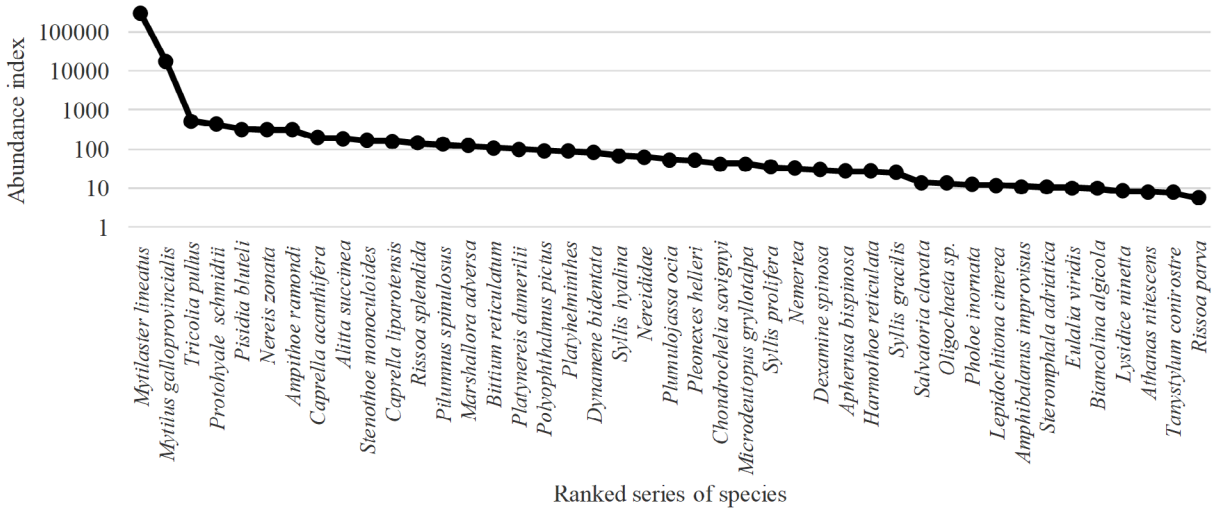

Fig. 3. Ranked series of macrozoobenthos species according to the functional abundance index (FAI).

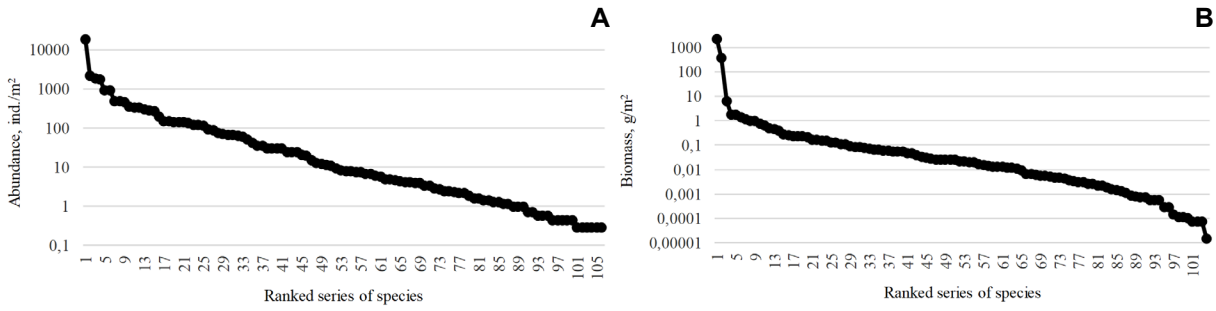

Fig. 4. Dominance and diversity of macrozoobenthos species at the marine rocky environment of Karadag Nature Reserve in 2021–2022. **A** – by abundance, **B** – by biomass.

Table 2. Comparative analysis of the species composition of macrozoobenthos at the marine rocky environment of Karadag Nature Reserve in 2021–2022 according to the Sørensen-Czekanowski index.

	Kuzmichev Kamen'	Ivan Razboynik	Zolotye Vorota	Lev	Mayak	Barakhta	Serdoli-kovaya
Kuzmichev Kamen'	0	–	–	–	–	–	–
Ivan Razboynik	0.78	0	–	–	–	–	–
Zolotye Vorota	0.64	0.69	0	–	–	–	–
Lev	0.74	0.77	0.81	0	–	–	–
Mayak	0.69	0.67	0.84	0.79	0	–	–
Barakhta	0.75	0.71	0.68	0.73	0.71	0	–
Serdoli-kovaya	0.63	0.69	0.78	0.81	0.78	0.73	0

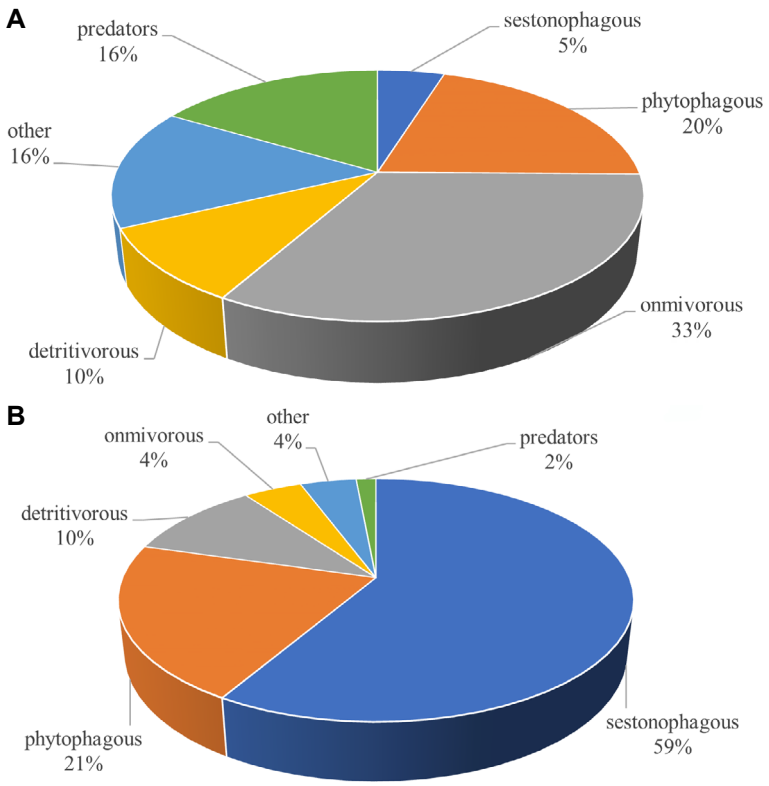

Fig. 5. Trophic structure of macrozoobenthos fouling communities at the marine rocky environment of Karadag Nature Reserve in 2021–2022. **A** – by species diversity, **B** – by abundance.

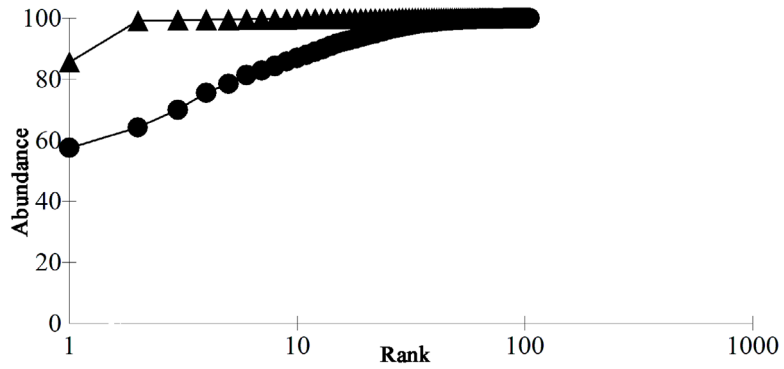

Fig. 6. The *k*-dominance curves of abundance (●) and biomass (▲) for macrozoobenthos communities at the marine rocky environment of Karadag Nature Reserve in 2022–2023.

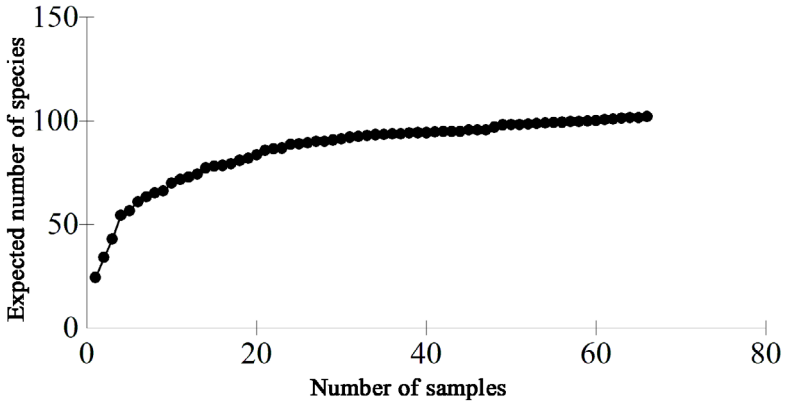

Fig. 7. Cumulative curve of the expected number of macrozoobenthos species (Sexp) at the marine rocky environment of Karadag Nature Reserve in 2022–2023.

The *k*-dominance curves, corresponding to the abundance and biomass of each species, were developed to assess changes in the rocky biotope under the influence of environmental factors (Fig. 6). In the graph, the biomass curve is located above the abundance curve, i.e., the community is more diverse in abundance than in biomass. Consequently, a predominance of *k*-strategy taxa, characteristic of an undisturbed community, is observed. Therefore, we assume that there was no environmental stress for the periphyton macrozoobenthos during the study period (Mazlumyan et al., 2009; Warwick, 1986).

The completeness of our data is characterized by the species cumulative curve (Fig. 7). Because the curve gradually increases but does not reach a horizontal asymptote, there is a possibility of discovering new species in the study area.

Conclusions

During 2021–2022, a total of 106 macrozoobenthic species are recorded in the fouling communities on the rocky substrates at 0–5-m depths in Karadag Nature Reserve. These include Polychaeta (38 species), Crustacea (43), Mollusca (18), Pycnogonida (Pantopoda; 2), as well as taxa identified only to higher levels: Acari, Ascidiidae, Platyhelminthes, Nemertea, and Actiniaria.

The average abundance and biomass of macrozoobenthos is 35355 ± 9958 ind./m^2 and 2678.38 ± 909.73 g/m^2, respectively. The highest macrozoobenthos abundance is recorded in the periphyton community at Mayak Rock (54878 ind./m^2), the highest biomass, at Lev Rock (5712.62 g/m^2). In the periphyton community of the Serdolikovaya Bay, crustaceans make a significant contribution to the total abundance (54%), in the remaining areas, these are mollusks (from 49 to 86%).

Three species included into the Red List of the Republic of Crimea, are registered: two species of decapod crustaceans (*Eriphia verrucosa* and *Pachygrapsus marmoratus*) and one species of bivalve mollusks (*Flexopecten glaber*).

Mytilaster lineatus community is common throughout the entire study area, as based on the functional abundance index. Species evenness in the community is low, with a large number of subdominant species and one dominant species.

The trophic structure of the rock community is represented by onmivorous, phytophagous, predators, detritophagous, sestonophagous taxa, and species with an unknown food spectra. Onmivorous taxa dominate by species number, while sestonophagous, by abundance and biomass. Among sestonophagous species, *Mytilaster lineatus* makes a significant contribution to the total abundance and biomass (98% and 86%, respectively).

The obtained results provide an idea of the species composition and quantitative characteristics of the macrozoobenthos communities of the rocky shores of Karadag Nature Reserve. These data may be useful for further monitoring of the area.

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