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Original paper

Spatiotemporal Changes in Macrophytobenthos in the Western Part of Sevastopol Bay (Black Sea)

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Abstract

For the first time, the paper presents data on the interannual dynamics of quantitative indicators of macrophytobenthos. A comparative analysis of spatiotemporal changes in the contribution of dominant macrophyte species in the western part of Sevastopol Bay over a 40-year period was performed. Hydrobotanical studies were carried out in the summer period of 1977, 2008 and 2017 on the same transects using standard methods. It was revealed that during the period under study, polydominant phytocommunities were formed in the composition of bottom vegetation, dominated by species inhabiting highly euthrophic environments, with a high proportion of epiphytic algae and an insignificant role of *Gongolaria barbata*. Over the studied period, the lower boundary of macrophyte growth rose and a sharp decrease in macrophytobenthos biomass was registered at a depth of over 5 meters. It was established that changes in the distribution and composition of bottom vegetation in the western part of the bay were caused by its geo-ecological state, which depends on the impact of anthropogenic and natural factors. The construction of hydraulic structures in the bay leads to redistribution of sea grasses growing on soft soils and algae occurring on a hard substrate. It was revealed that after extreme storms, the vegetation cover is predominated by seasonal and annual algae species, with only juvenile *Gongolaria barbata* beds observed at a depth of 0.5–1 m. The obtained results can be used to monitor the ecological situation in the bay and to organize the coastal-marine nature management.

Keywords: coastal zone, bottom vegetation, *Gongolaria barbata*, sea grasses, Black Sea, Sevastopol, Sevastopol Bay

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Пространственно-временные изменения макрофитобентоса в Севастопольской бухте (Черное море)

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Аннотация
Впервые приведены сведения о межгодовой динамике количественных показателей макрофитобентоса и проведен сравнительный анализ пространственно-временных изменений вклада доминирующих видов макрофитов в западной части Севастопольской бухты за 40-летний период. Гидроботанические исследования выполняли в летний период 1977, 2008 и 2017 гг. на одних и тех же разрезах по стандартной методике. Выявлено, что на протяжении изучаемого периода в составе донной растительности сформировались полидоминантные фитосообщества, где господствуют виды, обитающие в среде с повышенным уровнем эвтрофирования. При этом отмечены высокая доля эпифитирующих водорослей и незначительная роль *Gongolaria barbata*. За исследуемый промежуток времени произошло поднятие нижней границы произрастания макрофитов и зарегистрировано резкое снижение биомассы макрофитобентоса на глубине свыше 5 м. Установлено, что изменения в распределении и составе донной растительности в западной части бухты обусловлены ее геоэкологическим состоянием, которое зависит от воздействия антропогенных и природных факторов. Строительство в бухте гидротехнических сооружений приводит к изменению распространения зарослей морских трав, обитающих на мягких грунтах, и водорослей, встречающихся на твердом субстрате. Выявлено, что после экстремальных штормов в составе растительного покрова преобладают сезонные и однолетние виды водорослей, при этом на глубине 0.5–1 м отмечаются лишь ювенильные слоевища *Gongolaria barbata*. Полученные результаты могут быть использованы для мониторинговых исследований экологической ситуации в бухте, а также при организации прибрежно-морского природопользования.

Ключевые слова: прибрежная зона, донная растительность, морские травы, *Gongolaria barbata*, Черное море, Севастополь, Севастопольская бухта

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Introduction

In recent years, a notable increase in the level of eutrophication of the Crimean peninsula coastal zone has been attributed to a number of factors including an increase in the volumes of untreated wastewater, uncontrolled recreational load and active construction on the coast [1–3]. The most significant anthropogenic impact on the ecological state of the coastline is evident in bays and port water areas.

Sevastopol Bay is a water area subject to active economic utilisation. Currently, it functions as a reservoir that receives industrial and domestic wastewater as well as stormwater from the surrounding catchment area. On a daily basis, up to 10,000–15,000 m^3 of untreated or conditionally clean water is discharged into the bay resulting in the introduction of a diverse range of chemical compounds of organic and inorganic origin into it [4, 5]. This unfavourable ecological situation in the bay has resulted in significant alterations to the composition and biomass of the macrophytobenthos, with the potential for complete degradation observed in certain areas of the water body.

The current state of the macrophytobenthos in Sevastopol Bay is not well documented [6, 7]. The growth of certain species of macrophytes in the Black Sea, particularly in Sevastopol Bay, was first documented in the works of N. N. Voronikhin in the early 20th century [1), 2)]. The author noted that algae and higher aquatic vegetation grow on a particular type of substrate. During the same period, S. M. Pereyaslavtseva made a map of the bay showing the distribution of benthic communities [3)]. Later, S. A. Zernov presented a map of the distribution of bottom vegetation in Sevastopol Bay [4)]. The author showed that in the early 20th century, the bottom biocenoses of the bay followed the general pattern of the Black Sea biocenoses where the distribution of macrophytobenthos was mainly determined by the substrate (cystosira was found on hard substrates and sea grasses on soft substrates) [4)]. The paper suggests that significant changes in the state of biocenoses will occur in the bay under the influence of anthropogenic activities [4)]. It is notable that by the 1930s the bay had already been considerably polluted, which resulted in negative changes to the local fauna [8].

The first hydrobotanical survey of macrophytobenthos in Sevastopol Bay was carried out by A. A. Kalugina-Gutnik in 1967 [5)]. The materials presented in the work provide an overview of the species composition and calculate the biomass of macrophytes at varying depths across different regions of the bay. Subsequently, in 1977, A. A. Kalugina-Gutnik proceeded with her investigation of the bottom vegetation of the bays situated along the coastline of Sevastopol [9].

It is notable that over the last 40 years, the level of pollution in the bay has fluctuated repeatedly due to a range of socio-economic factors. Therefore, it is necessary to implement a monitoring programme to observe changes in the composition and structure of the macrophytobenthos, which is considered to be a bioindicator of the marine environment state.

[1)] Voronikhin, N.N., 1908. [On Distribution of Algae in the Black Sea near Sevastopol]. *Botanichesky Zhurnal. Trudy Imperatorskogo Sankt-Peterburgskogo Obshchestva Estestvoispytateley*, (7), pp. 181–198 (in Russian).

[2)] Voronikhin, N.N., 1909. [Red Algae (Rhodophyceae) of the Black Sea]. *Trudy Imperatorskogo Sankt-Peterburgskogo Obshchestva Estestvoispytateley*, 40(3–4), pp. 175–356 (in Russian).

[3)] Pereyaslavtseva, S.M., 1910. [Materials to Characterize the Black Sea Flora]. In: N. N. Voronikhin, ed., 1910. *Zapiski Imperatorskoy Akademii Nauk*. Saint Petersburg: Imperatorskaya Akademiya Nauk. Vol. 25, iss. 9, pp. 39 (in Russian).

[4)] Zernov, S.A., 1913. [On Studying Life of the Black Sea]. In: IAS, 1913. *Zapiski Imperatorskoy Akademii Nauk*. Saint Petersburg: Imperatorskaya Akademiya Nauk. Vol. 32, iss. 1, 304 p. (in Russian).

[5)] Kalugina-Gutnik, A.A., 1974. [Bottom Vegetation of Sevastopol Bay]. In: AS USSR, 1974. *Biologiya Morya*. Kiev: Naukova Dumka. Iss. 32, pp. 133–164 (in Russian).

The objective of this study is to identify the distinctive characteristics of the macrophytobenthos distribution interannual dynamics in the western part of Sevastopol Bay over the period 1977–2017.

Materials and methods of study

The length of Sevastopol Bay is approximately 7.5 km, with a maximum width of 1 km (Fig. 1). At the entrance to the bay, the depth reaches 20 m, at the top – 5 m. The bay was formed due to the flooding of the mouth of the Chernaya River during the post-glacial sea level rise. The shores of the bay are characterised by elevated terrain, comprising Sarmatian limestone, and the coastline displays a pronounced indentation. The coastal relief is dissected by gullies, the extensions of which give rise to smaller bays and concavities of the coastline. The shore type can be defined as abrasion-embayed ingression ria [10]. In modern conditions, the coastal zone has been significantly transformed (concreting of the coastline, construction of breakwaters, piers). It is established that in 2022, the untransformed shores of the bay constituted only 1.1 km (3% of the original length) of all the shoreline [11].

Sevastopol Bay is currently classified as a semi-enclosed estuarine-type water area with a relatively slow rate of water exchange [5]. The configuration of the bay renders it susceptible to wave action from the westward direction only. Since the construction of the entrance breakwaters in the late 1970s, the bay has remained largely protected from significant wave action [10]. The hydrochemical structure of the waters in the bay is primarily influenced by natural factors, namely interactions with the atmosphere, freshwater runoff from the Chernaya River into the eastern part of the bay and the inflow of saline marine waters through the entrance strait in its western part [5].

Hydrobotanical surveys in Sevastopol Bay were carried out using lightweight diving equipment and small vessels in July 2017. Macrophyte distribution and biomass were estimated for the coastal zone of the western part of the bay (profiles *1*–*4*) (Fig. 1). The coordinates of the transects were determined using an Oregon 650 portable GPS receiver (Table 1).

Fig. 1. Schematic map of the location of hydrobotanical profiles in the western part of Sevastopol Bay (*1* – Cape Konstantinovsky; *2* – Cape Khrustalny; *3* – Cape Slavy; *4* – Monument to Sunken Ships)

T a b l e 1. Coordinates and depth range of hydrobotanical profiles, number of sampled macrophytobenthos in Sevastopol Bay

Profile	Coordinates		Depth, m					Number of samples
	northern latitude	eastern longitude	0.5	1	3	5	7–10	
1	44°37'36"	33°30'44"	+	+	+	+	–	16
2	44°37'1"	33°31'2"	+	+	+	+	+	20
3	44°37'35"	33°31'59"	+	+	+	+	–	16
4	44°37'3"	33°31'29"	+	+	+	+	–	16

Note: dash – no bottom vegetation.

To study the composition of macrophytobenthos, samples were taken according to standard methods [6]. Four 25 × 25 cm survey plots were laid at depths of 0.5, 1, 3, 5, 10 and 15 m and a total of 68 quantitative samples were collected (Table 1). The dominant classification was used to describe the bottom vegetation in accordance with [7]. Shannon diversity index (*H*) was used to analyse the structure of phytocommunities. Algae were identified in accordance with [8], taking into account the latest nomenclature changes (available at: http://www.algaebase.org). Information on the composition and distribution of macrophytobenthos in the bay for 1977 and 2008 was obtained by one of the authors who participated in the collection and processing of material carried out in the summer period in the same areas using a similar methodology.

Results and discussion

The distribution of macrophytobenthos and its dominant macrophyte species in the western part of Sevastopol Bay is characterised on the basis of the conducted studies.

Distribution of bottom vegetation in the bay in 1977. In the estuary of Sevastopol Bay on the northern coastal area at profile *1* (Cape Konstantinovsky) bottom vegetation is registered up to 5 m depth. The maximum total biomass of

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[6] Kalugina-Gutnik, A.A., 1969. [Black Sea Benthic Vegetation Survey Using Light-Weight Diving Equipment]. In: AS USSR, 1969. [*Marine Underwater Studies*]. Moscow: Nauka, pp. 105–113 (in Russian).

[7] Kalugina-Gutnik, A.A., 1975. [*Phytobenthos of the Black Sea*]. Kiev: Naukova Dumka, 248 p. (in Russian).

[8] Zinova, A.D., 1967. [*Field Guide to Green, Brown and Red Algae of the Southern Seas of the USSR*]. Leningrad: Nauka, 397 p. (in Russian).

macrophytes was recorded at a depth of 3 m. At depths of 0.5 and 1 m, the quantitative index was slightly lower, while at a depth of 5 m, the biomass decreased sixfold (Table 2). *Gongolaria barbata* (Stackhouse) Kuntze (= *Cystoseira barbata*) was the most abundant species observed in the depth range studied, representing a significant proportion (Fig. 2). The macrophytobenthos included *Cladophora albida* (Nees) Kütz. and *Ulva rigida* L. The presence of epiphytic algae was not identified. The diversity index values by depth ranged widely from 0.07 to 1.48. Its low values at depths of 1 and 3 m are explained by the fact that almost pure vegetation of *Gongolaria barbata* was recorded at these depths (Table 2).

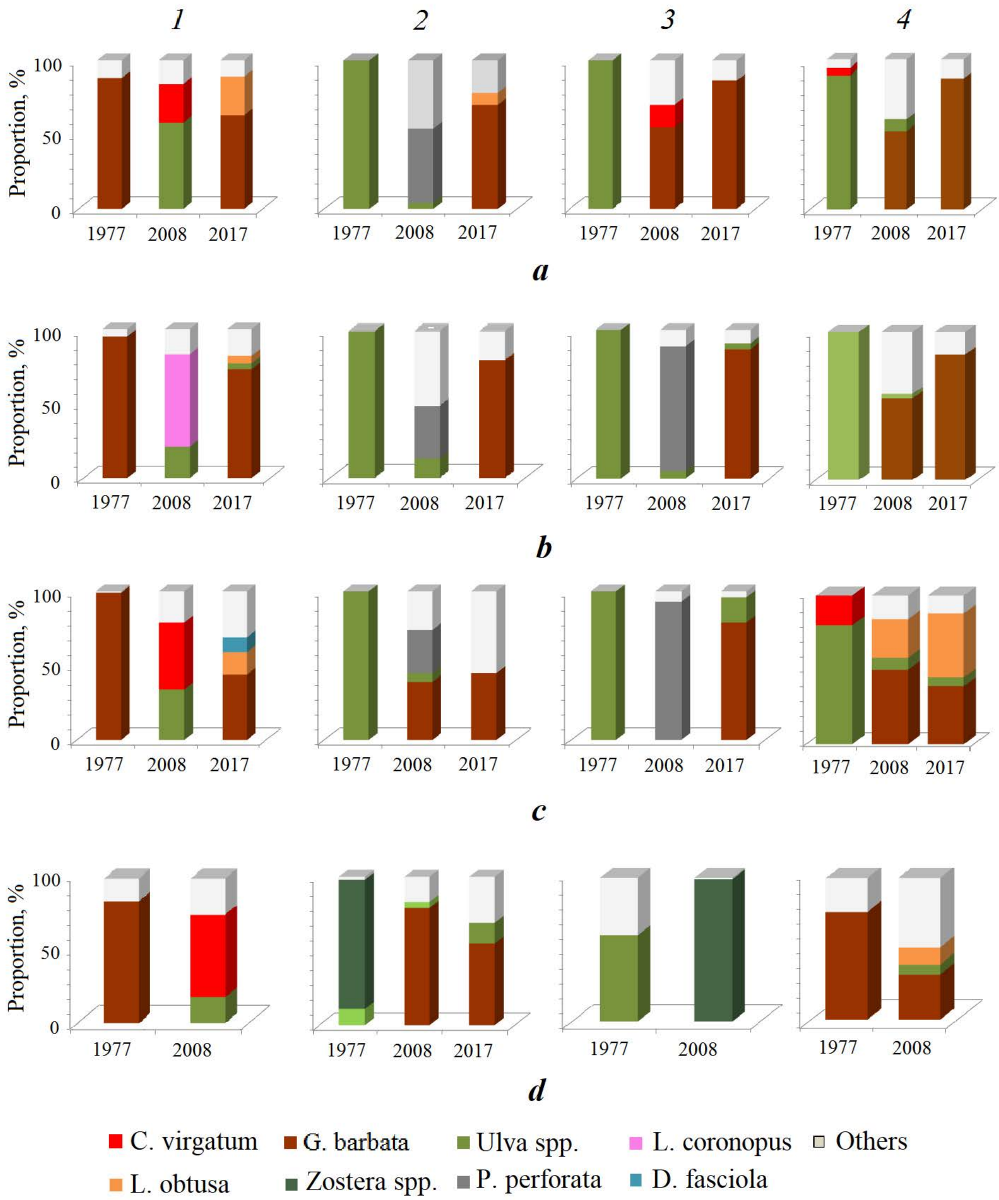
T a b l e 2. Changes in the total biomass of macrophytobenthos, percentage of its dominant and epiphytic macrophyte species, diversity index (H) in Sevastopol Bay by depth and years

Profile	Depth, m	Year	Total biomass of macrophytes, g·m^{-2}	Proportion, %		*H*
				Gongolaria barbata	Epiphytic	
1	0.5	1977	1608.4 ± 422.3	88	0	1.42
		2008	1088.9 ± 251.5	0	5	2.19
		2017	992.2 ± 302.1	63	3	1.58
	1	1977	1382.6 ± 214.9	95	0	0.31
		2008	1425.4 ± 396.4	0	11	1.99
		2017	422.6 ± 58.1	73	15	1.41
	3	1977	2249.8 ± 92.5	99	0	0.07
		2008	361.6 ± 92.6	0	5	2.52
		2017	424.3 ± 31.9	44	27	2.19
	5	1977	370.1 ± 117.7	84	0	1.48
		2008	296.5 ± 58.8	0	6	2.10
		2017	18.6±7.7	18	26	2.39
	7	2008	63.1 ± 18.7	20	23	3.37
2	0.5	1977	38.8 ± 5.2	0	0	0.64
		2008	360.2 ± 40.4	0	4	2.03
		2017	744.7 ± 330.3	70	9	1.76
	1	1977	375.0 ± 128.9	0	0	0
		2008	120.5 ± 60.2	3	6	2.54
		2017	1224.3 ± 135.5	80	17	1.24

Continued

Profile	Depth, m	Year	Total biomass of macrophytes, $g \cdot m^{-2}$	Proportion, %		*H*
				Gongolaria barbata	Epiphytic	
2	3	1977	623.8 ± 45.1	0	0	0
		2008	537.1 ± 194.4	39	2	2.31
		2017	1310.2 ± 431.9	45	48	1.86
	5	1977	600.9 ± 145.3	0	0	0.65
		2008	399.3 ± 141.3	79	14	1.29
		2017	306.3 ± 67.3	55	25	1.85
	10	2008	50.0 ± 2.9	38	1	2.32
	7	2017	13.1 ± 6.4	72	0	1.57
3	0.5	1977	623.3 ± 97.3	0	0	0.15
		2008	789.9 ± 343.9	55	3	2.11
		2017	4699.6 ± 1206.9	86	12	0.84
	1	1977	588.5 ± 128.2	0	0	0
		2008	253.3 ± 112.8	0	1	1.03
		2017	5063.6 ± 346.6	87	7	0.88
	3	1977	689.9 ± 130.7	0	0	0
		2008	202.7 ± 75.9	0	2	0.49
		2017	2322.8 ± 363.1	79	4	1.06
	5	1977	200.7 ± 76.9	0	0	0.97
		2008	228.4 ± 33.3	0	0	0.05
		2017	1.2 ± 0.54	0	0	1.23
4	0.5	1977	917.0 ± 122.4	0	0	0.77
		2008	955.9 ± 284.7	52	6	2.59
		2017	5483.0 ± 1536.9	87	8	0.97
	1	1977	1602.6 ± 127.4	0	0	0.02
		2008	1406.2 ± 431.1	55	22	2.26
		2017	3416.2 ± 1039.5	85	6	0.89
	3	1977	1079.0 ± 543,7	0	0	0.82
		2008	616.1 ± 172.1	50	4	2.06
		2017	1863.7 ± 327.0	39	10	1.91
	5	2008	270.9 ± 64.0	76	3	1.27
		2017	655.2 ± 135.5	32	39	2.42

In the estuary of Sevastopol Bay, *Ulva rigida* was the dominant species in the southern coastal area at profile *2* (Cape Khrustalny), occurring at depths of 0.5–3 m (Fig. 2). The total biomass of macrophytes in this range exhibited a 16-fold increase with increasing depth (Table 2). *Zostera noltei* Hornem predominated



F i g . 2 . Change in the proportion of dominant macrophyte species by profile and years at the depth of 0.5 m (*a*), 1 m (*b*), 3 m (*c*) and 5 m (*d*) (*1* – Cape Konstantinovsky; *2* – Cape Khrustalny; *3* – Cape Slavy; *4* – Monument to the Sunken Ships) at a depth of 5 m. *Ulva rigida* was noted among sea grasses. Epiphytes were absent. The diversity index values were low (0–0.65), indicating a monodominant structure of the phytocommunity.

Along the way further into the bay along the northern coastline, *Ulva rigida* exhibited a dominant presence at depths of 0.5–5 m at profile *3* (Cape Slavy) (Fig. 2). The total biomass of macrophytes exhibited minimal variation at depths of 0.5–3 m, demonstrating a notable decrease of approximately threefold at a depth of 5 m (Table 2). It is indicative that the macrophytobenthos is represented by accumulations of *Ulva rigida* at depth of 1–3 m, whereas *Ulva* sp. and *Bryopsis hypnoides* Lamour were noted in its composition at depths of 0.5 m and 5 m, respectively. The diversity index values provide insight into the dominant species within the algal community.

Further inland along the southern coastline of the bay, *Ulva rigida* was also dominant at depths of 0.5–3 m at profile *4* (Monument to the Sunken Ships) (Fig. 2). The maximum total biomass of macrophytes was recorded at a depth of 1 m, while at depths of 0.5 and 3 m, this index was found to be 1.7–1.5 times lower. Representatives of *Ceramium* were found in the composition of bottom vegetation at all depths. The diversity index values varied by depth from 0.03 to 0.82.

Distribution of bottom vegetation in the bay in 2008. At profile *1*, the dominant species at a depth of 0.5 m were *Ulva intestinalis* L., *U. rigida* and *Ceramium virgatum* Roth (Fig. 2). The composition of bottom vegetation also included *Callithamnion corymbosum* (Smith) Lyngb., *Ceramium diaphanum* (Lightf.) Roth. The dominant species at a depth of 1 m were *Laurencia coronopus* J. Ag. and *Ulva intestinalis*. *Ulva rigida*, *Ceramium virgatum* and species of *Cladophora* were also recorded at this depth. The depth range of 3–5 m was dominated by *Ceramium virgatum* and *Ulva rigida*. The proportion of these species exhibited considerable variation, with values ranging between 45–57 and 18–20% of the total macrophyte biomass, respectively. The total macrophyte biomass at these depths exhibited minimal variation (Table 2). It is significant that the contribution of *Ulva intestinalis* to the total macrophyte biomass decreased from 35 to 1% as the depth increased from 0.5 to 5 m. At a depth of 7 m, the total macrophyte biomass was found to be relatively low (Table 2). *Gongolaria barbata* and *Ulva rigida* dominated there. Epiphytic algae were abundant at this depth. Among them, the predominant ones were *Ceramium virgatum*, *Ectocarpus confervoides* (Roth) Le Jolis, *Laurencia coronopus* and *Vertebrata subulifera* (C. Ag.) Kütz. The diversity index values indicate a complex polydominant community structure with a high contribution of associated species and epiphytic algae.

At profile *2*, *Palisada perforata* (Bory) K.W. Nam dominated at depths of 0.5–1 m, with its proportion decreasing in this range with increasing depth from 50 to 36% of the total macrophyte biomass (Fig. 2), which also decreased threefold (Table 2). The composition of bottom vegetation included *Gelidium crinale* (Hare ex Turner) Gaillon, *Ulva intestinalis, U. rigida, Callithamnion corymbosum.* The representatives of *Cladophora* were found in both lithophytic and epiphytic forms. *Gongolaria barbata* and *Palisada perforata* predominated at a depth of 3 m. *Cladophoropsis membranacea* (Ag.) Börg., *Gelidium crinale*, *Ulva rigida* were also abundant in the composition of the macrophytobenthos. At depths of 5–10 m, *Gongolaria barbata* dominated, the proportion of which decreased by half with increasing depth, and the total biomass of macrophytes decreased by a factor of eight (Table 2). Under the cover and among the *Gongolaria barbata* beds, *Ulva rigida* was observed at a depth of 5 m, while *Cladostephus spongiosus* (Huds.) C. Ag., *Laurencia coronopus* and *Cladophora laetevirens* (Dillw.) Kütz were recorded at a depth of 10 m. Such deepwater species as *Zanardinia typus* (Nardo) P. C. Silva, *Carradoriella elongata* (Huds.) Savoie & G.W. Saunders., *Nereia filiformis* (J. Ag.) Zanard. were found in the composition of bottom vegetation at depths of 5–10 m. The greatest development of epiphytic synusia occurred at a depth of 5 m. *Vertebrata subulifera* and *Stilophora tenella* (Esper) P. C. Silva dominated among epiphytic algae. The diversity index values indicate a high proportion of associated species in the phytocommunity structure.

At profile *3*, *Gongolaria barbata* predominated at a depth of 0.5 m (Fig. 2). *Ceramium virgatum*, *Carradoriella denudata* (Dillw.) Savoie et G. W. Saunders, species of *Cladophora* and *Ulva* were abundant in the composition of the macrophytobenthos. *Palisada perforata* dominated at depths of 1–3 m, with this species accounting for 84–93% of the total macrophyte biomass. With increasing depth, the contribution of *Cladophora laetevirens* increased from 1 to 5% and that of *Ulva rigida* decreased from 5 to 1% of total macrophyte biomass. *Zostera marina* was dominant at a depth of 5 m. The contribution of epiphytic algae at all investigated depths was insignificant (Table 2). The diversity index values varied in a wide range and depended on the complexity of the community structure.

At profile *4*, *Gongolaria barbata* dominated at depths of 0.5–5 m (Fig. 2). The maximum total macrophyte biomass was recorded at a depth of 1 m, while at a depth of 0.5 m, this parameter was observed to be 1.5 times lower, and at depths exceeding 1 m, it decreased by a factor of two and five at depths of 3 and 5 m, respectively (Table 2). *Ulva rigida*, *Cladophoropsis membranacea* were found in the composition of bottom vegetation at all investigated depths. A high proportion of *G. crinale* and *Dermocorynus dichotomus* (J. Ag.) Gargiulo Morabito and Manghisi was observed at depths of 0.5–1 m, while at a depth of 3 m – the lithophytic form *Laurencia obtusa* (Huds.) J. V. Lamour., and at a depth of 5 m – *Zanardinia typus*. The contribution of *Cladophora laetevirens* decreased from 9 to 1% with increasing depth in the studied range. Epiphytes were most abundant at a depth of 1 m. *Vertebrata subulifera* and species of *Cladophora* dominated among them. High diversity index values indicate a polydominant community structure.

Distribution of bottom vegetation in the bay in 2017. In the estuary of Sevastopol Bay, bottom vegetation was recorded up to a depth of 5 m at profile *1*. *Gongolaria barbata* dominated at depths of 0.5–3 m (Table 2). The proportion of this species was observed to be at its maximum at a depth of 1 m, with a subsequent decrease in abundance with increasing depth, occurring at a rate of two and four times. The total macrophyte biomass exhibited a decrease of over 50 times with increasing depth. *Dictyota fasciola* (Roth) Howe was found in the macrophytobenthos composition at all investigated depths (Fig. 2). The proportion of this species at depths of 0.5–1 m exhibited a range of 2–4%, while at depths of 3–5 m, it showed a notable increase to 10–28% of the total macrophyte biomass.

The lithophytic form *Laurencia obtusa* was observed among *Gongolaria barbata* thickets at a depth of 0.5 m; at greater depths, this species was found as an epiphyte. *Cladophora serisea* (Huds.) Kütz. was abundant at a depth of 5 m. The contribution of epiphytic algae exhibited a notable increase with increasing depth. The shift in the diversity index suggests that the community structure becomes increasingly complex with increasing depth.

At profile *2*, *Gongolaria barbata* was predominant at depths of 0.5–5 m (Fig. 2). The total macrophyte biomass exhibited a significant increase, approximately twofold, with an increase in depth from 0.5 to 3 m (Table 2). With further increase in depth this indicator decreased more than fourfold, and at a depth of 7 m, bottom vegetation was practically absent. The proportion of the dominant species at depths of 0.5–1 m varied from 70 to 80% and decreased at depths of 3–5 m to 45–55% of the total macrophyte biomass. Green algae of *Cladophora* and *Ulva* were found in the macrophytobenthos at all depths among *Gongolaria barbata*. Deepwater species *Nereia filiformis* and *Carradoriella elongata* were recorded at depths of 3–5 m. The contribution of epiphytes increased from 9 to 17% with increasing depth (0.5 and 1 m) and decreased from 48 to 25% of total macrophyte biomass with further depth (3 and 5 m). Among the epiphytic algae, the predominant one was *Vertebrata subulifera*. The diversity index by depth varied from 1.24 to 1.86.

At profile *3*, bottom vegetation was found down to a depth of 3 m (Table 2). *Gongolaria barbata* dominated at these depths (Fig. 2). The total macrophyte biomass at depths of 0.5–1 m was found to be considerable (from 4699.6 ± 1206.9 to 5063.6 ± 346.6 $g \cdot m^{-2}$) and decreased twofold at a depth of 3 m, whereas at a depth of 5 m, macrophytobenthos was practically absent. The composition of the macrophytobenthos exhibited a notable increase in the proportion of *Ulva rigida* with increasing depth, from 1% to 17%. Conversely, the contribution of epiphytic algae demonstrated a significant decrease from 12% to 4% of the total macrophyte biomass. The epiphytes were dominated by *Shacelaria cirrhosa* (Roth) C. Ag. *Dictyota fasciola*, *Ulva rigida* and *Carradoriella elongata* occurred sporadically at a depth of 5 m. The diversity index at a depth of 0.5–3 m exhibited a narrow range (0.84–1.06) suggesting the dominance of a single species.

At profile *4*, *Gongolaria barbata* was predominant at depths of 0.5–5 m. The total biomass of macrophytes decreased eightfold with increasing depth in the studied range, and the proportion of the dominant species decreased almost threefold (Table 2). *Cladophora laetevirens* and *Ulva rigida* were noted in the composition of bottom vegetation at all depths. *Ulva* was sporadic at depths of 0.5–1 m, and at depths of 3–5 m, its proportion increased up to 6–7% of the total macrophyte biomass (Fig. 2). The lithophytic form *Laurencia obtusa* was abundant at a depth of 3 m, whereas this species epiphytised on *Gongolaria barbata* at a depth of 5 m. The greatest concentration of epiphytic algae was observed at a depth of 5 m, with significantly lower levels recorded at depths of 0.5–3 m. The most prevalent species among the epiphytes was *Vertebrata subulifera*. The diversity index values indicate that the community structure becomes more complex with increasing depth.

In the late 1970s, the western part of Sevastopol Bay was a water area that had been significantly affected by human activities. A notable proliferation of green algae was observed in the studied part of the bay (profiles *2–4*) during the specified period, with *Ulva rigida* exhibiting a marked dominance. This species is characteristically found in water with a high level of pollution from domestic sewage. It seems probable that the species composition of the macrophytobenthos has been affected by the sewage outlet from the north side urban development since 1964. Furthermore, a fish farm was situated in the vicinity of Severnaya Bay, and its operations also had a deleterious effect on benthic biocenoses. Thus, it is shown in [8] that in areas where ships and other vessels are moored, the concentration of organic and ammonium nitrogen in bottom sediments is found to be 1.5 and 5 times higher, respectively, than in the open sea.

During the construction period of the northern part of the breakwater at profile *1*, the macrophytobenthos is represented mainly by *Gongolaria barbata* (84–99% of the total macrophyte biomass), a cenosis-forming species of the Black Sea coastal zone (Table 2). Although partial water exchange with the open sea still occurred at this site in 1977, the total biomass of macrophytes at depth was 3–10 times lower than in the same year at the open coast of Omega Bay where the proportion of *Cystoseira* spp. also reached 95–98% [9].

Over the past more than 30 years (1977–2008), the composition of dominant macrophyte species has changed significantly in the studied area of the bay. At profiles *2–4*, where *Ulva* species had dominated in 1977, *Gongolaria barbata* became dominant at some depths in 2008 (Table 2). The shift in dominant species is likely indicative of a decline in water pollution. The aforementioned assumption is supported by the studies outlined in monograph [12]. The findings demonstrate that by the conclusion of the 20th century, the concentration levels of phosphates and biogenic elements indicating primarily the release of sewage and storm water were noticeably lower than in the period 1974–1983. Furthermore, it was observed that the concentration of phosphate was 16 times lower during the period 1998–1999 than it was during the 1970s.

Monograph [8] states that the concentration of such persistent organic pollutants of bottom sediments as petroleum hydrocarbons and chloroform bitumoid exhibited a slight increase in 1979–1985 in comparison to the period 1997–2000 (328–999 and 451–507 mg/100 g; 0.82–2.7 and 1.21–1.25 g/100 g). It has been established [13] that in the central part of Sevastopol Bay, in the bottom sediments at a depth of 5 to 20 cm, a zone of extremely high concentration of polychlorinated biphenyls (PCBs) was formed reaching concentrations of up to 600 $ng \cdot g^{-1}$ (per dry weight). The concentration of PCBs in the surface layer of bottom sediment in this area was observed to be slightly lower (from 200 to 450 $ng \cdot g^{-1}$), which resulted in the authors reaching the conclusion that the anthropogenic pollution of the bay had been reduced.

In June 2009, macrozoobenthos sampling was conducted at stations distributed throughout the bay. The quality of the environment in the vicinity of the Monument to Sunken Ships (profile *4*) was evaluated as “good” according to the M-AMBI index. In contrast, the quality at other stations (central and eastern parts of the bay) was classified as “moderate” or “poor” [14]. According to a number of researchers, the environmental situation of Sevastopol Bay improved during the late 1990s and early 2000s. However, this was not the result of environmental protection actions, but rather due to a reduction in the volume of sewage from industrial enterprises as a consequence of their cessation of operations as well as a decrease in oil pollution due to a reduction in the naval fleet [8, 12]. Nevertheless, the proliferation of algae

(*Ulva intestinalis, U. rigida, Cladophora laetevirens, Cl. serisea Ceramium virgatum, C. diaphanum, Callithamnion corymbosum, Carradoriella denudata, Ectocarpus confervoides*), which inhabit water with increased eutrophication, has become a pervasive phenomenon in the study areas, thus indicating the presence of pollutants in the bay.

It is characteristic that the construction of the northern (250 m long) and southern (500 m long) parts of the breakwater at the entrance to the bay has changed the longshore drift of deposits [11]. This provides an explanation for the change of substrate in some areas of the western part of the bay. As posited by the authors, the initial accumulations manifested in the form of sandbanks in both Severnaya and Aleksandrovskaya Bays. The influx of sand into the first bay has ceased entirely, while in the second bay, only residual fragments of sandbanks remain [11]. It is likely that the absence of soft substrates is responsible for the disappearance of sea grasses (*Zostera noltei*) in the area of Cape Khrustalny (profile *2*), which were previously (1977) recorded at a depth of 5 m. In 2008, algae species growing exclusively on hard substrate were found at this profile at this depth. At the same time, minor accumulations of *Zostera marina* appeared at a depth of 5 m near Cape Slavy (profile *3*).

It is possible that the distribution and composition of macrophytobenthos in the western part of the bay in 2008 were influenced by the effects of the storm. It is established that active storm activity results in the degradation and destruction of coastal biocenoses. For instance, following the most intense storm on record in 1992, a comprehensive decimation of benthic vegetation was documented in the Kara Dag region at depths of 0–10 m [15]. In November 2007, an extreme storm was recorded in the Black Sea area, with wind speeds reaching 27–32 $m \cdot s^{-1}$ and wave heights of up to 4 m [16]. It has previously been demonstrated that this storm had a negative impact on the macrophytobenthos in Laspi Bay [17]. It is well documented that the most intensive growth of macrophytes in the Black Sea occurs during the spring and summer months [8)]. Probably, that is why the bottom vegetation in the coastal zone of this part of Sevastopol Bay in summer 2008 was characterised by a high species mosaic, with annual algae species (*Ceramium* spp., *Cladophora* spp.) occurring en masse in the macrophytobenthos composition. During that period, algae of *Laurencia* (*L. coronopus, L. obtusa, L. papillosa* = *Palisada perforata*) were abundant in the studied areas of the bay (Fig. 2). It is known that the active growth of these species begins under intense sunlight and with the beginning of warming of the water column [18]. It is possible that the storm-destroyed *Gongolaria barbata*, with its thalli growing rather slowly, was originally replaced by the beds of representatives of *Laurencia* [8)] [18]. Thus, in the water area of profile *2* (Cape Khrustalny), *Gongolaria barbata* seedlings only were recorded at depths of 0.5–1 m and only at depths of 3–5 m, the proportion of this species was 39–79% of the total macrophyte biomass (Table 2).

The results of studies conducted in 2017 indicate that the western part of Sevastopol Bay is characterised by a decrease in the quantitative indicators of macrophytobenthos in the lower sublittoral zone. This trend is observed in other areas of the Black Sea coastline that have experienced an increase in eutrophication [19, 20]. The aforementioned trend precipitates a series of catastrophic outcomes in the bays.

Thus, in the area of Cape Konstantinovsky (profile *1*), at a depth of 5 m, the total macrophyte biomass decreased 20-fold and the proportion of *Gongolaria barbata* decreased 5-fold from 1977 to 2017 (Table 2). During the same period, the total biomass of macrophytes at the same depth exhibited a decrease of over two orders of magnitude in the area of Cape Slavy (profile *3*). The remaining study areas also showed a decrease in the contribution of *Gongolaria barbata* from 2008 to 2017.

It is notable that at the present time, epiphytic algae (*Vertebrata subulifera*, species of *Cladophora*) are prevalent in the macrophytobenthos at all profiles of the western part of the bay. This is attributed to their high competitive ability determined by their resistance to changing environmental conditions, rapid growth and effective assimilation of excessive amounts of organic and mineral elements [9)].

It can be reasonably deduced that the changes in the composition of the bottom vegetation in the western part of Sevastopol Bay are likely the result of a combination of natural factors and human economic activity:

– the geo-ecological situation in the bay, associated with high anthropogenic load, has led to the fact that the dominant role in the composition of macrophytobenthos belonged to species growing in the environment with an increased level of pollutants, with a high proportion of epiphytic algae, while the contribution of *Gongolaria barbata* is decreasing. In addition, a sharp decrease in the quantitative indicators of the vegetation component at depths greater than 5 m is observed. The diversity index values indicate a complex polydominant structure of phytocommunities;

– the construction of hydraulic structures in the bay, which have altered the longshore drift of deposits, has resulted in the redistribution of sea grasses growing on soft soils and algae occurring on hard substrates;

– increase in storm intensity affects the state of benthic communities negatively. It is revealed that after extreme storms, the vegetation cover is characterised by significant species mosaic and is predominated by seasonal and annual algae species, with only juvenile *Gongolaria barbata* beds observed at depths of 0.5–1 m.

Conclusion

The distribution of macrophytobenthos biomass and its constituent dominant macrophyte species by depth and years (1977, 2008 and 2017) in the western part of Sevastopol Bay was illustrated.

A comparative analysis of spatiotemporal changes in the contribution of dominant macrophyte species in the western part of Sevastopol Bay over a 40-year period was performed.

It was revealed that during the period under study, polydominant phytocommunities were formed in the composition of bottom vegetation, dominated by species inhabiting highly euthrophic environments, with a high proportion of epiphytic algae and an insignificant role of *Gongolaria barbata*. A sharp decrease in the quantitative indicators of macrophytobenthos at a depth of more than 5 m is a distinctive feature, accompanied by an upward shift in the lower boundary of the macrophyte growth.

[9)] Minicheva, G.G., 1990. [Predicting the Phytobenthos Structure Using Algal Surface Indicators]. *Botanichesky Zhurnal*, 75(11), pp. 1611–1618 (in Russian).

It was established that changes in the distribution and composition of bottom vegetation in the western part of Sevastopol Bay were caused by its geo-ecological state, which depends on the impact of anthropogenic and natural factors.

The obtained results can be used to monitor the ecological situation in the bay and to organize the coastal and marine nature management.

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