

Original paper

The Tier Structure of the *Ericaria*–*Gongolaria* Phytocenosis in the Coastal Zone of Protected Areas of Sevastopol

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Abstract

The paper describes the taxonomic diversity of the *Ericaria*–*Gongolaria* phytocenosis (*Ericaria crinita* + *Gongolaria barbata* – *Cladostephus spongiosus* – *Ellisolandia elongata*), which is the key part of the coastal ecosystems of specially protected natural areas of Sevastopol. The material was collected according to a standard procedure in the waters of six protected sites at depths of 1–5 m in summers from 2016 to 2021 during the peak of the macrophyte growing season. When analyzing the samples, we considered the species composition of the phytocenosis, the duration of life cycle of macroalgae, and their distribution by tiers and depths. The phytocenosis structure was found to be characterized by a high phytodiversity. Totally, 34 species of macroalgae were recorded. Two of them were found in the first tier, seven species were included in the second tier, and 25 taxa were represented in the third tier. The greatest diversity was found in red (Rhodophyta) algae: their share accounted for 52% of the total number of species. The contribution of brown (Ochrophyta) and green (Chlorophyta) macroalgae was 2.2 times less (24% each). In terms of life cycle, perennial and annual algae predominated: their share was 44 and 38%, respectively. The largest contribution of perennial species (70%) was registered near Cape Aya and Cape Sarych. In general, *Ericaria*–*Gongolaria* phytocenosis of different specially protected natural areas was characterized by low floral similarity: the values of the Jacquard coefficient (K_j) ranged from 7.1 to 66.7% and the average value was 21%. The taxonomic diversity, full tier structure and the predominance of perennial species indicate the stability of the key phytocenosis in specially protected natural areas of Sevastopol and effectiveness of their environmental regime.

Keywords: macrophytobenthos, *Ericaria crinita*, *Gongolaria barbata*, phytocenosis, phytocenosis vertical structure, species composition, marine protected areas, southwestern Crimea, Black Sea

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Ярусная структура эрикариево-гонголяриевого фитоценоза в прибрежной зоне особо охраняемых природных территорий Севастополя

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Аннотация

Дана характеристика таксономического разнообразия эрикариево-гонголяриевого фитоценоза (*Ericaria crinita* + *Gongolaria barbata* – *Cladostephus spongiosus* – *Ellisolandia elongata*), ключевого в составе макрофитобентоса особо охраняемых природных территорий г. Севастополя. Материал отбирали по стандартной методике в акваториях шести заповедных объектов на глубинах от 1 до 5 м в летний сезон с 2016 по 2021 г. в пик вегетационного периода макрофитов. При анализе проб учитывали видовой состав фитоценоза, продолжительность жизненного цикла макроводорослей, их распределение по ярусам и глубинам. Установлено, что ярусная структура фитоценоза характеризуется высоким разнообразием таксонов видового ранга. Из 34 выявленных видов макроводорослей в первом ярусе встречались два, во втором – семь и в третьем – 25 видов. Наибольшим разнообразием характеризовались красные (Rhodophyta) водоросли, на долю которых приходилось 52 % общего количества таксонов, вклад бурых (Ochrophyta) и зеленых (Chlorophyta) был меньше почти в 2.2 раза (по 24 %). По продолжительности жизненного цикла преобладали многолетние и однолетние водоросли, доля которых составляла 44 и 38 % соответственно, максимальный вклад многолетних видов (70 %) зарегистрирован у м. Айя и м. Сарыч. Показано, что на разных участках особо охраняемых природных территорий эрикариево-гонголяриевый фитоценоз характеризовался низким флористическим сходством, значения коэффициента Жаккара (K_j) варьировали от 7.1 до 66.7 % при среднем значении 21 %. Таксономическое разнообразие, полночленная ярусная структура и преобладание многолетних видов отражают устойчивость ключевого фитоценоза и могут свидетельствовать об эффективности действующего природоохранного режима на особо охраняемых природных территориях г. Севастополя.

Ключевые слова: макрофитобентос, *Ericaria crinita*, *Gongolaria barbata*, фитоценоз, вертикальная структура фитоценоза, видовой состав, охраняемые акватории, Юго-Западный Крым, Черное море

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Introduction

The nature conservation network of Specially Protected Natural Areas (SPNAs) in the city of Sevastopol comprises 19 sites, covering a total area of 23,768 km² (30% of the city's territory). This represents one of the highest figures among the subjects of the Russian Federation¹⁾. Although Marine Protected Areas (MPAs) account for only 3% of the total area of these protected sites, they play a significant role in conserving the biodiversity of coastal ecosystems. According to various estimates²⁾, the proportion of protected macrophyte species within the waters of SPNAs ranges from 18.2 to 45.5% of the species listed in the Red Book of Sevastopol³⁾.

The benthic vegetation of the MPA is dominated by the *Ericaria–Gongolaria* phytocenosis, comprising *Ericaria crinita* + *Gongolaria barbata* – *Cladostephus spongiosus* – *Ellisolandia elongata*, which is one of the key ecosystems for the Black Sea coastal ecosystems and is protected at the international level^{4), 5)}. The coenosis-forming species, *Ericaria crinita* (Duby) Molinari & Guiry and *Gongolaria barbata* (Stackhouse) Kuntze, also hold protected status^{6), 7)}. Along the open shores of southwestern Crimea, the *Ericaria–Gongolaria* phytocenosis forms a belt type⁸⁾ vegetation structure [1], with maximum productivity and the ecological-phytocenotic optimum of *E. crinita* and *G. barbata* recorded at depths from 1 to 5 m⁸⁾, where the influence of factors driving the transformation of benthic communities is most pronounced. The primary factor is anthropogenic impact, which leads to biotope degradation, pollution from inadequately treated or untreated domestic wastewater, etc. [2, 3].

1) Sevastopol City Administration, 2023. [Annual Report on State and Protection of Environment of the City of Sevastopol in 2023]. Sevastopol: Main Department of Natural Resources and Ecology of the City of Sevastopol. Part 1, 194 p. (in Russian).

2) Milchakova, N.A., ed., 2015. [Marine Protected Areas of Crimea. Scientific Reference Book]. Sevastopol, Simferopol: N. Orianda, 300 p. (in Russian).

3) Dovgal, I.V. and Korzhenevskiy, V.V., eds., 2018. *The Red Data Book of Sevastopol*. Sevastopol: ROST-DOAFK, 432 p. (in Russian).

4) EEC Council, 1992. *Habitats Directive 92/43/EEC*. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043> [Accessed: 22 August 2025].

5) Gubbay, S., Rodwell, J.R., Garcia Criado, M., Borg, J., Otero, M., Janssen, J.A.M., Haynes, T., Beal, S., Nieto, A. [et al.], 2016. *European Red List of Habitats. Part 1. Marine habitats*. Luxembourg: Publications Office of the European Union, 2016. 52 p. <https://doi.org/10.2779/032638>

6) Ena, A.V. and Fateryga, A.V., eds., 2015. *Red Book of the Republic of Crimea. Plants, algae and fungi*. Simferopol: ARIAL, 480 p. (in Russian).

7) Dumont, H.J., ed., 1999. *Black Sea Red Data Book*. New York: United Nations Office for Project Services, 413 p.

8) Kalugina-Gutnik, A.A., 1975. [Phytobenthos of the Black Sea]. Kiev: Naukova Dumka, 246 p. (in Russian).

Over the past two decades, negative anthropogenic factors have impacted the coastal waters of Crimea and Black Sea regions, including protected areas, leading to a decline in macrophyte diversity, a shift in their lower growth boundary toward the shore, reduced productivity of macrophytobenthos, and alterations in the spatial distribution and vertical structure of phytocenoses [2, 4–6]. Under conditions of high anthropogenic pressure and coastal water pollution, macrophytobenthos transformation has been marked by outbreaks of short-cycle and epiphytic algae, changes in the tiered structure of benthic phytocenoses, reduced ecosystem stability, and a consequent decline in the self-purification capacity of coastal ecosystems [4, 5, 7–12]. As a result of anthropogenic succession, *E. crinita* and *G. barbata* have lost their dominant positions in many areas of the coastal zone along the Caucasian shelf, as well as off the coasts of Romania, Bulgaria and Turkey, including MPAs [11, 13, 14]. Similarly, in the Mediterranean Sea, their phytocenoses, particularly in the lower tiers, have experienced a replacement of perennial species with short-cycle or ephemeral species, predominantly green and calciphilic red algae [6, 15–20]. Concurrently, in many Mediterranean MPAs, the area occupied by phytocenoses of perennial brown algae, including species of the genera *Ericaria* and *Gongolaria*, has significantly decreased, largely due to biotope degradation resulting from inadequate regulation of fishing in protected areas [19–22].

Considering the role of key brown algae phytocenoses – the primary producers in the coastal ecosystems of southwestern Crimea – and the limited research on their structure, the objective of this study was to characterize the species composition and tiered structure of the *Ericaria*–*Gongolaria* phytocenosis and to evaluate its stability in the waters of SPNAs of Sevastopol.

Materials and methods of research

The vertical tiered structure of the *Ericaria*–*Gongolaria* phytocenosis was investigated in six SPNAs in Sevastopol, including two State Natural Preserves (SNPs) – *Cape Aya* and *Karansky* – and four Natural Monuments (NMs): the *Coastal Aquatic Complex* (CAC) at *Cape Sarych*, CAC at *Cape Fiolent*, CAC at *Tauric Chersonese*, and CAC at *Cape Lukull* (Fig. 1). In the coastal zones of these protected areas, this phytocenosis occurs on rocky-block substrates at depths ranging from 0.5 to 10 m.

The study focuses on lithophytic macroalgae of the *Ericaria*–*Gongolaria* phytocenosis, a key component of the Black Sea macrophytobenthos⁸⁾.

Material was collected at depths of 1, 3 and 5 m, corresponding to the ecological-phytocenotic optimum for *E. crinita* and *G. barbata*, during the summer periods of 2016–2021. Quantitative samples of macrophytes were collected using a standard method⁸⁾, employing a 25 × 25 cm sampling frame at each depth horizon in four replicates. To assess the species diversity across tiers, qualitative samples were gathered at various horizons within the phytocenosis distribution zone.

When processing the samples, the species composition, biomass of macrophytes by vertical tiers, the number of cenosis-forming lithophytic macroalgae, and

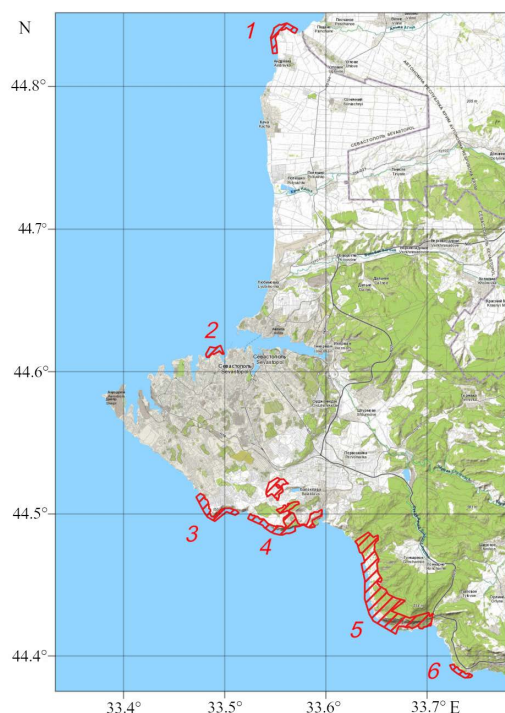


Fig. 1. The map of specially protected natural areas of Sevastopol: 1 – Natural Monument at Cape Lukull, 2 – Natural Monument at Tauric Chersonese, 3 – Natural Monument at Cape Fiolent, 4 – State Nature Preserve Karansky, 5 – State Nature Preserve Cape Aya, 6 – Natural Monument at Cape Sarych (the borders of objects are highlighted in red colour)

total projective cover of the phytocenosis were evaluated. A total of 93 quantitative and 20 qualitative samples of macrophytobenthos were collected and analyzed along six vertical transects located in the central part of SPNAs.

To characterize the vertical tiered structure of the *Ericaria–Gongolaria* phytocenosis, we analyzed the species composition of lithophytes in the 1st–3rd tiers. For the 4th tier, comprising crustose lithophytes, only the presence or absence of species was recorded using the underwater photofixation method [6].

A comparative analysis of the diversity of lithophytic synusia was conducted across three vertical tiers, evaluating the proportion of species by division (Chlorophyta, Ochrophyta, Rhodophyta) and life cycle duration. For each species, the coefficient of occurrence P_o (%) was calculated using the formula:

$$P_o = P \frac{a}{n} 100,$$

where a represents the number of sites where the species was recorded; and n is the total number of surveyed sites⁹⁾.

The similarity of the species composition of the phytocenosis across the water areas of the SPNAs was assessed using the Jaccard coefficient K_j (%)⁹⁾

$$K_j = 100 \frac{c}{a + b - c},$$

where a is the number of species in one site; b is the number of species in another site; and c is the number of species common to both sites.

⁹⁾ Pesenko, Yu.A., 1982. [Principles and Methods of Quantitative Analysis in Fauna Studies]. Moscow: Nauka, 287 p. (in Russian).

To evaluate the similarity of the vertical tier structure of the *Ericaria–Gongolaria* phytocenosis in SPNAs, a cluster analysis was performed using data on species occurrence and presence or absence¹⁰⁾. Macroalgal names were updated to reflect recent taxonomic revisions and nomenclature changes¹¹⁾.

Results and discussion

The phytodiversity of the tiered structure of the *Ericaria–Gongolaria* phytocenosis in the coastal zone of Sevastopol's SPNAs exhibited high species richness, comprising 34 species. These were distributed as follows: 2 species in the 1st tier, 7 in the 2nd tier, and 25 in the 3rd tier. The 1st tier was dominated by the coenosis-forming species *Ericaria crinita* and *Gongolaria barbata*, the second was dominated by *Phyllophora crispa* (Hudson) P. S. Dixon, *Cladostephus spongiosus* (Hudson) C. Agardh and *Ulva rigida* C. Agardh, the third by *Apoglossum ruscifolium* (Turner) J. Agardh, *Chondria da-syphylla* (Woodward) C. Agardh, *Dictyota fasciola* (Roth) J. V. Lamouroux, *Ellisolandia elongata* (J. Ellis & Solander) K. R. Hind & G. W. Saunders, *Gelidium crinale* (Hare ex Turner) Gaillon, *G. spinosum* (S. G. Gmelin) P. C. Silva, *Jania rubens* (Linnaeus) J. V. Lamouroux, *J. virgata* (Zanardini) Montagne, *Laurencia coronopus* J. Agardh and *Vertebrata subulifera* (C. Agardh) Kuntze.

Analysis of the species composition by taxonomic division revealed that red algae (Rhodophyta) contributed the largest proportion, accounting for 52% of the total species, while brown algae (Ochrophyta) and green algae (Chlorophyta) each represented 24%. Notably, species proportions varied significantly across vertical tiers. In the 2nd tier, brown algae comprised 57% of the species, seven times higher than in the 3rd tier (8%). Conversely, green and red algae were 2–2.2 times less (29% and 64%, and 14% and 28%, respectively).

The number of species in SPNAs varied significantly across vertical tiers, ranging from one to five species in the 2nd tier and from one to eight in the 3rd tier. In the 2nd tier, the highest frequency of occurrence ($Po = 75–100\%$) was recorded for *C. spongiosus*, *Ph. crispa*, and *U. rigida*. In the 3rd tier, high occurrence frequencies (from 50 to 75%) were noted for *A. ruscifolium*, *D. fasciola*, *E. elongata*, *G. crinale*, *G. spinosum*, *J. rubens*, *J. virgata*, *C. dasyphylla*, *L. coronopus*, and *V. subulifera*.

The highest species richness of lithophytes in the 2nd and 3rd tiers was observed in the waters of the NM CAC at Cape Fiolent, while the lowest was recorded in the Karansky SNP (Fig. 2). The greatest proportion of red algae was found in the coastal zones of the Cape Aya SNP and the NM CAC at Cape Sarych, accounting for 67% and 80% of the total species, respectively⁸⁾. Brown algae contributed 23% in the NM CAC at Cape Lukull, indicating relatively clean water conditions in these areas [2]. A high proportion of green algae (38%) was recorded in the CAC at Cape Fiolent, likely due to elevated recreational pressure in the coastal zone during spring and summer.

¹⁰⁾ Zaytsev, G.N., 1990. [Mathematics in Experimental Botany]. Moscow: Nauka, 296 p. (in Russian).

¹¹⁾ Algaebase Team. Algaebase. 2025. [online] Available at: <http://www.algaebase.org> [Accessed: 22 August 2025].

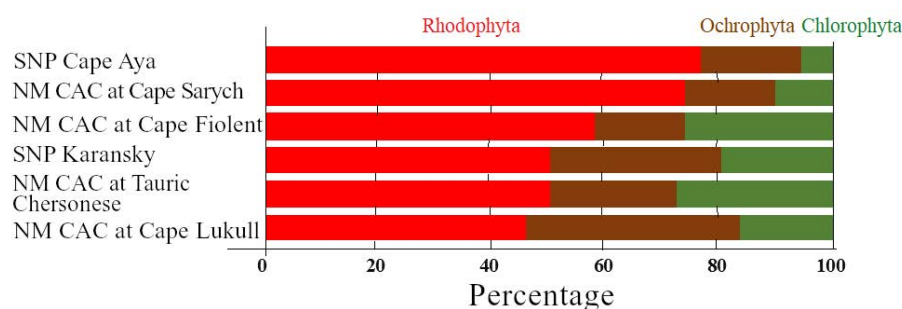


Fig. 2. Ratio of green, brown and red algae of the *Ericaria–Gongolaria* phytocenosis in the marine area of specially protected natural areas of Sevastopol

Analysis of species richness across the tiers in SPNAs of Sevastopol revealed slight variations with depth. The 1st tier, dominated by *E. crinita* and *G. barbata*, occurs at depths of 1 to 5 m and 3 to 5 m, respectively. In the 2nd and 3rd tiers, the highest number of species was recorded at depths of 1 and 5 m (22 species each), while diversity was lower at 3 m (15 species). The proportion of species by taxonomic division also varied slightly with depth; across all sites, red algae contributed twice as much to species richness as green and brown algae. In the 3rd tier, the proportion of Rhodophyta was three times higher than that of Ochrophyta and Chlorophyta, whereas no such pattern was observed in the 2nd tier.

Across SPNAs, the number of macroalgal species in the tiers also varied slightly with depth (Fig. 3). The highest phytodiversity was observed in the NM CAC at Cape Fiolent at a depth of 1 m. In the 2nd tier, the greatest species richness (five species) was recorded in the phytocenosis of the NM CAC at Cape Fiolent at 1 m, while the lowest (one species) was recorded in the Karansky SNP and the NM CAC at Cape Sarych at 3 m. Near Cape Lukull, species richness in the 2nd tier increased slightly with depth, reaching a maximum at 5 m.

In the 3rd tier, the highest species richness was observed in the waters of the NM CAC at Tauric Chersonese and the NM CAC at Cape Sarych at a depth of 5 m (7 and 8 species, respectively). The lowest species richness was recorded at depths of 3 and 5 m in the Karansky SNP and at 1 m in the NM CAC at Tauric Chersonese (one species each). Notably, in certain areas of the Cape Aya and Karansky SNPs, as well as the NM CAC at Cape Fiolent, at depths from 3 to 5 m within the ecological-phytocenotic optimum of the phytocenosis⁸⁾, no algae were found in the 2nd and 3rd tiers, which is probably due to the high density of coenosis-forming species in the 1st tier [1].

Comparative analysis of the phytodiversity across the three tiers of the *Ericaria – Gongolaria* phytocenosis revealed that the total species richness in SPNAs of Sevastopol was 1.3 times higher (34 species) than in other areas of the Crimean and Caucasian coasts (27 species) [1, 2, 5, 8, 10, 11, 13, 14, 23]. However, within protected waters, the number of taxa in the tiers ranged from 8 to 17 species, compared to 6 to 27 species in other areas of the Russian Black Sea shelf.

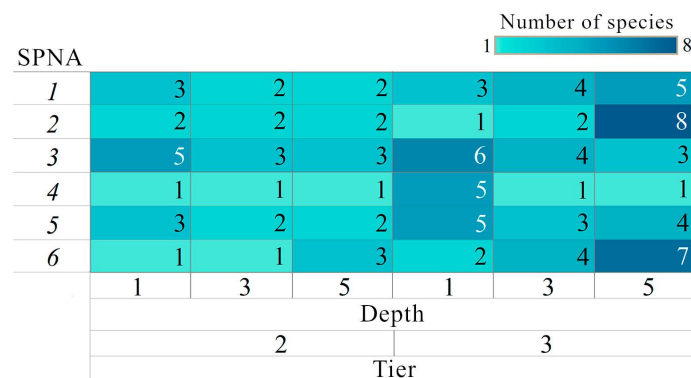


Fig. 3. The change in the number of species in the 2nd and 3rd tiers of the *Ericaria–Gongolaria* phytocenosis at depths of 1, 3 and 5 m in the marine area of specially protected natural areas of Sevastopol (see Fig. 1)

In the phytocenoses of protected areas, the 2nd tier contained 7 species, 1.6 times fewer than the 11 species reported elsewhere, while the 3rd tier exhibited 1.5 times greater species richness (21 species) compared to other studies (14 species). The increased diversity in the 3rd tier may be attributed to the presence of certain macroalgae, specifically *A. ruscifolium*, *C. dasyphylla*, *L. coronopus*, *L. obtusa* and *V. subulifera*, which were identified as lithophytic in this study but are typically epiphytic in other regions [8].

Analysis of the proportion of macroalgal species with varying life cycle durations in the tiers of the *Ericaria–Gongolaria* phytocenosis in SPNTs of Sevastopol revealed that perennial algae accounted for 44%, annual algae for 38%, and ephemerooids for 18% of the total species identified. Among brown algae, perennial and short-cycle species predominated; among red algae, perennial and annual species were prevalent; and among green algae, annual species dominated. The 1st tier consisted exclusively of perennial species, while in the 2nd and 3rd tiers, perennial species contributed 43% and 40%, respectively, and short-cycle species accounted for 57% and 52%, respectively. The highest proportion of perennial species (78%) was recorded in the waters of the NM CAC at Cape Sarych (Fig. 4), while the lowest (18%) was found in the *Karansky SNP*. The predominance of annual species (67%) in the *Karansky SNP* is likely associated with the influx of domestic and industrial wastewater from the Balaklava collector under specific synoptic conditions [24, 25].

The greatest proportion of perennial algae, ranging from 50 to 70%, was observed in the waters of the NM CAC at Tauric Chersonese (depth 1 m), the NM CAC at Cape Sarych and the Cape Aya SNP (depth 3 and 5 m). No seasonal or ephemeral species were recorded in the phytocenosis of the latter two sites.

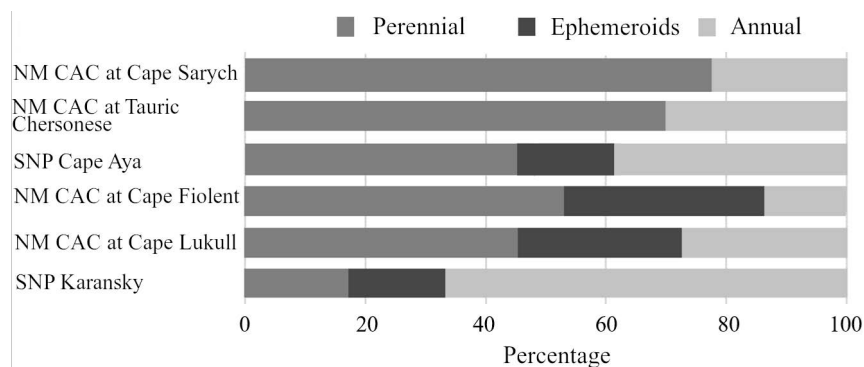


Fig. 4. The ratio of *Ericaria*–*Gongolaria* phytocenosis species by their life history in the marine area of specially protected natural areas of Sevastopol

The proportion of species with different vegetation periods reflects both the condition of benthic phytocenoses and their resilience to adverse environmental factors⁸⁾ [4, 18]. The predominance of perennial species in the *Ericaria*–*Gongolaria* phytocenosis (Fig. 4) suggests favorable conditions for macrophytobenthos in the coastal zone of Sevastopol's SPNAs, which is confirmed by evidence of improved environmental quality in these protected waters over recent decades [12, 24–26].

Previous studies have demonstrated that increased domestic pollution and eutrophication result in reduced species richness in perennial brown algae phytocenoses of the Black Sea, decreased biomass of coenosis-forming species in the 1st and 2nd tiers, and an increase in coralline calciphilic macroalgae in the 3rd tier [1, 2, 4, 8, 11, 13, 16]. Under the influence of these adverse factors, some key phytocenoses in the Mediterranean Sea have exhibited a replacement of perennial brown algae in the 1st tier with red coralline algae, such as *Corallina officinalis* Linnaeus, *E. elongata*, *J. rubens*, and others. This shift has led to significant structural transformation and a decline in the productivity of macrophytobenthos [17–20].

Analysis of the species diversity across the tiers of the *Ericaria*–*Gongolaria* phytocenosis in SPNAs revealed low structural similarity. The average value of K_j between sites did not exceed 21% (Fig. 5), compared to 56–62% in other areas of the coastal zone of Crimea⁸⁾. The highest number of shared species was observed between the phytocenoses of the *Cape Aya SNP* and the *NM CAC at Cape Sarych* (K_j from 33.3 to 46.2%). In other sites, K_j values were 3–5 times lower.

Significant variation in K_j was observed across depths. The highest species similarity was recorded in the phytocenoses near Cape Aya and Cape Fiolent at a depth of 3 m ($K_j = 66.7\%$), while the lowest was found near the *Karansky SNP* and the *NM CAC at Cape Lukull* at depths of 3 and 5 m ($K_j = 7.1\%$).

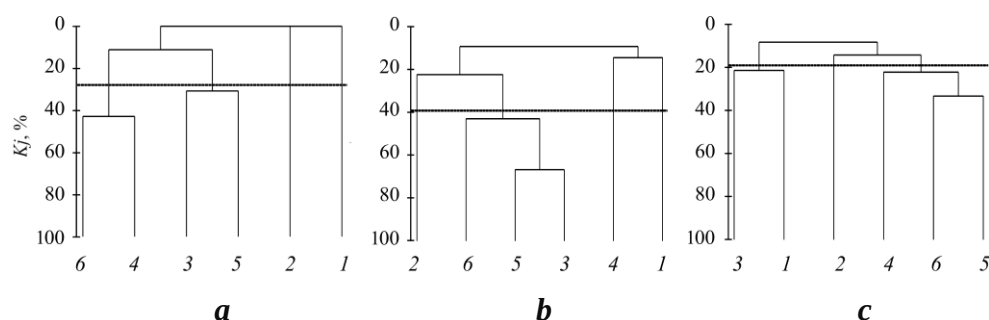


Fig. 5. Dendrogram of similarity in species composition of *Ericaria–Gongolaria* phytocenosis in the specially protected natural areas of Sevastopol (see Fig. 1): *a* – depth of 1 m, *b* – 3 m, *c* – 5 m

Conclusion

The *Ericaria–Gongolaria* phytocenosis (*Ericaria crinita* + *Gongolaria barbata* – *Cladostephus spongiosus* – *Ellisolandia elongata*) is a key component of the Black Sea macrophytobenthos, exhibiting high taxonomic diversity in the coastal SPNAs of Sevastopol. Thirty-four macroalgal species were identified in the lithophytic synusia across three tiers, of which Chlorophyta and Ochrophyta each contributed 24% to the total species richness, while Rhodophyta accounted for 52%. The 1st tier was dominated by coenosis-forming brown algae (Ochrophyta), in the 2nd and 3rd tiers, their proportions were 57% and 28%, red algae (Rhodophyta) – 29% and 64%, green algae (Chlorophyta) – 14% and 8%, respectively. The proportion of species across taxonomic divisions varied slightly across regions and depths, with brown and red algae consistently 2–3 times more abundant than green algae.

Perennial species predominated in the composition of the tiered synusia of the phytocenosis, with their highest proportion (53–78%) recorded in the phytocenoses of the NM CAC at Cape Fiolent, the NM CAC at Cape Sarych, and the Cape Aya SNP. In other protected waters of SPNAs of Sevastopol, the proportion ranged from 17 to 46%. The floristic similarity of the species composition across the tiers in these protected areas was low, with the highest number of shared species observed among the phytocenoses of the Cape Aya SNP, the NM CAC at Cape Sarych, and the NM CAC at Cape Fiolent.

Elements of restorative succession, indicative of ecological stability, were identified in the *Ericaria–Gongolaria* phytocenosis within the coastal zone of SPNAs of Sevastopol. These include a well-developed structure, high floristic diversity across tiers, and the predominance of perennial brown and red algae. The ecological and phytocoenotic characteristics of this phytocenosis suggest that the protected waters of Sevastopol can be classified as relatively clean. However, due to significant fuel oil inputs into the waters of the Cape Aya SNP and the NM CAC at Cape Fiolent, regular monitoring of key benthic phytocenoses, which are critical for the self-purification of coastal waters, remains an essential conservation priority.

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