Original paper

Approaches to Formation of the Ecological Framework of the Western Coast of Sevastopol

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Abstract

For the first time, the paper proposes an outline of an ecological framework for the western coast of Sevastopol. An ecological framework is a network of protected areas and objects of different status represented by areal, linear and point elements. The studying of the bottom landscape structure and hydro-botanical survey of the coastal zone were carried out in summer 2020. Based on the obtained data, a map of underwater landscapes in the study water area was made. Six underwater landscapes dominated by key macrophyte species were identified in the landscape structure: *Ericaria crinita*, *Gongolaria barbata,* and *Phyllophora crispa*. For each underwater landscape, the phytocenosis is described, and quantitative and qualitative indicators of macrophytobenthos are calculated (species composition of macrophytes, presence of protected red-listed algae species, phytomass stock of macroalgae and its dominant species). Based on the landscape approach, spatial and functional conservation elements (key, transit, buffer and restorative) were identified taking into account the indicators of the vegetation component of underwater landscapes. It was revealed that for the coastal area under study the key water areas include underwater landscapes with "*Cystoseira*" phytocenosis, the transit ones include landscapes with "*Cystoseira*" – *Phyllophora* phytocenosis, and restorative ones include landscapes with *Phyllophora* phytocenosis. All elements of the ecological framework have different protection regimes and are of different types of nature management. The obtained results and proposed approach can be used to form an ecological framework of the marine areas of Sevastopol and the Republic of Crimea.

Keywords: underwater landscapes, macrophytobenthos, protected water areas, landscape approach, Black Sea.

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Подходы к формированию экологического каркаса западного прибрежья Севастополя

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Аннотация

Впервые предложена схема экологического каркаса для западного прибрежья Севастополя. Экологический каркас представляет собой сеть природоохранных территорий и объектов разного статуса, состоящих из площадных, линейных и точечных элементов. Работы по изучению ландшафтной структуры дна и гидроботаническая съемка прибрежной зоны проведены в летний период 2020 г. На основе полученных сведений составлена карта подводных ландшафтов исследуемой акватории. В ландшафтной структуре выделено шесть подводных ландшафтов с доминированием ключевых видов макрофитов: *Ericaria crinita*, *Gongolaria barbata* и *Phyllophora crispa*. Для каждого подводного ландшафта описан фитоценоз, рассчитаны количественные и качественные показатели макрофитобентоса (видовой состав макрофитов, наличие охраняемых краснокнижных видов водорослей, запас фитомассы макроводорослей и входящих в ее состав доминирующих видов). На основе ландшафтного подхода с учетом показателей растительной компоненты подводных ландшафтов выделены пространственно-функциональные природоохранные элементы (ключевые, транзитные, буферные и восстановительные). Выявлено, что на изучаемом прибрежье к ключевым акваториям относятся подводные ландшафты с «цистозировым» фитоценозом, к транзитным – с «цистозирово»-филлофоровым, к восстановительным – с филлофоровым. Все элементы экологического каркаса имеют разные режимы охраны и относятся к разным типам природопользования. Полученные результаты и предложенный подход могут быть использованы для формирования экологического каркаса морских акваторий Севастополя и Республики Крым.

Ключевые слова: подводные ландшафты, макрофитобентос, охраняемые акватории, ландшафтный подход, Черное море

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Introduction

Specially protected natural reservations (SPNR) play an important role in preserving biological and landscape diversity. One of the recognized forms of territorial nature conservation is creation of ecological networks. Currently, the concept of ecological networks for land territories has been quite fully developed [1]. Models of regional ecological networks have been proposed for a number of constituent entities of the Russian Federation [2, 3]. However, the lack of a unified legislative framework, generally accepted methods and approaches makes it difficult to create regional and national ecological networks, especially for territories with anthropogenically transformed landscapes. In recent years, approaches [1), 2)] to the formation of marine ecological networks have been actively developed – mainly in regions where marine reserves have been created [4, 5]. Nevertheless, "the criteria for identifying and optimal areas of the main structural elements, and especially the issues of their connection into a functionally integral system" remain insufficiently developed [1, p. 134].

In 2008, a regional ecological network project was developed for the Autonomous Republic of Crimea and the city of Sevastopol. In addition, other schemes of ecological networks for Crimea are presented in the scientific literature [6, 7].

In the coastal waters of the Crimean Peninsula, 13 coastal elements of the eco-network have been identified (8 eco-centers and 5 eco-corridors). The SPNR of Sevastopol, which include marine protected areas (MPA), are located within the boundaries of the Heraclea and Aya Sarych seaside eco-centers, as well as the Kalamitskiy seaside eco-corridor [3)]. Most of the Crimean MPA are isolated, have a small area and have a low protection status, which does not allow them to fully carry out environmental protection tasks. The research carried out at the Crimean MPA shows that currently there is degradation of natural bottom complexes associated with an increased anthropogenic load [8].

In this regard, the ecological network elements of Crimea, including the city of Sevastopol, are in the need of developing an ecological framework of sustainability, consisting of interconnected spatial-functional environmental elements (key, transit, buffer and restoration) [9]. The works of a number of authors highlight the use of this approach to form ecological networks and their elements in land landscapes [10, 11]. With the landscape approach, attention is focused on "landscape diversity, environment-forming functions of geosystems, material and energy flows in the landscape" [1, p. 133]. The use of the landscape approach for marine ecological

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1) Kelleher, G. and Recchia, C., 1998. Lessons from Marine Protected Areas around the World. *Parks,* 8(2), pp. 1–4. URL: https://parksjournal.com/wp-content/uploads/2017/06/parks_8_2.pdf [accessed: 12 September 2023].

2) Salm, R.V., Clark, J.R. and Sirila, E., 2000. *Marine and Coastal Protected Areas: A Guide for Planners and Managers*. Washington DC: IUCN, 371 p. URL: http://seaknowledgebank.net/sites/default/files/marine-and-coastal-protected-areas-a-guide-for-planners-and-managers_0.pdf [accessed: 12 September 2023]

3) TNU, 2008. [*Development of Regional Ecological Network Scheme of Autonomous Republic of Crimea: Report on Research Project*]. Simferopol, 312 p. (in Russian).

networks raises certain methodological difficulties due to poor development of theoretical foundations of underwater landscape science [9, 12].

One of the most important components of underwater landscapes is bottom vegetation, which is considered an indicator of morphological complexes of horizontal division of landscape structure. It is known that macrophytobenthos is the main production link of the Black Sea shelf and plays a leading role in stabilization and self-regulation of coastal ecosystems. Based on the fact that macrophytes actively respond to environmental changes, their quantitative and qualitative indicators can be used as criteria for identifying elements of an ecological network [8, 13].

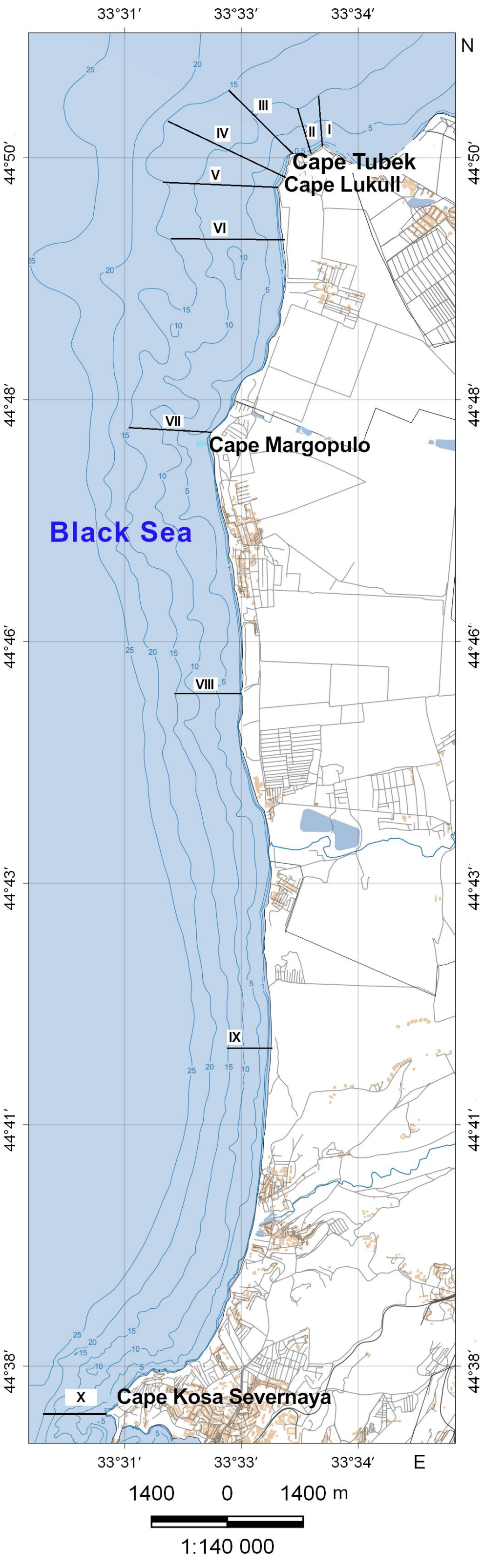
The coastal zone of the western part of Sevastopol, which is distinguished by its biological and landscape diversity, was chosen as a model region. Currently, this zone is being actively developed – projects to develop infrastructure in the coastal zone are being implemented here. In this regard, it is relevant to develop recommendations for conservation of underwater coastal landscapes.

The purpose of this article is to develop an outline of the ecological framework of the western coastal area of Sevastopol.

Materials and research methods

The coastline length of the western coast of Sevastopol (Cape Kosa Severnaya – Cape Tubek) is about 26 km. The coastal waters are characterized by shallow depths and bottom slopes. On the bench, sandy and pebble bottom sediments are developed, replaced by a blocky pile [14]. The water area is located within the boundaries of the Kalamitskiy seaside eco-corridor of the ecological framework of the Crimean Peninsula. The SPNR is represented by the natural monument "Cape Lukull Coastal Aquatic Complex (CAC)", the length of its coastline reaches 3448.6 m, the width of the water area is 300 m. The total area of the natural monument is 128.5 ha, of which the territory area is 15.1 ha, and the water area is 113.4 ha.

The work to study the bottom landscape structure of the coastal zone was carried out on the basis of general provisions of the underwater landscape research program in the summer of 2020 [15]. The underwater landscaping work was carried out from small vessels using light diving equipment. When studying the structure of coastal landscapes, we used the method of landscape profiling with a description of profiles and key areas [16]. Landscape profiles were compiled for 10 profiles (Fig. 1). Landscape profiling made it possible to identify underwater landscapes and establish their boundaries. To create a landscape map, we used the QGIS 2.18.25 software package and the electronic basis of the navigation map. A combined analysis of bathygraphy, maps of lithological composition and diving survey data made it possible to extrapolate areas of the bottom with similar parameters to identify the boundaries of underwater landscapes. The results of generalization of studies of the landscape structure of the western coastal region of Sevastopol are reflected on the landscape map.



F i g . 1. Schematic map of the location of landscape and hydrobotanical profiles in the coastal zone Cape Kosa Severnaya – Cape Tubek (Roman numerals stand for profiles)

The study of bottom vegetation was carried out according to generally accepted methods [4)]. To study the composition and structure of macrophytobenthos, we used materials from hydrobotanical surveys carried out on the same profiles. The sampling was carried out at depths of 0.5; 1; 3; 5; 10 and 15 m, where four counting areas measuring 25 × 25 cm were laid. The algae identification was carried out taking into account the latest nomenclature changes [5)]. The resources of macroalgae (t, wet weight), the stock of phytomass of macrophytes and the key species of algae included in its composition (t·ha^{-1}, wet weight) were calculated using a method modified for marine research [8]. The water area was determined using the QGIS program.

The criteria selected for identifying elements of the ecological network were quantitative and qualitative indicators of macrophytobenthos (species composition of macrophytes, presence of protected Red Book species of algae, stock of phytomass of macroalgae and its key species, share of *Ericaria crinita* (Duby) Molinari & Guiry = *Cystoseira crinita* and *Gongolaria barbata* (Stackhouse) Kuntze = *Cystoseira barbata* in the total reserves of macrophytes), characterizing the plant component of underwater landscapes. When working on the article, we used annotated lists of algae recorded in the area of the western coast and the natural monument "Cape Lukull Coastal Aquatic Complex (CAC)", given in the articles by I.K. Evstigneeva and I.N. Tankovskaya [17, 18].

Based on the mapping of underwater landscapes, qualitative and production characteristics of macrophytobenthos, a functional-areal distribution of the main elements of the ecological network (key environmental (protected cores), buffer protective, transit and restorative water areas) is proposed.

Results and discussion

In the landscape structure of the coastal zone, six underwater landscapes were identified with the participation of dominant species of macrophytes: *Ericaria crinita*, *Gongolaria barbata* and *Phyllophora crispa* (Hudson) P.S. Dixon (Fig. 2). The developed coastal landscape map is a cartographic basis for identifying water areas that form elements of the ecological framework.

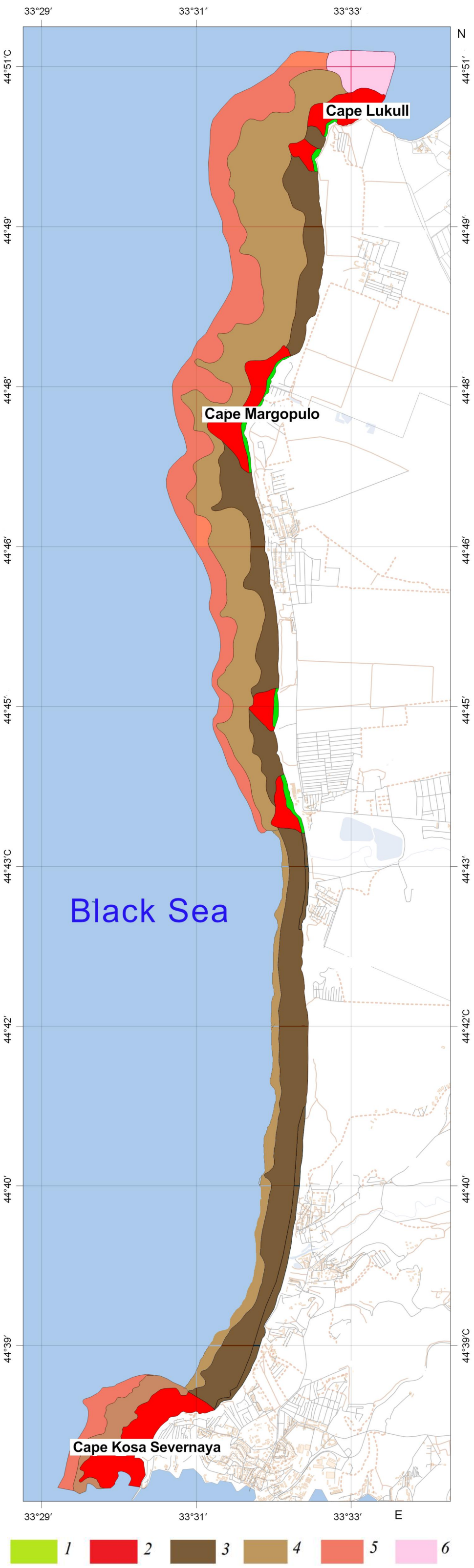
For each landscape contour, quantitative and qualitative indicators of macrophytobenthos were calculated and presented in the table.

Based on the landscape approach, taking into account the values of the plant component of underwater landscapes, a map was drawn up and elements of the ecological framework of the western coast of Sevastopol were identified (Fig. 3).

The underwater landscapes located within the boundaries of the natural monument "Cape Lukull Coastal Aquatic Complex (CAC)" belong to **the key environmental water areas (protected cores) (KEWA)** (Fig. 3).

[4)] Kalugina-Gutnik, A.A., 1969. [Study of the Black Sea Bottom Vegetation Using Lightweight Diving Equipment]. In: Academy of Sciences of the USSR, 1969. [*Marine Underwater Studies*]. Moscow: Nauka, pp. 105–113 (in Russian).

[5)] Available at: http://www:algaebase.org [accessed: 12 September 2023].



F i g . 2 . Schematic map of the landscape structure of the coastal zone (Cape Kosa Severnaya – Cape Tubek): *1* – boulder benches with dominance of *Ericaria crinita* and *Gongolaria barbata*; *2* – upper shoreface consisting of psephitic sediments predominated by *Ericaria crinita* and *Gongolaria barbata*; *3* – upper shoreface consisting of sandy sediments with small ripple marks (riffles), devoid of bottom vegetation (species of *Ericaria crinita* and *Gongolaria barbata* or *Padina pavonica* and *Dictyota fasciola* dominate on some clumps); *4* – upper shoreface consisting of psephitic deposits predominated by *Gongolaria barbata* with mosaic alternation of pebble and gravel deposits and shell fragments predominated by *Phyllophora crispa*; *5* – gently dipping accumulation plain formed by psammitic deposits with inclusion of shell fragments predominated by *Phyllophora crispa*; *6* – gently dipping accumulation plain formed by sandy sediments, with no bottom vegetation

The landscape structure of this protected water area is dominated by underwater slopes dominated by *Cystoseira* species (*Ericaria crinita* and *Gongolaria barbata*), where the phytocenosis *Ericaria crinita*+*Gongolaria barbata* was recorded at depths of 0.5–5 m.

On the underwater slope at a depth of 0.5–1 m, ***a block-boulder bench with a predominance of Ericaria crinita and Gongolaria barbata (1)*** was recorded (Fig. 2). The plant component of this landscape is characterized by high species diversity (Table) – five species of algae listed in the Red Book of the Russian Federation, the Republic of Crimea and the city of Sevastopol are registered here (*Stilophora tenella* (Esper) P.C. Silva, *Laurencia coronopus* J. Ag, *Osmundea hybrida* (A.P. de Candolle), *Ericaria crinita* and *Gongolaria barbata*). The largest reserve of phytomass of macrophytes and their dominant species of *Cystoseira* (*Ericaria crinita* and *Gongolaria barbata*) is noted here (Table). The share of these algae in the total reserves of macrophytobenthos is maximum (86 %) (Table).

The underwater slope, composed of coarse sediments, dominated by Ericaria crinita and Gongolaria barbata (2), located at depths of 1–5 m, is distinguished by the greatest species diversity compared to other studied landscapes of the western coastal region (Table). The number of red-listed species of macrophytes reaches six (in addition to the above species, with the exception of *Osmundea hybrida*, *Phyllophora crispa* and *Osmundea pinnatifida* (Hudson) Stackhouse were discovered). The phytomass reserve of macrophytes, as well as *Ericaria crinita* and *Gongolaria barbata*, is slightly lower than at depths of 0.5–1 m (Table).

According to the information about the composition and structure of macrophytobenthos collected along the western coast of Sevastopol using a similar method by A.A. Kalugina-Gutnik and N.M. Kulikova [19] in 1964, we calculated the stock of *Cystoseira* phytomass in this selected landscape. Thus, a comparative analysis showed that at depths of 1–5 m the phytomass reserve of *Ericaria crinita* and *Gongolaria barbata* was 40.7 $t \cdot ha^{-1}$, which is approximately one and a half times lower than in 2020.

However, it is well known that at present, along the coast of Crimea, significant compaction of *Cystoseira* thickets is observed everywhere in the upper and middle sublittoral zone, while degradation and transformation of bottom vegetation is recorded in the lower zone [8]. Thus, over the past 56 years, the safety of the water area belonging to the KEWA has remained quite high.

In the rest of the coastal waters of the study region, the underwater landscapes dominated by *Cystoseira*, due to their environmental value, should be considered as **restorative water areas (RWA)**. In the future, in this part of the coastal zone it is expected to reduce the influence of anthropogenic impact, and in certain cases it is necessary to take special measures to restore biotopes and landscapes as a whole.

For ***an underwater slope composed of sandy sediments with small ripple marks (ripples), devoid of bottom vegetation, where individual blocks are dominated by the species of Ericaria crinita and Gongolaria barbata or Padina pavonica and Dictyota fasciola (3)***, at depths of 1–5 m the phytocenoses of

Ericaria crinita + *Gongolaria barbata* or *Padina pavonica* + *Dictyota fasciola* are characteristic. This landscape also shows high species diversity and the presence of red-listed species (Table). The phytomass reserve of macrophytes, *Ericaria crinita* and *Gongolaria barbata*, is significantly lower (Table). However, this isolated underwater landscape is characterized by an intensive exchange of material flows due to the movement of fine-clastic clay-sandy material by alongshore currents. In addition, this landscape provides the necessary connection between the underwater landscapes of the KEWA and RWA and provides an opportunity for distribution, migration and genetic exchange of aquatic species. Thus, this underwater landscape corresponds to the **transit water area (TWA)** of the coastal area under study, while in marine protected areas it must be included in the TWA.

Species composition and productivity of macrophytobenthos in the underwater landscapes of the western coast of Sevastopol

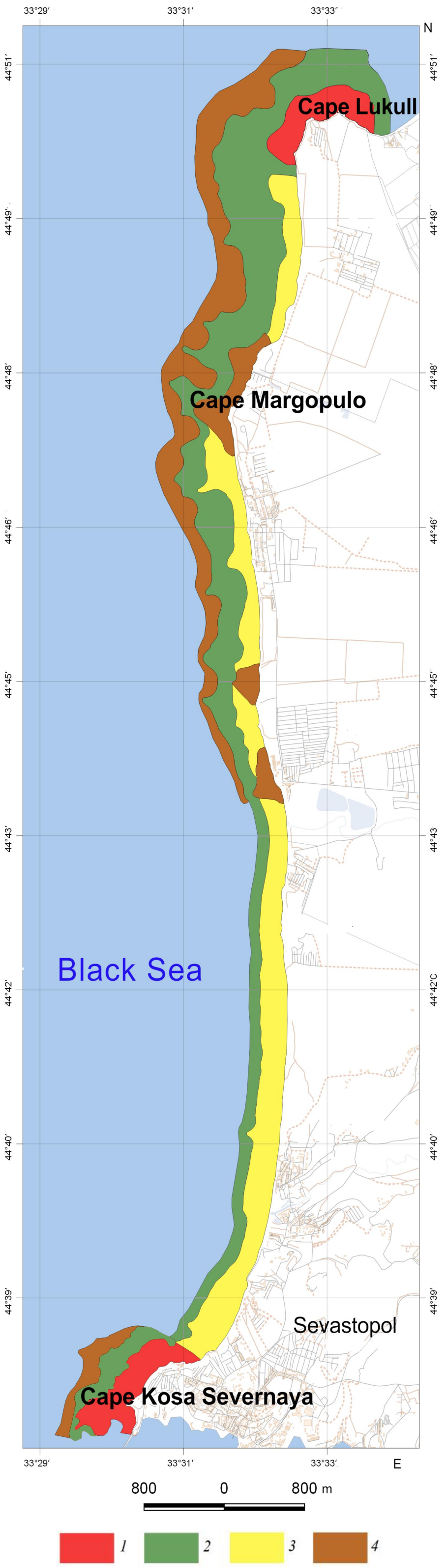
Species composition of algae					Number of protected algae species listed in Red Book of			Total biomass of, t·ha^{-1}		
Underwater landscape	Total number	Green	Brown	Red	Sevastopol [6)]	Republic of Crimea [7)]	Russian Federation [8)]	macrophytes	*Ericaria crinita* + *Gongolaria barbata*	*Phyllophora crispa*
1	40	12	7	21	1	4	1	78.8	67.8	0
2	49	8	8	29	2	6	2	69.1	49.1	0.1
3	40	9	8	23	1	5	0	17.1	13.1	0
4	43	8	8	27	2	6	1	40.2	20.1	2.4
5	30	6	7	17	1	3	1	39.4	13.0	3.1

Note: the numbering and description of underwater landscapes corresponds to the information presented in the text and in Fig. 2. Information on the algal species composition by depth is given in [17, 18].

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

[7)] Ivanov, S.P. and Fateryga, A.V., eds., 2015. Red Book of the Republic of Crimea. Animals. Simferopol: ARIAL, 440 p. (in Russian)..

[8)] Bardunov, L.V. and Novikov, V.S., eds., 2008. [*Red Data Book of the Russian Federation (Plants and Fungi)*]. Moscow: Tovarishchestvo Nauchnyh Izdaniy KMK, 885 p. (in Russian).



F i g . 3 . Elements of the ecological framework of the Sevastopol western coast: *1* – key environmental water areas; *2* – buffer water areas; *3* – transit water areas; *4* – restorative water areas

It is characteristic that within the boundaries of the Kalamitskiy eco-corridor there is no sufficient number of natural cores, which is one of the prerequisites for the creation of the natural monument "Cape Kosa Severnaya Coastal Aquatic Complex (CAC)". Previously obtained research results in this coastal area indicate high floristic and landscape diversity in the depth range of 0.5–10 m [20]. The algal flora contains species of macrophytes included in the Red Book lists of the Russian Federation, the Republic of Crimea and Sevastopol (*Phyllophora crispa*, *Stilophora tenella*, *Ericaria crinita*, *Gongolaria barbata*, *Laurencia coronopus*, *Nereia filiformis* (J. Ag.) *Zanard.*). The indigenous phytocenoses of these underwater landscapes are characterized by a high degree of preservation, which makes it possible to recommend the water area near Cape Kosa Severnaya as promising for conservation and to include it in the KEWA.

The role of **a buffer water area (BWA)** is played by ***an underwater slope composed of coarse clastic sediments, dominated by Gongolaria barbata, mosaically alternating with pebble-gravel deposits with broken shells, dominated by Phyllophora crispa (4)*** (depth 5–10 m). The phytocenoses of *Gongolaria barbata* and *Phyllophora crispa* are described. This underwater landscape occupies the peripheral parts of the KEWA, RWA and TWA, and therefore performs a protective function of the water areas and ensures optimal functioning of protected species. Uniqueness of this underwater landscape lies in the fact that it represents a transitional strip where several perennial phytocenoses occur simultaneously at the same depth, and their distribution is determined by the peculiarities of bottom lithology. At these depths, there is a gradual change in the composition of bottom vegetation along the illumination gradient. The reserves of phytomass of macrophytes and *Cystoseira* are decreasing, but this indicator is increasing in *Phyllophora crispa* (Table). The contribution of *Ericaria crinita* and *Gongolaria barbata* to the total macrophyte reserves does not exceed 50 %.

In this area in 1964, the phytomass reserve of *Ericaria crinita* and *Gongolaria barbata* was 24.8 $t \cdot ha^{-1}$, and the phytomass reserve of *Phyllophora crispa* was 2.6 $t \cdot ha^{-1}$ in the depth range of 5–10 m [18]. These values are only slightly higher than comparable values in 2020 (Table), confirming the relatively unchanged state of benthic vegetation in the study area in this depth interval.

At a depth of more than 10 m, ***a slightly inclined plain, composed of gravel-sand deposits with broken shells and dominated with Phyllophora crispa (5)*** was recorded. For this underwater landscape, the maximum supply of *Phyllophora crispa* was noted (Table). The share of *Cystoseira* species is less than 33 % (of the total macrophyte reserves). More than half a century ago, at depths of 10–15 m, the stock of *Phyllophora crispa* phytomass reached 9.7 $t \cdot ha^{-1}$, which is three times higher than the value recorded in 2020 [19].

A sharp decline in the stock of *Phyllophora crispa* phytomass indicates the need to preserve this landscape. Since this species is protected at the international, state and regional levels [9)], the underwater landscapes with phyllophora phytocenosis must be classified as **RWA**.

The obtained research results indicate that at present, underwater landscapes and their plant components are distinguished by a high degree of preservation in the coastal waters of the western coast of Sevastopol. This is confirmed in the article by I.K. Evstigneeva and I.N. Tankovskaya [21]. According to the work of these authors, the results of phytoindication along the western coast of Sevastopol show a widespread dominance of oligosaprobic macrophyte species, an abundance of mesosaprobic species and a small share of polysaprobic species, which corresponds to the ratio of saprobiological groups in clean areas of the sea. Taking into account high biological and landscape diversity of the studied region, it is advisable to develop an ecological framework of the coastal zone, which will make it possible to identify areas with different environmental management regimes.

Thus, when identifying the main structural elements of the ecological framework of the western coastal area of Sevastopol, the biocentric and landscape approaches were used for the first time. As studies have shown, both approaches to the formation of the ecological framework of the coastal zone are complementary and reflect different aspects of its organization. It is characteristic that with a biocentric approach, special attention is paid to the preservation of living organisms (species diversity of aquatic organisms, presence of rare and endangered species, etc.). Thus, in the paper by S.E. Sadogursky and colleagues [22], it was noted that the qualitative and quantitative indicators of coastal marine biota are highest in areas where thickets of macrophytes are noted. It should be noted that some indicators of macrophytobenthos presented by the authors in the article correspond to the criteria for a comprehensive assessment of the ecological state of marine natural complexes, which underlie the protection of the marine environment in the European Union [10)]. The landscape approach enables us to identify the main framework-forming underwater landscapes, as well as to determine their relative positions, ensuring ecological balance in the coastal zone. At the same time, the use of two approaches for the formation of ecological networks of marine areas requires further development and additional field research.

Conclusions:

1. For the first time, an ecological framework has been developed for the western coast of Sevastopol and its functional elements have been identified. It is shown that for its formation it is advisable to use complementary approaches: landscape and biocentric.

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9) Rodwell, J.R, García Criado, M., Gubbay, S., 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, 52 p. https://doi.org/10.2779/032638

10) EU, 2008. *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008. Marine Strategy Framework Directive.* Available at: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32008L0056 [accessed: 12 September 2023).

2. The coastal zone of the studied region was mapped, six underwater landscapes were identified, and a map of the landscape structure was compiled. It is shown that the landscape map is a cartographic basis of the ecological framework.

3. Quantitative and qualitative indicators of macrophytobenthos were calculated and used as criteria to substantiate the ecological framework elements.

4. It has been established that for the coastal region under study, KEWA include underwater landscapes with *Cystoseira* phytocenosis, TWA – landscapes with *Cystoseira – Phyllophora* phytocenosis, and RWA – landscapes with *Phyllophora* phytocenosis. All elements of the eco-framework have different environmental management regimes.

5. The obtained results and the proposed approach can be used to form the ecological framework of the marine waters of the city of Sevastopol and the Republic of Crimea.

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Anastasia V. Parkhomenko – preparation of cartographic materials, preparation of the manuscript

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