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# Long-term Dynamics of Underwater Landscapes of the Coastal Zone Cape Kosa Severnaya – Cape Tolsty (Sevastopol)

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**Abstract**

Data on the long-term dynamics of underwater landscapes of the coastal zone at Cape Kosa Severnaya–Cape Tolsty are given for the first time for the period from 1964 to 2017. Landscape maps of the water area are made on the basis of landscape and hydrobotanical studies. The distribution of bottom natural complexes with key Black Sea phytocenoses is shown. It is found that the spatial distribution of underwater landscapes and the qualitative and quantitative indicators of their vegetation component have changed over a period of more than 50 years. It is probably due to both natural factors and increased anthropogenic activity. The bottom natural complexes of the boulder benches and upper shoreface consisting of psephitic sediments with dominance of *Ericaria crinita* and *Gongolaria barbata* typical of depths of 0.5–5 m, have changed the least. These changes touched only the configuration of their boundaries and the depth of their distribution. Changes were noted in the vegetation component: macrophytobenthos biomass values increased, a high proportion of phytocenosis edificators was identified, epiphytes made a significant contribution, macrophytes appeared that prefer areas with higher levels of marine eutrophication. The most significant transformation of the bottom natural complexes occurred at a depth of 5–15 m. It was noted that the depth of distribution of the following bottom complexes had changed: 1) that of a gently dipping accumulation plain formed by psammitic deposits with admixed shell fragments and predominated by *Phyllophora crispa*, and 2) that of the upper shoreface formed by psephitic deposits predominated by *Gongolaria barbata* with alternation of pebble and gravel deposits and broken shells, where *Phyllophora crispa* predominates. The vegetation component is characterized by a sharp decrease in the contribution of phytocenosis edificators, substitution of perennial macrophyte species by annual ones, and a vertical decrease of the depth of habitat of deep-water species. This is probably due to a decrease in light exposure.

**Keywords**: coastal zone, bottom natural complex, dynamics, macrophytobenthos, Black Sea, Sevastopol

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# Многолетняя динамика подводных ландшафтов прибрежной зоны мыс Коса Северная – мыс Толстый (Севастополь)

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**Аннотация**
Впервые приведены сведения о многолетней динамике подводных ландшафтов прибрежной зоны м. Коса Северная – м. Толстый за период с 1964 по 2017 г. На основе проведенных ландшафтных и гидроботанических исследований составлены ландшафтные карты исследуемой акватории, показано распространение донных природных комплексов с ключевыми черноморскими фитоценозами. Установлено, что за более чем 50-летний период изменилось пространственное распределение подводных ландшафтов, а также качественные и количественные показатели их растительной компоненты, что, вероятно, связано как с влиянием природных факторов, так и с возросшей антропогенной деятельностью. Выявлено, что наименьшие изменения претерпели донные природные комплексы глыбово-валунного бенча и подводного склона, сложенного грубообломочными отложениями, с доминированием эрикарии косматой и гонголарии бородатой, характерные для глубин 0.5–5 м. Эти изменения коснулись лишь конфигурации их границ и глубины распространения. В донных природных комплексах отмечены изменения растительной компоненты: увеличились значения биомассы макрофитобентоса, выявлены высокая доля эдификаторов фитоценозов и значительный вклад эпифитов, появились макрофиты, предпочитающие районы с повышенным уровнем эвтрофирования морской среды. Наиболее существенная трансформация донных природных комплексов произошла на глубинах 5–15 м. Отмечены изменения глубины распространения донного комплекса слабонаклонной аккумулятивной равнины, сложенной псаммитовыми отложениями с примесью битой ракуши, где доминирует филлофора курчавая, и донного комплекса подводного склона, сложенного грубообломочными отложениями, где преобладает гонголария бородатая, с мозаичным чередованием галечно-гравийных с битой ракушей донных осадков, где господствует филлофора курчавая. Растительная компонента этих комплексов характеризуется резким снижением вклада эдификаторов фитоценозов, заменой многолетних видов макрофитов на однолетние и вертикальным снижением глубин обитания глубоководных видов, которое, вероятно, связано с уменьшением освещенности.

**Ключевые слова**: прибрежная зона, донный природный комплекс, динамика ландшафтов, макрофитобентос, Черное море, Севастополь

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## Introduction

Modern environmental management in the coastal zone of the sea leads to the formation of an unfavorable environmental situation, a decrease in the quality and quantity of natural resources, a reduction in biological and landscape diversity. To solve the issues of rational environmental management in the coastal area, it is necessary to "determine in which direction, at what speed and how specifically the properties of the landscape change both in space and time" [1, p. 198]. According to V.B. Sochava and colleagues, landscape dynamics can only be understood by studying spatial and temporal aspects "in their inextricable connection" [1)]. In the works of G.A. Isachenko [2], the main provisions of the concept of long-term dynamics of landscapes were considered. Questions on the study of the dynamics of territorial landscapes were widely covered in the works of V.N. Sukachev [3], N.A. Solntsev [4], N.L. Beruchashvili [2)], A.A. Krauklis [3)], V.A. Bokov [4)], A.G. Isachenko [5], and I.I. Mamai [6].

However, there are few scientific works devoted to the study of the dynamics of underwater landscapes due to the limited experience of such studies, the lack of methodological foundations [5)] and the accumulated data array [7–9]. In this regard, the study of spatio-temporal changes in underwater landscapes is an urgent task of geographical science.

Until now, the issue of indicators of the dynamics of underwater landscapes remains debatable. It is known that for marine geosystems, the leading functional role in the formation of the environment and ensuring the sustainable development of the biotic component of the coastal ecosystem of the shelf is played by macrophytes, which are considered a landscape-forming factor and an indicator of the originality of morphological complexes of horizontal division of underwater landscapes [5)]. Being a vulnerable component of the coastal zone, macrophytobenthos actively responds to environmental changes, which

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1) Sochava, V.B., Krauklis, A.A. and Mikheev, V.S., 1974. [Landscape Dynamics and the Idea of Epifacies]. In: Yu. M. Matarzin, ed., 1974. [*Current State of the Landscape Study Theory: Proceedings of the 7th All-Union Meeting on Landscape Study*]. Perm, p. 9 (in Russian).

2) Beruchashvili, N.L., 1972. [Seasonal Dynamics of the Facies Structure and Functioning]. In: TGU, 1972. [*Landscape Collection*]. Tbilisi: Izd-vo TGU, pp. 100–115 (in Russian).

3) Krauklis, A.A., 1979. [*Issues of Experimental Landscape Study*]. Novosibirsk: Nauka, 232 p. (in Russian).

4) Bokov, V.A., 1983. [*Spatial and Temporal Organization of Geosystems*]. Simferopol: SGU, 55 p. (in Russian).

5) Petrov, K.M., 1989. [*Underwater Landscapes: Theory, Study Approaches*]. Leningrad: Nauka, 126 p. (in Russian).

makes it possible to use its quantitative and qualitative indicators to study the state of underwater landscapes [10].

The coastal zone of Cape Kosa Severnaya – Cape Tolsty (Sevastopol) was chosen as a model polygon, which is distinguished by biological and landscape diversity. As part of the bottom vegetation of the studied area, there are species of macrophytes listed in the Red Book of the Russian Federation [6)] and the Red Book of Sevastopol [7)] – *Phyllophora crispa* (Huds.) P.S. Dixon and *Stilophora tenella* (Esper) P.C. Silva.

In this regard, the purpose of the article is to identify spatio-temporal changes in the landscape structure of the coastal zone between Cape Kosa Severnaya and Cape Tolsty based on the quantitative and qualitative characteristics of macrophytobenthos over more than a 50-year period (1964–2017).

**Materials and methods of research**

The authors collected, analyzed and summarized the materials of field landscape and hydrobotanical studies (summer period of 1997, 2006 and 2017) carried out in the coastal zone of Cape Kosa Severnaya – Cape Tolsty. Works in the coastal area were carried out with the use of light diving equipment and small boats. When studying the structure of bottom landscapes, the method of landscape profiling was used with a detailed description of key areas (see work [5)] and [8]). In 2017, three landscape and one hydrobotanical profiles were laid, and in 1997 and 2006, hydrobotanical surveys were carried out (Fig. 1). Transect coordinates were determined using a portable GPS receiver (*Oregon* 650) (Table 1).

Divers-researchers passed along the profile, taking photographs and shooting videos, visually describing bottom sediments, using the classification of marine clastic sediments according to their granulometric composition [8]. Sampling of macrophytobenthos was carried out according to the standard method [8)]. Algae were identified by the guide [9)] taking into account the latest nomenclature changes. Isolation of phytocenoses was carried out according to the dominant classification of A.A. Kalugina-Gutnik [8)]. A total of 64 quantitative samples were collected and processed. When analyzing the structure of phytocenoses, the Shannon diversity index (*H*) was used. To analyze long-term changes in the composition and structure of macrophytes (depths of 1–15 m), archival materials from the Institute of Biology of the Southern Seas for 1964 and published data known for this region and collected using a similar method [11] were used.

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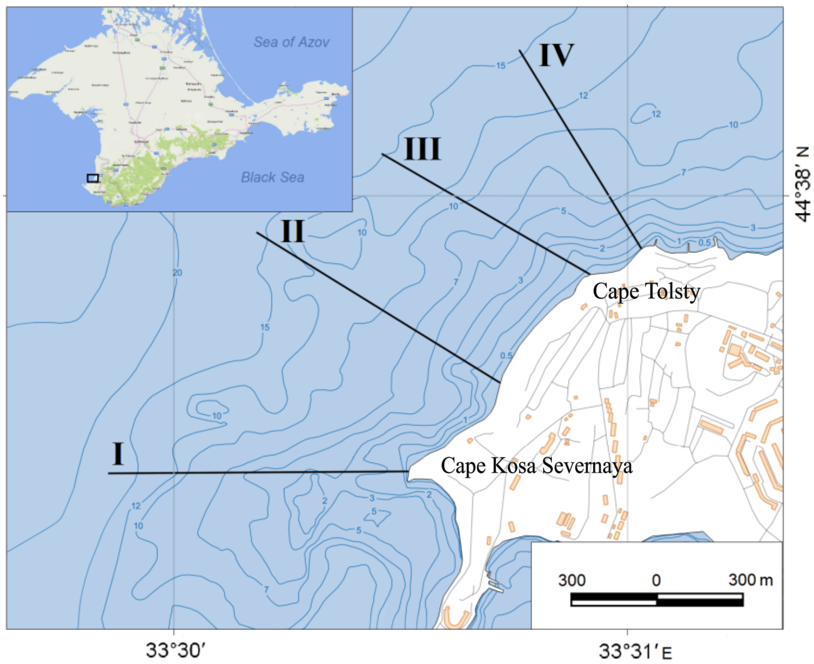
[6)] Bardunov, L.V. and Novikov, V.S., eds., 2008. [*Red Data Book of the Russian Federation (Plants and Fungi)*]. Moscow: Tovarishscestvo Nauchnykh Izdaniy KMK, 885 p. (in Russian).

[7)] Dovgal, I.V. and Korzhenevsky, V.V., eds., 2018. [*Red Data Book of Sevastopol*]. Kaliningrad; Sevastopol: Izdatelsky Dom “ROST-DOLFK”, 432 p. (in Russian).

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

[9)] Zinova, A.D., 1967. [*Identification Guide for Green, Brown and Red Algae of the South Seas of the USSR*]. Leningrad: Nauka, 397 p. (in Russian).




F i g . 1 . Schematic map of the location of landscape and hydrobotanical profiles in the coastal zone Cape Kosa Severnaya – Cape Tolsty (2017) (Roman numerals stand for profiles)

T a b l e 1 . Coordinates and depth range of hydrobotanical profiles in the coastal zone Cape Kosa Severnaya – Cape Tolsty

| Profile | Coordinates | | Depth range, m |
|---|---|---|---|
| | Northern latitude | Eastern longitude | |
| I | 44°37.887′ | 33°30.653′ | 0.5–15 |
| II | 44°37.984′ | 33°30.811′ | 0.5–15 |
| III | 44°38.306′ | 33°31.254′ | 0.5–15 |
| IV | 44°38.305′ | 33°31.440′ | 0.5–15 |

To create a landscape map, the *QGIS* 2.14.18 software package and the electronic basis of the bathymetric map were used. The conjugated analysis of the geological structure maps, the topographic map, and the information from the field surveys made it possible to extrapolate water areas with similar parameters to identify the boundaries of bottom natural complexes (BNCs). BNCs are relatively homogeneous bottom areas characterized by the unity of interrelated components: the lithogenic base, the bottom water mass, and the marine organisms inhabiting them [8]. The georeferencing of the boundaries of landscape complexes was carried out using the *QGIS* program. The landscape map is a cartographic basis, and the BNCs are aquatic units for studying long-term changes in the spatial distribution of the composition and structure of macrophytobenthos.

Statistical data processing was performed using the *MS Excel* 2000 (*Microsoft Corp*.) and *Statistica* 6.0 (*Statsoft Inc*., *OK*, USA) software packages. As a result of processing the obtained materials, landscape maps of different years were created (Fig. 2).

**Results and discussion**

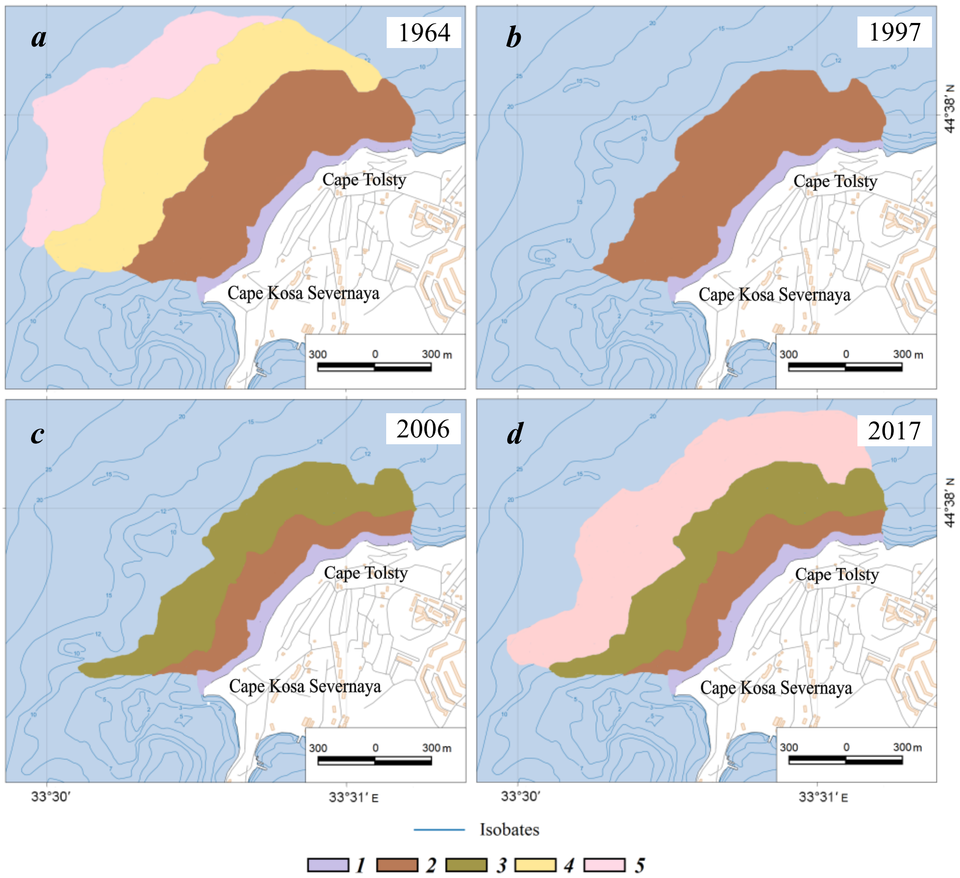
In the landscape structure of the coastal zone of Cape Kosa Severnaya – Cape Tolsty, BNCs were identified (4 – in 1964; 3 – in 1997; 2 – in 2006; 4 – in 2017) with the participation of dominant macrophyte species of *Ericaria crinita* (*Ericaria crinita* (Duby) Molinari & Guiry = *Cystoseira crinita*), *Gongolaria barbata* (*Gongolaria barbata* (Stackhouse) Kuntze = *Cystoseira barbata*) and *Phyllophora crispa* (*Phyllophora crispa* (Huds.) P.S. Dixon)) (Fig. 2).

Landscape structure of the coastal zone Cape Kosa Severnaya – Cape Tolsty (1964) (Fig. 2, *a*):

*1*. A boulder bench predominated by *Ericaria crinita* was recorded at depths of 0.5–1 m. The phytocenosis of *Ericaria crinita* – *Cladostephus spongiosus* – *Gelidium crinale* was described in this BNC. The contribution of the community edificator was high (Table 1). As part of the algocenosis, *Ulva rigida* C. Ag. and occasionally *Padina pavonica* (L.) Thivy were noted. Epiphytic synusia was poorly represented (species of the genus *Ceramium*) (Table 2). The values of the Shannon diversity index were low, which indicated a homogeneous structure of the phytocenosis with a predominance of the dominant species (Table 3).

*2*. An upper shoreface, composed of psephitic deposits, predominated by *Ericaria crinita* and *Gongolaria barbata*, was located at depths of 1–5 m. The phytocenosis *Ericaria crinita* + *Gongolaria barbata* – *Cladostephus spongiosus* – *Gelidium crinale* was described in this BNC. The values of biomass in general in the 1–5 m layer and at shallower depths were comparable (Table 2). The proportion of dominants was the highest for the entire observation period (Table 2). *Ulva rigida* was also noted in the composition of algocenosis. *Vertebrata subulifera* (C. Ag.) Kuntz was noted among epiphytes. The value of the species diversity index indicated the oligodominant structure of the phytocenosis (Table 3).

*3*. An upper shoreface, composed of psephitic deposits, predominated by *Gongolaria barbata*, with mosaic alternation of pebble and gravel deposits with shell fragments, predominated by *Phyllophora crispa*, was located at depths of 5–10 m. The phytocenosis (*Gongolaria barbata*) – *Phyllophora crispa* – *Gelidium spinosum* was described in this BNC. Its biomass and the contribution of *Gongolaria barbata* dropped by almost half, while the proportion of *Phyllophora crispa* more than tripled with the increasing depth (Table 2). Epiphytic species of algae were practically non-existent (Table 2). The values of the species diversity index were low, which indicated a small contribution of associated and epiphytic macrophyte species (Table 3).




F i g . 2 . Schematic map of the landscape structure of the coastal zone Cape Kosa Severnaya – Cape Tolsty:
*1* – boulder benches with dominance of *Ericaria crinita*; *2* – upper shoreface consisting of psephitic sediments predominated by *Ericaria crinita* and *Gongolaria barbata*; *3* – 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*; *4* – upper shoreface consisting of psephitic sediments predominated by Dictyota; *5* – gently dipping accumulation plain consisting of psammitic deposits with inclusion of shell fragments predominated by *Phyllophora crispa*.

Table 2. Total biomass of macrophytes, percentage of dominant species and their epiphyts in BNC of the coastal zone Cape Kosa Severnaya – Cape Tolsty (Fig. 2) in variuos years

| Year | BNC | Depth, m | Total biomass of macrophytes, $g \cdot m^{-2}$ | Proportion, % | | |
|---|---|---|---|---|---|---|
| | | | | *Ericaria crinita, Gongolaria barbata* | *Phyllophora crispa* | Epiphytic |
| 1964 | *1* | 0.5–1 | 3040.0 ± 550.9 | 93 | 0 | 1 |
| | *2* | 1–5 | 3109.0 ± 273.9 | 94 | 0 | 2 |
| | *3* | 5–10 | 2451.0 ± 236.1 – 1615.0 ± 163.1 | 84–42 | 16–52 | 0 |
| | *5* | 10–15 | 826.0 ± 51.4 | 0 | 75 | 0 |
| 1997 | *1* | 0.5–1 | 3506.7 ± 572.9 – 1492.3 ± 451.5 | 89–32 | 0 | 1–3 |
| | *2* | 1–5 | 1444.0 ± 381.6 | 58 | 0 | 0 |
| | *3* | 5–10 | 1141.6 ± 319.3 – 571.1 ± 42.5 | 68–44 | 13–20 | 1 |
| 2006 | *1* | 0.5–1 | 3984.2 ± 771.1 – 2786.2 ± 136.1 | 86–67 | 0 | 12–29 |
| | *2* | 1–10 | 2247.0 ± 538.4 – 591.2 ± 151.9 | 48–38 | 0 | 51–57 |
| 2017 | *1* | 0.5–1 | 11457.8 ± 2031.5 – 12888.7 ± 4380.1 | 94–96 | 0 | 5–4 |
| | *2* | 1–10 | 5572.2 ± 825.2 – 3157.1 ± 501.9 | 78–65 | 0 | 16–33 |
| | *4* | 10–15 | 130.6 ± 41.2 | 5 | 0 | 15 |
| | *5* | 15–20 | 74.6 ± 18.6 | 0 | 96 | 3 |

Table 3. Changes in the values of the Shannon (H) index of species diversity at Cape Kosa Severnaya – Cape Tolsty in variuos years

| Year | Depth, m | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1 | 3 | 5 | 10 | 15 |
| 1964 | – | 0.46 | 0.45 | 0.68 | 0.98 | 0.99 |
| 1997 | 0.77 | 2.31 | 1.58 | 1.93 | 2.48 | – |
| 2006 | 0.87 | 2.03 | 2.43 | 1.90 | 1.84 | – |
| 2017 | 0.45 | 0.35 | 1.23 | 1.90 | 1.77 | 0.32 |

*5*. A gently dipping accumulation plain consisting of psammitic deposits with admixed shell fragments predominated by *Phyllophora crispa* was located at depths of 10–15 m. The phytocenosis *Phyllophora crispa* was described in this BNC. Its biomass and the proportion of the dominant species were relatively high (Table 2). The epiphytes were absent (Table 1). As part of the algocenosis, *Cladostephus spongiosus* (Huds.) C. Ag., *Gracilaria dura* (C. Ag.) J. Ag. and *Dictyota* sp. were present. The values of the *H* index indicate a low species diversity of the phytocenosis (Table 3).

<u>Landscape structure of the coastal zone Cape Kosa Severnaya – Cape Tolsty (1997)</u> (Fig. 2, *b*):

*1*. A boulder bench predominated by *Ericaria crinita* was recorded at depths of 0.5–1 m. In this BNC of 1997, as in 1964, the phytocenosis of *Ericaria crinita – Cladostephus spongiosus – Gelidium crinale* was described. Its biomass and the proportion of *Ericaria crinita* dropped by more than half with the increasing depth, while at a depth of 0.5 m their values were relatively comparable with those in 1964, and at a depth of 1 m they were two and three times lower, respectively, than in 1964 (Table 2). *Gelidium crinale* (Hare ex Turner) Gaillon (35 % of the total biomass of macrophytes) was abundant in the structure of the algocenosis at a depth of 1 m; *Gelidium spinosum* (S. G. Gmel.) P. C. Silva, *Ellisolandia elongata* (J. Ellis & Sol.) K.R. Hind & G.W. Saunders and *Ulva rigida* were also present. The role of epiphytic synusia was small (Table 1). The values of the species diversity index indicate the polydominant structure of the algocenosis (Table 3).

*2*. An upper shoreface, composed of psephitic deposits, predominated by *Ericaria crinita* and *Gongolaria barbata*, was located at depths of 1–5 m in 2006, as in 1964. The phytocenosis of *Ericaria crinita + Gongolaria barbata – Cladostephus spongiosus – Gelidium crinale* was described in this BNC. Its biomass was two times lower than in 1964. The share of edificators was low, almost two times lower than in 1964 (Table 2). A significant contribution of *Gelidium crinale* (33 % of the total biomass of macrophytes) was noted in the community; *Ulva rigida, Ellisolandia elongata* were also found, and *Phyllophora crispa* was found sporadicly. Epiphytic algae were practically non-existent (Table 2). Relatively high values of the species diversity index testify to the polydominant structure of the phytocenosis (Table 3).

*3*. An upper shoreface, composed of psephitic deposits, predominated by *Gongolaria barbata*, with mosaic alternation of pebble and gravel deposits with admixed shell fragments, where *Phyllophora crispa* predominates, was recorded in 1997 at depths of 5–10 m, as in 1964. This BNC described the same phytocenosis (*Gongolaria barbata*) – *Phyllophora crispa – Gelidium spinosum*. Its biomass decreased by half with increasing depth, while being 2–3 times lower than in 1964. The contribution of *Gongolaria barbata* dropped almost by half, while the contribution of *Phyllophora crispa* increased by the same factor with the increasing depth (Table 2). The community included *Ericaria crinita, Cladostephus spongiosus, Ulva rigida*. Epiphytic synusia was poorly developed (Table 2). The values of the *H* index indicate the complex structure of phytocenosis, where a high contribution of associated algae species is noted (Table 3).

Landscape structure of the coastal zone Cape Kosa Severnaya – Cape Tolsty (2006) (Fig. 2, *c*):

*1*. A boulder bench predominated by *Ericaria crinita* was recorded at depths of 0.5–1 m. In this BNC of 2006, the phytocenosis of *Ericaria crinita – Cladostephus spongiosus – Gelidium crinale* was described. Its biomass in the studied depth range slightly decreased with the increasing depth (Table 2). The contribution of the community edificator as a whole reached significant values (Table 2). In the structure of algocenosis, *Cladophoropsis membranacea* (Hofm. Bang ex C. Ag.), *Ulva rigida*, and *Gelidium spinosum* were occasionally noted. As part of the community, a significant contribution of epiphytic algae to the total biomass of macrophytes was noted (more than an order of magnitude higher than at the same depths in 1964 and 1997). The epiphytic synusia was dominated by *Vertebrata subulifera, Laurencia coronopus* J.Ag. and species of the genus *Cladophora*. The values of the Shannon diversity index indicate a high species diversity of phytocenosis (Table 3).

*2*. An upper shoreface, composed of psephitic deposits, predominated by *Ericaria crinita* and *Gongolaria barbata*, was located, unlike in 1964 and 1997, at depths of 1–10 m. The same phytocenosis (*Ericaria crinita + Gongolaria barbata – Cladostephus spongiosus – Gelidium crinale*) was described in this BNC. In 2006, its biomass decreased by almost four times with the increasing depth and was at the upper boundary of the community about one and a half times lower than in 1964, and by the same amount higher than in 1997 (Table 2). The contribution of algocenosis dominants was minimal for the entire observation period. Species of the genus *Ulva* occasionally occurred in the composition of phytocenosis in the depth range of 1–5 m, while *Carradoriella elongata* (Huds.) Savoie & G.W. Saunders was registered at the depths of 5–10 m, and *Phyllophora crispa* – sporadically. The contribution of epiphytic synusia reached maximum values and accounted for about half of the total macrophyte biomass (Table 1). Among epiphytes, *Vertebrata subulifera* dominated at all depths; *Laurencia coronopus, Chondria capillaris* (Huds.) M. J. Wynne, and species of the genus *Cladophora* were recorded at the depths of 3–5 m. The values of the *H* index indicate the complex structure of phytocenosis, where a high contribution of associated and epiphytic algae species is noted (Table 3).

Landscape structure of the coastal zone Cape Kosa Severnaya – Cape Tolsty (2017) (Fig. 2, *d*):

*1*. A boulder bench predominated by *Ericaria crinita* was located at depths of 0.5–1 m. At present, the phytocenosis of *Ericaria crinita* was described in this BNC. Its biomass in the studied depth range was characterized by high quantitative indicators, the value of which increased slightly with the increasing depth (Table 2). The contribution of the community edificator was also high (Table 2). Among the thickets of *Ericaria crinita*, *Cladostephus spongiosus* and *Gelidium crinale* are found sporadically. Epiphytes are poorly represented; their maximum contribution falls on *Vertebrata subulifera*. At these depths, *Laurencia coronopus, Myriactula rivulariae* (Suhr ex Aresch.) Feldmann, and *Corynophlaea umbellata* (C. Ag.) Kütz were also found in the epiphytic synusia. The values of the Shannon diversity index were low, which indicated a homogeneous structure of the phytocenosis with a predominance of the dominant species (Table 3).

*2*. An upper shoreface, composed of psephitic deposits and predominated by *Ericaria crinita* and *Gongolaria barbata,* was recorded in 2017 at depths of 1–10 m, as in 2006. The same phytocenosis *Ericaria crinita* + *Gongolaria barbata – Cladostephus spongiosus – Gelidium crinale* was described in this BNC. Its biomass dropped by almost half with the increasing depth, while at the upper and lower boundaries of the community it was 2.5–5 times higher, respectively, than in 2006 (Table 2). The proportion of edificators in this depth interval was characterized by high values, which were approximately twice as high as in 2006 (Table 2). Representatives of the genus *Ulva* were registered in the community. At these depths, a significant role of epiphytic algae was noted (Table 2). Among them, *Vertebrata subulifera* prevailed, *Stilophora tenella* (Esper) P.C. Silva and *Ectocarpus siliculosus* (Dillwyn) Lyngb were also noted. The values of the Shannon diversity index were significantly higher compared to those at shallower depths, which indicates a more complex structure of the algocenosis (Table 3).

*4*. An upper shoreface composed of psephitic deposits predominated by a species of the genus *Dictyota* was located at depths of 10–15 m. The phytocenosis *Dictyota* sp was described in this BNC. Its biomass was low, while the community edificator accounted for 50 % of the total biomass of macrophytes (Table 2). At these depths, the lithophytic form of *Chondria capillaris* was abundant. *Ericaria crinita, Gongolaria barbata, Osmundea pinnatifida* (Huds.) Stackh., *Cladostephus spongiosus* were also registered in the algocenosis. Epiphytic synusia was represented mainly by *Callithamnion corymbosum* (Smith) Lyngb. The complex structure of phytocenosis is confirmed by the value of the Shannon diversity index (Table 3).

*5*. A gently dipping accumulation plain consisting of psammitic deposits with admixed shell fragments and predominated by *Phyllophora crispa* was located at depths of 15–20 m. *Phyllophora crispa* phytocenosis was described in this BNC. Its biomass was low, while at the upper boundary of the community it was more than an order of magnitude lower than in 1964 (Table 2). Algocenosis edificator dominated. The community included *Zanardinia typus* (Nardo) P.C. Silva. *Ectocarpus siliculosus* dominated among epiphytes. The value of the species diversity index indicates the oligodominant structure of the phytocenosis (Table 3).

Thus, the analysis of the material obtained showed that over more than a 50-year period in the coastal zone of Cape Kosa Severnaya – Cape Tolsty, there were changes in the spatial distribution of underwater landscapes, as well as in the qualitative and quantitative indicators of their plant component.

It is characteristic that the BNC of the boulder bench predominated by *Ericaria crinita* (1) was noted at depths of 0.5–1 m throughout the entire period under study. However, in 2017, at these depths, a significant increase in the total biomass of macrophytes was recorded, mainly due to *Ericaria crinita*, compared with its values in earlier years (Fig. 2; Table 2). The values of the Shannon diversity index show that the composition and structure of phytocenoses have changed over 53 years, they have become more homogeneous, and not polydominant. The share of the algocenosis edificator during the study period remained generally high and varied from 96 % to 32 % of the total macrophyte biomass, while its maximum value was noted in 2017 and the minimum – in 1997 (Table 2). In this BNC of 2006, the macrophytobenthos included the most significant contribution of epiphytes (12–29 %), while in 1997 and 2017, their share did not exceed 5 %, in 1964 it was about 1 % of the total macrophyte biomass (Table 2).

The BNC of the upper shoreface, composed of psephitic deposits and predominated by species of *Ericaria crinita* and *Gongolaria barbata* (2), was also recorded during the entire study period. However, the depth of its distribution varied over the years. Thus, if in 1964 and 1997 the BNC was described at depths of 1–5 m, in 2006 and 2017 it was recorded at depths of 1–10 m (Fig. 2; Table 2). This BNC was characterized by a more complex structure of algocenosis. Its edificators, in addition to *Ericaria crinita*, include *Gongolaria barbata*, which prefers areas protected from waves at greater depths for growth [8)]. The dominance of *Ericaria crinita* at shallow depths is explained by the high surf zone of the near-shore zone of Cape Kosa Severnaya – Cape Tolsty. At the upper boundary of the BNC, the proportion of dominant species is quite high and varies from 48 % (2006) to 94 % (1964), while at the lower boundary it decreases to 38 % (2006) – 65 % (2017) of the total macrophyte biomass (Table 2).

It is indicative that the spatial distribution of BNCs *1* and *2*, where *Ericaria crinita* and *Gongolaria barbata* predominate, is determined by the stability of the bottom lithogenic base, which is a substrate for the attachment of macrophytes. However, in the composition and structure of macrophytobenthos of these BNCs, significant changes occurred, which apparently are a response to changes in environmental conditions. It is known that since the end of the last century, in many areas of the Crimean shelf, where an increase in the level of eutrophication of water masses has been recorded, an increase in the density of thickets of *Ericaria crinita* and *Gongolaria barbata* in the upper sublittoral zone (depths of 0.5–3 m) has been observed, which is probably associated with a decrease in water transparency [12]. Such changes at the depths of growth of these species caused a shift in their ecological and phytocenotic optimum [8)], which was previously located at depths of 3–5 m.

The abundant development of epiphytic species growing on the thalli of *Ericaria crinita* and *Gongolaria barbata* and having a high surface area of thalli may be a response to an increase in dissolved organic matter in the coastal zone of the sea. The most significant proportion of epiphytic synusia at depths of 0.5–1 and 1–10 m (12–29 % and 51–57 % of the total macrophyte biomass, respectively) was recorded in 2006, which may be due to the continuing increase in water pollution compared to 1964 and 1997. Indirectly, an increase in the level of trophicity of the environment in the area of Capes Kosa Severnaya and Tolsty is evidenced by the index of species diversity, which was minimal in 1964 and varied from 0.46 to 0.99, then increased in 1997 (0.77–2.48) and 2006 (0.87–2.43), and slightly decreased in 2017 (0.32–1.90). In 2017, in BNCs *1* and *2*, the total biomass of macrophytobenthos, the proportion of *Ericaria crinita* and *Gongolaria barbata* increased, while the contribution of epiphytic algae decreased, which allows us to conclude that the state of the marine environment has improved (Table 1). Our assumption can be confirmed by information about the current classification of this water area as conditionally clean. Thus, in 2018, the *E-TRIX* value varied from 1.44 to 2.20 (according to this criterion, the water corresponds to a low trophic level), while in 2007 this indicator was about 4 [13].

In 1964 and 1997 at depths of 5–10 m, the BNC of an upper shoreface composed of psephitic deposits was described, where *Gongolaria barbata* predominated, with mosaic alternation of pebble and gravel deposits with admixed shell fragments, where *Phyllophora crispa* dominated (3). In 2006 and 2017 the BNC was not observed at these depths. This phytocenosis is typical for the Black Sea coast of Crimea. The existence of a "transition zone" where several phytocenoses meet at the same depth at the same time was pointed out by A.A. Kalugina-Gutnik [8)] as early as the end of the previous century. This intermediate zone previously extended at depths of 15–20 m. At present, it has shifted to depths of 7–10 m. According to U.V. Simakova [14], these areas represent an ecocline, a zone with a gradual change in the composition of bottom vegetation along the illumination gradient [8]. However, the existence of "transitional" BNCs largely depends on the intensity of hydro- and lithodynamic processes occurring in the coastal zone. The studied area is characterized by an active redistribution of deposits, where the direction and intensity of alongshore flows depend on the wind-wave regime [15].

More than 50 years ago, at depths of 10–15 m, the BNC of a gently dipping accumulation plain was recorded, it was composed of psammitic deposits with admixed shell fragments, where *Phyllophora crispa* dominated. At these depths, relatively significant concentrations of the dominant species were noted (Table 2). Based on the analysis of archival material collected along the Crimean coast in the 1960s–1970s [8)], it can be assumed that at depths of more than 15 m, the phyllophora biomass would have been much higher (in the area of Laspi Bay at depths of 15–25 m it was about 5000 g $m^{-2}$). In 2017, single specimens of *Phyllophora crispa* were found at depths of 15–20 m, and one-year-old *Dictyota* sp. grew abundantly at depths of 10–15 m and *Gongolaria barbata* and *Ericaria crinita* were occasionally noted (Table 1).

For the Black Sea coast of Crimea in the 1960s–1970s at depths of more than 25 m, phytocenoses with the participation of deep-water species of *Zanardinia typus*, *Nereia filiformis*, and *Carradoriella elongata* were described. At present (2017), in the region of Cape Kosa Severnaya – Cape Tolsty, these species have been found in BNCs *4* and *5* at depths of 10–15 m. It is characteristic that in 1964 they were not registered at these depths, which indicates a vertical decrease in the depths of their habitat, which is probably associated with a decrease in illumination.

Thus, the BNC of a gently dipping accumulation plain, composed of psammitic deposits with admixed shell fragments, where *Phyllophora crispa* prevails, and the BNC of an upper shoreface, composed of psephitic deposits, predominated by *Gongolaria barbata* with a mosaic alternation of pebble and gravel deposits with admixed shell fragments of bottom sediments dominated by *Phyllophora crispa* turned out to be more susceptible to transformation, which was reflected in a change in the depth of their distribution, degradation of the plant component, and a sharp decrease in the contribution of edificatory species.

It is significant that over the period from 1964 to 2017, the anthropogenic load on the coastal zone of Cape Kosa Severnaya – Cape Tolsty increased sharply. In the last decade, there has been an active development of this coast with residential and recreational facilities. Intensive construction has led to activation of gravitational processes in the coastal zone. In addition, the volume of wastewater discharge into the water area of this region has significantly increased.

Spatio-temporal changes in the BNC in the landscape structure are probably associated with the influence of both natural factors and increased economic activity. Thus, in modern conditions, under the influence of natural and anthropogenic fluctuations, new BNCs are formed, containing elements of the previous ones. According to L.A. Bespalova [16], who studied the anthropogenic impact on the landscape structure of the Sea of Azov, its return to a pre-existing state is impossible due to irreversible changes in landscape components. In favor of the proposed assumption, one can also cite Dollo's law known in the theory of evolution, from which it follows that a decrease in the influence of anthropogenic and natural factors acting on the system does not mean that it will return to its previous state [10)].

In general, the question of the reasons for the restructuring of the BNC, including structural changes in the vegetation component of the landscape of the coastal zone of Cape Kosa Severnaya – Cape Tolsty, remains debatable. Many of the stated provisions require further elaboration and comprehensive research [8].

**Conclusion**

The analysis of the obtained materials showed that during the period of research in the coastal zone of Cape Kosa Severnaya – Cape Tolsty, the spatial distribution of underwater landscapes, as well as the qualitative and quantitative indicators of their plant component, have changed, which is probably due to the influence of both natural factors, and increased anthropogenic activity.

The BNCs of the boulder bench and the upper shoreface, composed of psephitic deposits and predominated by *Ericaria crinita* and *Gongolaria barbata*, located at depths of 0.5–5 m, underwent the least changes. These changes affected only the configuration of their boundaries and the depth of distribution, which is probably due primarily to the stability of the lithogenic base, which is the substrate for the strong attachment of macrophytes. The plant component of these BNCs is distinguished by the maximum values of macrophyte biomass, a high proportion of phytocenosis edifiers, and a significant contribution of epiphytes.

The most significant restructuring occurred in the BNCs located at depths of 5–15 m: the BPC of a gently dipping accumulation plain composed of psammit-

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[10)] Dollo, L., 1893. Les Lois de l'evolution. *Bulletin de la Société belge de géologie, de paléontologie et d'hydrologie*, 7, pp. 164–166. Available at: https://www.biodiversitylibrary.org/item/159645#page/183/mode/1up [Accessed: 25 May 2022].

ic deposits with admixed shell fragments, where *Phyllophora crispa* dominates, and the BPC of an upper shoreface composed of psephitic deposits, where *Gongolaria barbata* dominates, with a mosaic alternation of pebble and gravel deposits with admixed shell fragments, where *Phyllophora crispa* dominates. During the period under study (1964–2017), there were changes in the depth of their distribution, degradation of the plant component, a sharp decrease in the contribution of edificators of phytocenoses, replacement of perennial macrophyte species with annual ones, and a vertical decrease in the depth of habitat of deep-sea species, which is, probably, associated with a decrease in illumination.

The study of the dynamics of underwater landscapes will make it possible to predict their development and behavior under certain conditions, to scientifically substantiate the type of environmental management, to provide for nature conservation measures, and to determine the value of the maximum allowable load on the BNC.

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*All the authors have read and approved the final manuscript.*