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The Current State of the *Zostera marina* + *Stephanocystis crassipes* Community in the Eastern Bosphorus Strait, Sea of Japan

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Abstract—The state of the macrophyte community of *Zostera marina* + *Stephanocystis crassipes* in the cove off Cape Tokarevsky (Eastern Bosphorus Strait, Sea of Japan) was evaluated, using the method of sample plots, in June 2014. The taxonomical and morpho-functional composition, as well as the structure of the community, has been studied. A total of 39 species of marine macrophytes have been found in this area, including 6 species of Chlorophyta, 22 species of Rhodophyta, 10 species of Phaeophyceae, and 1 species of Tracheophyta (*Zostera marina*), which constitute 15, 56, 26, and 3% of the total number of species in the community, respectively. The studied phytocenosis is characterized by a poor taxonomic composition, a high biomass of opportunistic species (auxiliary species on the dominance scale), and the proportions of higher algal taxa typical of the clean waters of Peter the Great Bay. Thus, based on a combination of these characteristics, the *Zostera marina* + *Stephanocystis crassipes* phytocenosis can be regarded as being in an early stage of anthropogenic transformation and the waters are classified as moderately polluted.

Keywords: seagrasses, macroalgae, community structure, anthropogenic pollution, subtidal zone, Eastern Bosphorus Strait, Sea of Japan

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INTRODUCTION

The macrophytobenthos is the primary producer of organic matter in the sea; it plays an important role in the structuring of space and formation of feeding and protective biotopes for many species of animals and also has a substantial influence on the functions of marine ecosystems. Variations in the structure of the vegetation affect the entire population of a biotope, up to changes in the composition of biocenoses and reduction in stocks of aquatic organisms. Therefore, information about the current state of macrophytobenthos makes a significant contribution to forming the ideas about trends of succession processes in marine ecosystems exposed to anthropogenic impacts.

Assessment of short- and long-term variations in benthic plant communities caused by effects of various natural and anthropogenic factors is possible on the basis of a retrospective analysis of their composition and temporal and spatial distribution. Unfortunately, the available data on the composition and structure of intertidal and subtidal macrophytobenthos communities in Ussuri and Amur bays of the Sea of Japan are fragmentary. The vegetation has been investigated most thoroughly in the apical part of Amur Bay [5, 9, 21, 25, 36], the western part of Ussuri Bay (Patrokl and Sobol bays) [8, 28, 41], the waters off Cape Zeleny [25], and in some bays of Russky [2, 9, 16] and Reineke islands [6]. The structure of plant communities in the Eastern Bosphorus Strait that connect these two bays remains almost unstudied.

The first studies of benthic biocoenoses in the Eastern Bosphorus Strait were conducted in the first quarter of the 20th century under the guidance of I.G. Zaks. A schematic map of distribution of substrata and benthic groups of plants and animals in Patrokl Bay, located on the mainland coast of the northeastern Eastern Bosphorus Strait, was composed as a result of these works [8]. From the 1930s to the middle of the 1990s, the strait was closed for scientific study. An ecological appraisal of the state of benthic communities in Patrokl Bay was performed in the early 2000s [28]. In 2008, intertidal communities of the Ayaks and Paris bays (Russky Island, southeastern Eastern Bosphorus Strait) were described without providing quantitative data [16].

Since the middle of the 20th century, the Eastern Bosphorus Strait was under strong pressure of industrial pollution. Sewage waters of the Dal'zavod Shipyard (with high concentrations of cadmium, nickel, manganese, iron, and copper) and the facilities of the Vladivostok seaport (with petroleum hydrocarbons) exerted a considerable impact on the condition of benthic communities off Cape Tokarevsky. The decline in

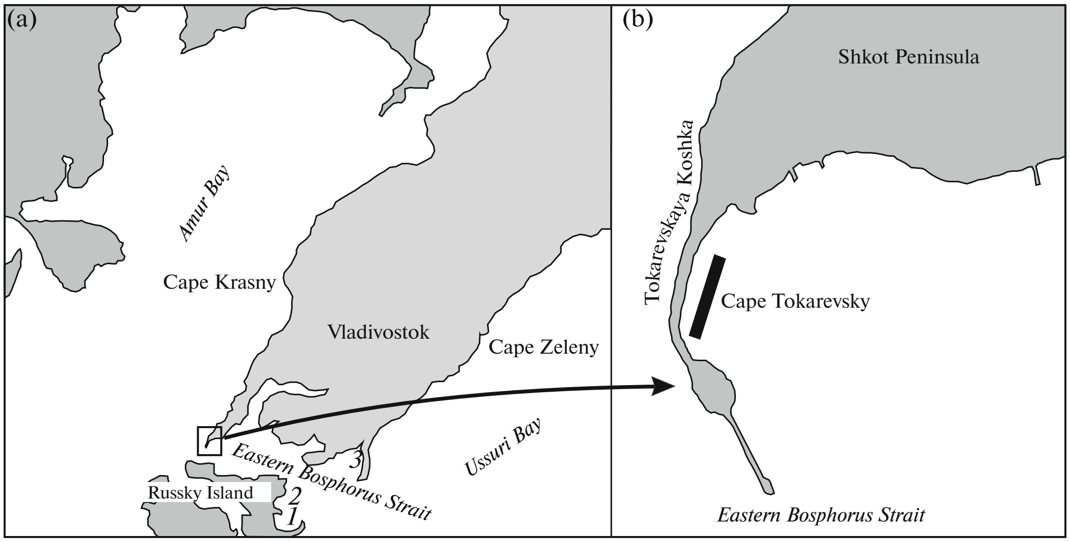

Fig. 1. The study area. The black rectangle indicates the location of the *Zostera marina* + *Stephanocystis crassipes* phytocenosis. (*1*) Paris Bay; (*2*) Ayaks Bay; (*3*) Patrokl Bay.

industrial production in the 1990s caused a reduction in the amounts of pollutants, primarily heavy metals and petroleum products, discharged into the strait [12]. However, the gradual increase in marine traffic and human population along the coast, as well as the development of infrastructure of the Far Eastern Federal University, will undoubtedly affect the ecological situation in the Eastern Bosphorus Strait. Therefore, particulate matter and municipal/household wastewater are expected to constitute a substantial proportion of pollutants.

In these conditions, it is crucially important to record the qualitative and quantitative variations in the composition, structure, and distribution of benthic communities, which would allow timely identification of the signs and trends of transformation of phytocenoses caused by anthropogenic pressure. In the absence of information about the native (prior to the onset of anthropogenic impact) state of the macrophytobenthos in the study area, this problem can be resolved by comparing the considered communities to phytocenoses in relatively clean waters. Previously, we described the communities dominated by *Zostera marina* from two water areas of Peter the Great Bay with different degrees of anthropogenic pollution: eutrophic off Cape Krasny (Amur Bay) and mesotrophic off Cape Zeleny (Ussuri Bay).

The goal of this work is to study the *Zostera marina* + *Stephanocystis crassipes* phytocenosis off Cape Tokarevsky (western Eastern Bosphorus Strait) and compare this community to the phytocenoses in Amur and Ussuri Bay, Sea of Japan, that we described earlier.

MATERIALS AND METHODS

The sampling site was a small cove off the southwestern tip of the Shkot Peninsula, located south of Cape Tokarevsky along the so-called Tokarevskaya Koshka, which is a long (796 m) stony spit artificially raised in the form of a dam [17]. The spit forms the western shore of the cove, facing the Eastern Bosphorus Strait (Fig. 1). The substratum here is stones and silt with sparse boulders and cobbles. The bay is exposed to various groups of pollutants, including petroleum hydrocarbons, pesticides, heavy metals, as well as household and industrial sewage [1, 13, 30]. By 2013, the quality of water in the Eastern Bosphorus Strait increased from class IV (polluted) to class III (moderately polluted) [7].

The studied community of seagrasses is located in the subtidal zone at a depth of 0.5–1.5 m. Distribution of this phytocenosis to deeper horizons is limited by mobile hard substrata (gravel, pebbles, and small boulders). In the shallow horizon, there is a mosaic polydominant phytocenosis of red algae.

Macrophytes were collected in June 2014 along the spit, within a segment of approximately 200 m in length from Cape Tokarevsky to the wider middle part (Fig. 1). A total of five quantitative samples were collected within 0.25 m^2 square plots randomly arranged on the bottom. In addition, qualitative sampling of macrophytes was conducted within the community. Samples were immediately transported to the laboratory. The plants were sorted out into species, excess moisture was removed with filter paper, and the biomass of each species was determined with a CAS MT-300T digital balance (accurate to 0.01 g). Plants of unidentified species were placed in a herbarium numbering 15 sheets.

To identify the classes of dominance by biomass, the Lyubarsky's cubically transformed scale [14] was used (Table 1).

Table 1. The scale of dominance in terms of biomass (B is the proportion of species in the total biomass of the community)

Score	Boundary of classes, %	Degree of species dominance
1	$0 < B \leq 1$	Accidental
2	$1 < B \leq 6$	Auxiliary
3	$6 < B \leq 22$	Subdominant
4	$22 < B \leq 50$	Dominant
5	$50 < B \leq 100$	Absolute dominant

We interpret the term "phytocenosis," used in this work as "a conventionally limited and homogeneous (visually) contour of vegetation, a part of the phytocenotic continuum..." [19]. Phytocenosis names are given based on the species dominating in biomass, without defining the vegetation strata [4]. The terms "phytocenosis" and "community" are here used as synonyms. When considering "assemblage," we mean "a set of phytocenoses, identical in composition of dominants and having a more or less similar composition and similar relationships among organisms and between organisms and the environment" [22].

Species of algae were identified using keys [3, 10, 22, 23]. The names of the mentioned taxa are given in accordance with AlgaeBase [35].

The morpho-functional characteristics of macrophytes correspond to those published earlier [37]. The opportunistic species are annual, in most cases fast growing, algae with thin sheet-like, tubular, filamentous, and coarsely-branched thalli. Seagrasses and perennial algae with highly differentiated blade-like and branched thalli, as well as calcareous algae, are referred to as late successional species [39].

The PRIMER v.6 package of statistical programs was used to analyze the similarity between the considered phytocenoses [32]. Biomass values for each species were standardized and square-root transformed. The level of similarity of the communities was determined using the Bray-Curtis coefficient, calculated based on biomass of species in the compared communities. The percentage contribution of species to the community structure was estimated using the SIMPER module. Samples with the maximum and minimum biomass were averaged.

RESULTS

The *Zostera marina* + *Stephanocystis crassipes* phytocenosis in the study area was located on pebbly/silty substrata. A total of 39 species of macrophytes were found here: 6 species of Chlorophyta, 22 species of Rhodophyta, 10 species of Phaeophyceae, and 1 species of Tracheophyta (*Zostera marina*), which constituted 15, 56, 26, and 3% of the total number of species in the community, respectively (Table 2). The width of the algal belt along the coast varied from 5 to 20 m. The average biomass of the community was 2336.77 ± 1074.06 g/m^2.

The absolute dominant in the community was the seagrass *Z. marina*, whose biomass varied from 0 to 3897.24 g/m^2 (mean 1290.46 ± 1624.61 g/m^2), which accounted for 55.2% of the community biomass (Fig. 2). The branched perennial brown alga *S. crassipes* from the family Sargassaceae grew between clumps of seagrass and played the dominant role in the community, accounting for 25.9% of biomass, which was on average 606.03 ± 818.14 g/m^2. The string-like, unbranched brown alga *Chorda filum*, whose biomass varied from 39.16 to 451.68 g/m^2 (mean 144.36 ± 142.28 g/m^2), occurred mosaically among these plants. The proportion of this alga in the biomass of phytocenosis reached 8.7%, which allowed us to consider it as a subdominant. Auxiliary species in the phytocenosis were represented by *Ulva lactuca* [= *U. fenestrata*] (1.4%), *Ulvaria splendens* (1.7%), *Colpomenia peregrina* (1.9%), *Punctaria plantaginea* (2.1%), and *Ceramium kondoi* (1.7%). The biomass of these species varied from 0 to 167.76 g/m^2. The following accidental species most frequently occurred singly or in groups in the community: *Cladophora stimpsonii* (usually among branches of brown algae from the family Sargassaceae), *Desmarestia viridis*, *Sargassum miyabei*, *S. pallidum*, and *Gelidium elegans* (among rhizomes of seagrasses and rhizoids of large brown algae). Their combined biomass in the community did not exceed 29.7 g/m^2. Other accidental species such as *Ulva linza*, *Scytosiphon lomentaria*, *Gracilaria vermiculophylla*, *Laurencia nipponica*, *Mazzaella japonica*, *Palmaria stenogona*, *Ptilota filicina*, *Schizymenia pacifica*, and *Symphyocladia latiuscula* were even rarer and occurred among rhizomes of seagrasses and rhizoids of large algae. Their total biomass was approximately 6.5 g/m^2. At times thalli of *Bryopsis plumosa* and *Dictyopteris divaricata*, *Ahnfeltiopsis flabelliformis*, *Campylaephora crassa*, *Chrysymenia wrightii*, *Chondrus armatus*, *Ch. pinnulatus*, *Corallina officinalis*, *Dasya sessilis*, *Gloiosiphonia californica*, *Laurencia saitoi*, *Lomentaria hakodatensis*, *Bossiella compressa*, *Polysiphonia morrowii*, and *Tichocarpus crinitus* developed on rhizoids of algae and on rocks; *Leathesia marina* usually grew on branches of sargassacean brown algae. The combined contribution of these species to the biomass of the phytocenosis was slightly greater than 1 g/m^2. The epiphyte *Acrochaete geniculata* grew abundantly on branched red algae. A few specimens of the foliaceous brown alga *Petalonia fascia* were also found.

Macrophytes from 35 genera, 25 families, 15 orders, and 4 phyla were found in the studied community. Each order was represented by an average of

Table 2. The species composition of the *Zostera marina* + *Stephanocystis crassipes* phytocenosis off Cape Tokarevsky (Eastern Bosphorus Strait, Sea of Japan)

Taxon	Biomass	MFG
Chlorophyta		
Ulvales		
Ulvaceae		
Ulva lactuca Linnaeus	32.2	S
U. linza Linnaeus	<1.0	S
Ulvaria splendens (Ruprecht) K.L. Vinogradova	36.7	S
Ulvellaceae		
Acrochaete geniculata (N.L. Gardner) O'Kelly	+e	F
Cladophorales		
Cladophoraceae		
Cladophora stimpsonii Harvey	3.2	F
Bryopsidales		
Bryopsidaceae		
Bryopsis plumosa (Hudson) C. Agardh	<1.0	F
Ochrophyta		
Phaeophyceae		
Ectocarpales		
Chordariaceae		
Leathesia marina (Lyngbye) Decaisne	<1.0	S
Punctaria plantaginea (Roth) Greville	49.8	S
Scytosiphonaceae		
Colpomenia peregrina Sauvageau	43.5	S
Petalonia fascia (O.F. Müller) Kuntze	<1.0	S
Scytosiphon lomentaria (Lyngbye) Link	<1.0	
Desmarestiales		
Desmarestiaceae		
Desmarestia viridis (O.F. Müller) J.V. Lamouroux	3.3	B
Laminariales		
Chordaceae		
Chorda filum (Linnaeus) Stackhouse	203.2	L
Dictyotales		
Dictyotaceae		
Dictyopteris divaricata (Okamura) Okamura	<1.0	S
Fucales		
Sargassaceae		
Sargassum miyabei Yendo	18.3	L
S. pallidum (Turner) C. Agardh	1.7	L
Stephanocystis crassipes (Mertens ex Turner) Draisma, Ballesteros, F. Rousseau & T. Thibaut	606.0	L
Rhodophyta		
Gelidiales		
Gelidiaceae		
Gelidium elegans Kützing	3.2	B
Gracilariales		
Gracilariaceae		
Gracilaria vermiculophylla (Ohmi) Papenfuss	<1.0	B
Corallinales		
Corallinaceae		
Bossiella compressa N.G. Kloczcova	<1.0	C
Corallina officinalis Postels et Ruprecht	<1.0	C
Gigartinales		
Phyllophoraceae		
Ahnfeltiopsis flabelliformis (Harvey) Masuda	<1.0	L

Table 2. (Contd.)

Taxon	Biomass	MFG
Gigartinaceae		
Chondrus armatus (Harvey) Okamura	<1.0	L
C. pinnulatus (Harvey) Okamura	<1.0	L
Mazzaella japonica (Mikami) Hommersand	1.4	B
Tichocarpaceae		
Tichocarpus crinitus (S.G. Gmelin) Ruprecht	<1.0	L
Nemastomataceae		
Schizymenia pacifica (Kylin) Kylin	<1.0	S
Gloiosiphoniaceae		
Gloiosiphonia californica (Hudson) Carmichael	<1.0	B
Rhodymeniales		
Lomentariaceae		
Lomentaria hakodatensis Yendo	<1.0	B
Rhodymeniaceae		
Chrysymenia wrightii (Harvey) Yamada	<1.0	B
Palmariales		
Palmariaceae		
Palmaria stenogona Perestenko	<1.0	B
Ceramiales		
Ceramiaceae		
Campylaephora crassa (Okamura) Nakamura	<1.0	F
Ceramium kondoi Yendo	39.8	F
Dasyaceae		
Dasya sessilis Yamada	<1.0	F
Wrangeliaceae		
Ptilota filicina J. Agardh	<1.0	B
Rhodomelaceae		
Polysiphonia morrowii Harvey	<1.0	F
Symphyocladia latiuscula (Harvey) Yamada	<1.0	B
Laurencia nipponica Yamada	<1.0	B
L. saitoi Perestenko	<1.0	B
Tracheophyta		
Alismatales		
Zostera marina Linnaeus	1290.5	SG

The values are the average biomass of the species in the community (g/m^2). MFG is the morpho-functional group. Opportunistic species are as follows: F, algae with branched and unbranched uniseriate and multiseriate filamentous thalli; S, species with thin sheet-like, tubular thalli; B, annual algae with coarsely corticated, branched thalli. Late successional species are as follows: L, perennial algae with highly differentiated, thick leathery, heavily corticated, blade-like, and branched thalli; C, calcareous algae; SG, seagrasses; e, epiphyte. "+" means rare species with a biomass in the community of <0.1 g.

1.7 families, 2.3 genera, and 2.5 species; each family was represented by an average of 1.4 genera and 1.5 species. The largest in their numbers of species were the orders Ceramiales and Gigartinales (Rhodophyta), which contained eight and seven species, respectively. In these orders, the richest families were Rhodomelaceae (four species) and Gigartinaceae (three species). Among brown algae, the largest numbers of species were recorded from the order Ectocarpales (five species) with the family Scytosiphonaceae (three species) and Fucales with the family Sargassaceae (three species). In green algae, the best represented order was Ulvales (four species) with the family Ulvaceae (three species).

An analysis of morpho-functional groups in the community revealed a prevalence of coarsely branched annual algae in number of species: 12 species, or 30.8% (Fig. 3a). A considerable number of species were also found among algae with sheet-like or tubular (ten species, or 25.6%) and filamentous (seven species, or 17.9%) thalli. The representativeness of perennial species with highly differentiated thalli (late successional algae) was the same as that of macrophytes with sheet-like thalli (10 species, or 25.6%). Nevertheless, the late successional species (10 species)

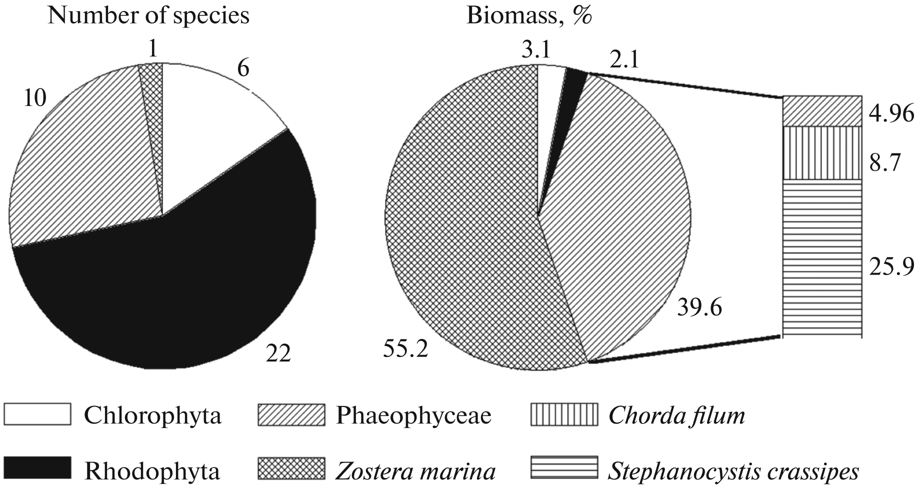

Fig. 2. The proportions of the highest taxa in the *Zostera marina* + *Stephanocystis crassipes* phytocenosis in terms of number of species and biomass. The contribution of dominant and subdominant species is shown separately.

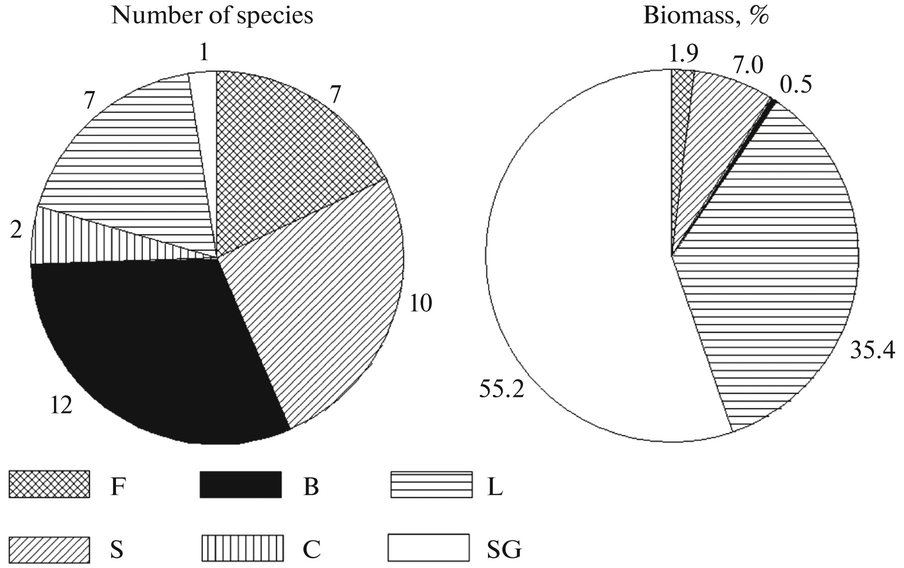

Fig. 3. The proportions of morpho-functional groups in the *Zostera marina* + *Stephanocystis crassipes* phytocenosis in terms of number of species and biomass. Opportunistic species are as follows: F, algae with branched and unbranched uniseriate, multiseriate, or filamentous thalli; S, species with thin sheet-like, tubular thalli; B, annual algae with coarsely branched, corticated thalli. Late successional species are as follows: L, perennial algae with highly differentiated, thick leathery, heavy corticated, blade-like and branched thalli; C, calcareous algae; SG, seagrasses.

accounted for more than 90% of macrophytobenthos biomass, whereas the abundance of the opportunistic species (29 species) was not higher than 10% (Fig. 3b).

DISCUSSION

A study of the *Zostera marina* + *Stephanocystis crassipes* phytocenosis off Cape Tokarevsky was conducted for the first time. According to the species composition and set of dominant species, the studied community is most similar to the *Zostera marina* + *Sargassum* spp. assemblage, described earlier from the waters off Cape Zeleny (Ussuri Bay) and Cape Krasny (Amur Bay) [25]. This assemblage is distributed all over Peter the Great Bay on sandy/gravel silted substrata in semi-sheltered bays with a weak wave impact (bionomic type of subtidal zone I; degree of wave impact IV) [22]. However, the phytocenosis we studied at Cape Tokarevsky had a number of characteristic features. Thus, the second dominant species in the community of seagrasses were *Sargassum pallidum* off Cape Zeleny and *S. miyabei* off Cape Krasny, whereas off Cape Tokarevsky the second dominant species was *Stephanocystis crassipes*. This perennial brown alga, as well as the species of the genus *Sargassum*, belongs to the family Sargassaceae. *S. crassipes* has a morphology and phenology close to those in *S. pallidum* and *S. miyabei* and therefore can perform the same cenotic role in the community as these two species do. However, *S. crassipes* typically forms independent phytocenoses on rocky and stony substrata of open shores exposed to a strong wave impact (bionomic type of subtidal zone II; degree of wave impact III) [22]. The replacement of members of the genus *Sargassum* by *S. crassipes* in the studied community can probably be explained by a stronger hydrodynamics in the cove formed by the spit at Cape Tokarevsky. On the one hand, this cove is sheltered from heavy wave action; on the other hand, strong regular currents are observed in the strait, which makes it possible to classify the subtidal zone as transitional from bionomic type I to type II. Thus, the velocity of the currents in the Eastern Bosphorus Strait varies from 17 to 23 cm/s and increases to 80 cm/s during cyclones, which is slightly higher than in Amur Bay (from 6 to 10 cm/s; during cyclones, up to 20–40 cm/s) and Ussuri Bay (from 10 to 20 cm/s; during cyclones, up to 50–60 cm/s) [24].

Moreover, the species typical of the *Zostera marina* + *Sargassum* spp. assemblage, such as *Codium fragile*, *Chordaria flagelliformis*, *Coccophora langsdorfii*, *Sphacelaria* spp., *Sphaerotrichia divaricata*, *Chondria* spp., *Neorhodomela munita*, and *Melanothamnus japonicus* [=*Neosiphonia japonica*], were not observed in the studied community. At the same time, in the studied *Zostera marina* + *Stephanocystis crassipes* phytocenosis we found such species as *Cladophora stimpsonii*, *Ulva linza*, *Desmarestia viridis*, *Petalonia fascia*, *Campylaephora crassa*, *Chrysymenia wrightii*, *Laurencia saitoi*, and *Schizymenia pacifica*. These algae are typical components of *Phyllospadix iwatensis* or *Saccharina cichorioides* phytocenoses, usually located on rocky substrata with sand, gravel, and pebble under conditions of stronger wave impact (wave impact degree III; bionomic type of subtidal zone I) [22]. Thus, the composition of the studied seagrass community corresponded not only to the substrata, but also to the hydrodynamics of the cove.

A statistical analysis of the data, based on biomass and the presence of species in the studied phytocenoses of seagrasses off capes Krasny, Zeleny, and Tokarevsky, showed that all three communities differ at a level of 61–70% (Fig. 4). A substantial contribution to the dissimilarity (approximately 50%) is made by dominant and subdominant species (Table 3). In these three communities, the subdominants were plants that differ in morphology and phenology: off Cape Krasny, the perennial red calcareous alga *Corallina officinalis*; in the cove south of Cape Zeleny, the perennial brown branched alga *C. langsdorfii* [25]; off Cape Tokarevsky, the annual brown alga with a string-like unbranched thallus *Chorda filum*.

The preliminary data show that the analysis of the taxonomic structure of the *Zostera marina* + *Sargassum* spp. assemblage can be used to evaluate the ecological condition of coastal waters in Peter the Great Bay [25]. The following parameters of the community are the most informative: (1) the proportions of higher taxa; (2) the total number of species, families, and orders; (3) the number of species in the order; (4) the composition of dominant species; (5) the proportions of morpho-functional groups by number of species and biomass; and (6) the presence/absence of species characteristic of the native assemblage [25].

The proportions of the highest algal taxa off Cape Tokarevsky (Chlorophyta, 16% of the total number of species; Phaeophyceae, 26%; and Rhodophyta, 58%) generally corresponded to those in Peter the Great Bay (14, 29, and 57%) [22], including its cleanest body of water, that is, Vostok Bay (15, 29, and 56%) [18]. In the eutrophic waters off Cape Krasny, the percentage of number of species from different highest taxa substantially varied: the proportions of Chlorophyta and Phaeophyceae decreased by almost 2 times (to 9% and 15%, respectively), while that of Rhodophyta was higher by 20% [25]. According to the number of families (25) and orders (15), the phytocenosis off Cape Tokarevsky held an intermediate position: the flora in the mesotrophic water area off Cape Zeleny was more diverse (31 families and 20 orders), whereas in the eutrophic waters off Cape Krasny it was somewhat poorer (18 families and 13 orders). A similar trend was observed when analyzing the species diversity of the orders typical of the flora in Peter the Great Bay: Ceramiales contained 8 species off Cape Tokarevsky, 12 species off Cape Krasny, and 12 species off Cape Zeleny; Gigartinales, 7, 5, and 7 species, respectively; Ectocarpales, 3, 1, and 8 species; Fucales, 3, 2, and 4 species. The order Ulvales (four species) was represented by the largest number of species in the studied community off Cape Tokarevsky; off Cape Zeleny, there were more members of the order Cladophorales (three species) [25]. The species diversity of the order Ceramiales varied substantially between the considered communities. Thus, algae with branched thalli from the family Rhodomelaceae prevailed off Cape Zeleny (six species); algae with filamentous thalli, off capes Krasny and Tokarevsky (respectively, eight and four species), which was the only area where members of the family Ceramiaceae were found. The decrease in the species diversity of the community-forming orders in the flora of the studied cove, compared to the relatively undisturbed phytocenosis off Cape Zeleny [25], may indicate the onset of destructive transformation of the seagrass phytocenosis in the Eastern Bosphorus Strait.

As is known, considerably fewer species [33, 38], as well as orders and families, of macrophytes [11] are found in eutrophic waters compared to cleaner ones. The predominance of polysaprobic species from the order Ulvales and filamentous red algae from the order

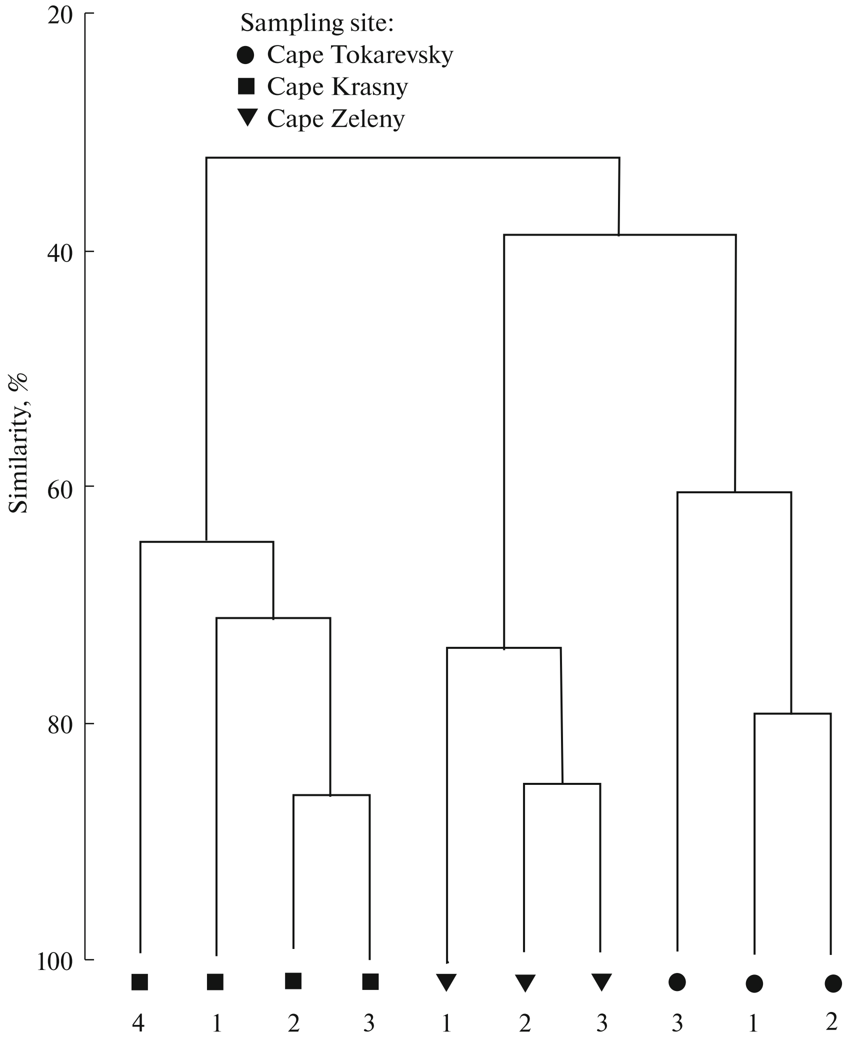

Fig. 4. The results of comparison between three summer phytocenoses of the *Zostera marina* assemblage in biomass, using the Bray–Curtis similarity coefficient.

Ceramiales in the flora is usually associated with pollution of waters with organic substances [13, 42], which is confirmed by hydrochemical parameters. Thus, the level of biological oxygen demand (BOD_5) off Cape Tokarevsky, 2.2 mg O_2/L (in 2002) and 2.47 mg O_2/L (in 2005) [13, 30], indicates a moderate level of water pollution here [15].

An analysis of morpho-functional groups has shown that in terms of number of opportunistic species (74.3% of the species list) the seagrass community off Cape Tokarevsky holds an intermediate position between the communities off capes Krasny (67.6%) and Zeleny (76.4%); in the studied phytocenosis, the biomass of opportunistic species is 1.5 times higher than that off capes Krasny and Zeleny. Researchers have repeatedly noted an increase in the abundance of annual and ephemeral species with filamentous, tubular, and thin sheet-like thalli in polluted waters [34, 39]. Having a large specific surface, these species are capable of rapid absorption of nutrients from the environment and more active growth compared to late successional species [37]. Thus, in the eutrophic waters near Cape Krasny, the biomass of coralline algae reached 18% [25], whereas in the phytocenosis off Cape Tokarevsky they did not play any important role. In the Mediterranean Sea, *Corallina elongata* are known to have replaced the perennial brown alga *Cystoseira mediterranea* due to the heavy organic pollution [33, 40]. A similar process is probably observed in the seagrass community off Cape Krasny. The proportions of higher taxa that correspond to clean waters indicate that the seagrass phytocenosis off Cape Tokarevsky is not disturbed. However, this community is in the initial stage of destructive transformation, as the species diversity here is lower and the abundance of opportunistic species is higher than in phytocenoses of clean waters.

Similar floro-cenotic changes were previously described for phytocenoses of the eutrophic waters of

Table 3. The species that make the greatest contribution to the dissimilarity between the seagrass communities from various locations, according to SIMPER analysis (percentage similarities of samples and contribution of species by biomass)

Species	Average biomass, g/m^2		Contribution, %	Cumulative contribution, %
Dissimilarity 66.06%	Cape Tokarevsky	Cape Krasny		
Sargassum miyabei	18.33	289.13	13.23	13.23
Corallina officinalis	0.01	172.23	13.22	26.45
Stephanocystis crassipes	606.03	0.00	11.05	37.49
Chorda filum	203.20	2.33	7.93	45.42
Zostera marina	1290.53	426.80	6.69	52.11
Punctaria plantaginea	49.83	0.01	3.99	56.10
Symphyocladia latiuscula	0.51	11.34	3.85	59.95
Mazzaella japonica	1.40	19.94	3.82	63.77
Ulvaria splendens	36.71	0.01	3.35	67.12
Chondrus pinnulatus	0.04	6.84	3.31	70.43
Dissimilarity 61.28%	Cape Tokarevsky	Cape Zeleny		
Sargassum pallidum	1.70	1345.31	22.89	22.89
Stephanocystis crassipes	606.03	130.21	12.08	34.97
Chorda filum	203.20	12.1	9.31	44.27
Coccophora langsdorfii	0.00	122.33	4.70	48.97
Zostera marina	1290.53	1680.00	4.38	53.35
Chondria dasyphylla	0.00	67.40	3.89	57.24
Ulvaria splendens	36.71	0.00	3.71	60.95
Neorhodomela larix	0.00	49.30	3.67	64.63
Colpomenia peregrina	43.50	0.01	3.32	67.94
Ceramium kondoi	39.81	0.00	3.11	71.05
Dissimilarity 69.49%	Cape Krasny	Cape Zeleny		
Sargassum pallidum	6.21	1345.31	19.24	19.24
Sargassum miyabei	289.13	31.50	12.24	31.49
Corallina officinalis	172.23	11.41	10.71	42.19
Zostera marina	426.80	1680.00	5.11	47.30
Coccophora langsdorfii	0.00	122.33	3.96	51.26
Mazzaella japonica	19.94	0.00	3.96	55.22
Symphyocladia latiuscula	11.34	0.01	3.79	59.01
Punctaria plantaginea	0.01	48.00	3.31	62.32
Chondria dasyphylla	0.00	67.40	3.27	65.59
Chondrus pinnulatus	6.84	0.00	3.12	68.71
Bryopsis plumosa	9.81	0.00	3.11	71.82

Peter the Great Bay [25, 29, 36]. At the same time, it was shown that similar signs of transformation of macrophyte communities can be caused by the effect of any destructive factor, including contamination by petroleum hydrocarbons [27]. Thus, under chronic oil pollution a gradual substitution of the dominance of perennial brown algae by annual seasonal species occurs [11] (Kalugina and Gutnik, 1975, cited by [27]). As was already noted, the Eastern Bosphorus Strait is exposed to heavy oil pollution. The highest concentration of petroleum products was recorded from the western part of the strait (off Cape Tokarevsky): 0.95 mg/L in the water and 370 mg/kg in the bottom sediments [31]. These concentrations cause some species to increase the rate of photosynthesis [26]. As an example, at an oil concentration of 0.7 mg/L, the photosynthesis rate in the green alga *Ulva* is higher than that in clean water by 80% (Shiels et al., 1973, cited by [27]). Thus, water contamination by petroleum products is very likely to contribute to the increase in abundance of green algae from the order Ulvales, as has already been recorded from the investigated cove.

Thus, the *Zostera marina* + *Stephanocystis crassipes* phytocenosis in the cove formed by the spit extending from Cape Tokarevsky is characterized by a poor taxonomic composition (a small number of species and supraspecific taxa) and a high abundance of opportunistic species (1.5 times higher than that in the phytocenosis of the clean water area off Cape Zeleny), which here play the role of auxiliary species. However, the proportions of the highest taxa remain typical of the clean waters of Peter the Great Bay. Consequently, the *Zostera marina* + *Stephanocystis crassipes* phytocenosis in the cove off Cape Tokarevsky is in the initial stage of anthropogenic transformation.

REFERENCES

1. Belan, T.A., Belan, L.S., and Berezov, A.V., Living conditions and pattern of distribution of macrozoobenthos in the marine waters of the port of Vladivostok (Peter the Great Bay, Sea of Japan), in *Morskaya biologiya i ekologiya* (Marine Biology and Ecology), 2009, no. 1, pp. 116–128.
2. Bregman, Yu.E., Sedova, L.G., Manuilov, V.A., et al., A complex study of the environment and benthic biota of Novik Bay (Russky Island, Sea of Japan) after a long-term anthropogenic pressure, *Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 1998, vol. 124, pp. 320–343.
3. Vinogradova, K.L., *Opredelitel' vodoroslei dal'nevostochnykh morei SSSR. Zelenye vodorosli* (Key to Algae from the Far Eastern Seas of the USSR: Green Algae), Leningrad: Nauka, 1979.
4. Vorob'ev, V.P., Benthos of the Azov Sea, *Tr. Azovo–Chernomorsk. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 1949, no. 13, pp. 1–193.
5. Gusarova, I.S., Macrophytobenthos of the northern Amur Bay, *Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 2008, vol. 155, pp. 88–98.
6. Gusarova, I.S., Kolpakov, N.V., and Kulepanov, V.N., Distribution of bottom vegetation and fishes along the coast of Reineke Island (Peter the Great Bay) in summer, *Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 2012, vol. 171, pp. 26–39.
7. *Doklad ob ekologicheskoi situatsii v Primorskom krae v 2013 godu* (Report on the Ecological Situation in Primorsky Krai in 2013), Vladivostok: Adm. Primorsk. Kraya, 2014.
8. Zaks, I.G., Preliminary data on distribution of fauna and flora in the coastal zone of Peter the Great Bay, Sea of Japan, *Proizviditel'nye Sily. Zhivotny Mir*, 1927, no. 4, pp. 213–248.
9. Kalita, T.L. and Skriptsova, A.V., The current state of subtidal macrophyte communities of Ussuriysky and Amursky Bays, Sea of Japan, *Russ. J. Mar. Biol.*, 2014, vol. 40, no. 6, pp. 418–425.
10. Klochkova, N.G., *Flora vodoroslei-makrofitov Tatarskogo proliva i osobennosti eyo formirovaniya* (Flora of Macrophytic Algae in the Tatar Strait and the Features of its Formation), Vladivostok: Dal'nauka, 1996.
11. Klochkova, N.G. and Berezovskaya, V.A., *Makrofitobentos Avachinskoi guby i ego antropogennaya destruktsiya* (Macrophytobenthos of Avacha Bay and Its Anthropogenic Destruction), Vladivostok: Dal'nauka, 2001.
12. Kobzar', A.D. and Khristoforova, N.K., Assessment of contamination of the Peter the Great Bay waters by heavy metals based on their concentration in brown algae-macrophytes, in *Sovremennoe ekologicheskoe sostoyanie zaliva Petra Velikogo Yaponskogo morya* (The Current Ecological Condition of Peter the Great Bay, Sea of Japan), Vladivostok: Dal'nevost. Fed. Univ., 2012, pp. 362–381.
13. Kozhenkova, S.I. and Khristoforova, N.K., Distribution of green algae macrophytes in the Amur Bay (Japan Sea), *Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 2009, vol. 159, pp. 156–167.
14. *Kolichestvennye metody ekologii i gidrobiologii* (Quantitative Methods in Ecology and Hydrobiology), Tolyatti: Samarsk. Nauch. Tsentr, Ross. Akad. Nauk, 2005.
15. Kosov, V.I. and Ivanov, V.N., *Okhrana i ratsional'noe ispol'zovanie vodnykh resursov. Chast 1. Okhrana poverkhnostnykh vod* (Conservation and Rational Use of Aquatic Resources, Part 1: Protection of Surface Waters), Tver: Tver. Gos. Tekh. Univ., 1995.
16. Levenets, I.R., The intertidal flora of Russky Island, Peter the Great Bay, *Mater. nauchn. konf., posvyashch. 70-letiyu S.M. Konovalova "Sovremennoe sostoyanie vodnykh bioresursov"* (Proc. Sci. Conf. Commem. 70th Anniv. S.M. Konovalov "Current Status of Aquatic Bioresources"), Vladivostok: Tikhookean. Nauchno–Issled. Rybokhoz. Tsentr, 2008, pp. 148–151.
17. *Lotsiya severo-zapadnogo berega Yaponskogo morya. Ot reki Tumannaya do mysa Belkina* (Northwestern Sea of Japan Coast Pilot. From the Tumen River to Cape Belkin), Moscow: Gl. Upr. Navig. Kartogr. Minist. Oborony Ross. Fed., 1984, no. 1401.
18. Makienko, V.F., Algal macrophytes of Vostok Bay (Sea of Japan), *Sov. J. Mar. Biol.*, 1975, vol. 1, no. 2, pp. 117–128.
19. Mirkin, B.I., Rozenberg, G.S., and Naumova, L.G., *Slovar' ponyatii i terminov sovremennoi fitotsenologii* (Dictionary of Concepts and Terms in Modern Phytocenology), Moscow: Nauka, 1989.
20. Naumov, Yu.A., The anthropogenic impact on the coastal shelf zone of Russia's Far-Eastern seas (a case study of the Peter the Great Bay), *Geogr. Prir. Resur.*, 2007, no. 1, pp. 106–114.
21. Paimeeva, L.G., Distribution of *Zostera* beds in Peter the Great Bay, *Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 1973, vol. 87, pp. 145–148.
22. Perestenko, L.P., *Vodorosli zaliva Petra Velikogo* (Algae of Peter the Great Bay), Leningrad: Nauka, 1980.
23. Perestenko, L.P., *Krasnye vodorosli dal'nevostochnykh morei Rossii* (Red Algae of Far Eastern Seas of Russia), St. Petersburg: Ol'ga, 1994.
24. Rostov, I.D., Peter the Great Bay, The physico-geographical, hydrological characteristics and hydrometeorological conditions, 2005. http://pacificinfo.ru/data/cdrom/3/html/1_00.htm. Cited May 28, 2007.
25. Skriptsova, A.V., Kalita, T.L., and Nabivailo, Yu.V., Evaluation of state of the community *Zostera marina* + *Sargassum* in conditions of anthropogenic pollution,

Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr., 2013, vol. 174, pp. 257–270.

26. Stepaniyan, O.V., Effects of crude oil on major functional characteristics of macroalgae of the Barents Sea, *Russ. J. Mar. Biol.*, 2008, vol. 34, no. 2, pp. 131–134.
27. Stepanyan, O.V. and Voskoboinikov, G.M., Effect of oil and oil products on morphofunctional parameters of marine macrophytes, *Russ. J. Mar. Biol.*, 2006, vol. 32, Suppl. 1, pp. S32–S39.
28. Tarasov, V.G., Kasyanov, V.L., Adrianov, A.V., et al., The ecological state and bottom communities in the Patrokl Bight and Sobol Bight (Peter the Great Bay, Sea of Japan): The past and the present, *Vestn. Dal'nevost. Otd. Ross. Akad. Nauk*, 2005, no. 1, pp. 3–18.
29. Khristoforova, N.K., Galysheva, Yu.A., and Kozhenkova, S.I., Assessment of human impact on Vostok Bay (Sea of Japan): Evidence from macrobenthic algae, *Dokl. Earth Sci.*, 2005, vol. 405, no. 9, pp. 1423–1425.
30. Khristoforova, N.K. and Salomai, M.S., Chemico-ecological assessment of quality of the coastal waters in Vladivostok, *Issled. Ross.*, 2006. http://zhurnal.ape.relern.ru/articles/2006/147/pdf. Cited July 4, 2012.
31. Chernyaev, A.P., Petroleum hydrocarbons distributions in seawater and bottom sediments in the Amur Bay (Japan Sea), *Izv. Tikhookean. Nauchno–Issled. Inst. Rybn. Khoz. Okeanogr.*, 2005, vol. 140, pp. 240–244.
32. Clarke, K.R. and Gorley, R.N., *PRIMER Version 6: User Manual/Tutorial*, Plymouth: PRIMER-E, 2006.
33. Dáez, I., Secilla, A., Santolaria, A., and Gorostiaga, J.M., Phytobenthic intertidal community structure along an environmental pollution gradient, *Mar. Pollut. Bull.*, 1999, vol. 38, no. 6, pp. 463–472.
34. Eriksson, B.K., Johansson, G., and Snoeijs, P., Long-term changes in the macroalgal vegetation of the inner Gullmar Fjord, Swedish Skagerrak coast, *J. Phycol.*, 2002, vol. 38, no. 2, pp. 284–296.
35. Guiry, M.D. and Guiry, G.M., AlgaeBase. World-wide Electronic Publication, Galway: Natl. Univ. Ireland, 2017. http://www.algaebase.org. Cited April 6, 2017.
36. Levenets, I.R. and Skriptsova, A.V., Benthic flora of the inner part of Amursky Bay (Sea of Japan), in *Ecological Studies and the State of the Ecosystem of Amursky Bay and the Estuarine Zone of the Razdolnaya River (Sea of Japan)*, Vladivostok: Dal'nauka, 2008, pp. 284–301.
37. Littler, M.M. and Littler, D.S., The evolution of thallus form and survival strategies in benthic marine macroalgae: Field and laboratory tests of a functional form model, *Am. Nat.*, 1980, vol. 116, pp. 25–44.
38. Munda, I.M., Changes and degradation of seaweed stands in the Northern Adriatic, *Hydrobiologia*, 1993, vol. 260, no. 1, pp. 239–253.
39. Orfanidis, S., Panayotidis, P., and Stamatis, N., Ecological evaluation of transitional and coastal waters: A marine benthic macrophytes-based model, *Mediterr. Mar. Sci.*, 2001, vol. 2, no. 2, pp. 45–65.
40. Pinedo, S., Zabala, M., and Ballesteros, E., Long-term changes in sublittoral macroalgal assemblages related to water quality improvement, *Bot. Mar.*, 2013, vol. 56, pp. 461–469.
41. Skriptsova, A.V. and Levenets, I.R., Seasonal dynamics of subtidal macrophyte assemblages in Sobol Bay (Peter the Great Bay, Sea of Japan) in relation to depth, *J. Mar. Biol. Assoc. U. K.*, 2012, vol. 92, pp. 429–437.
42. Titlyanov, E.A., Titlyanova, T.V., Belous, O.S., and Kalita, T.L., Inventory change (1990s–2010s) in the marine flora of Sanya Bay (Hainan Island, China), *J. Mar. Biol. Assoc. U. K.*, 2015, vol. 95, no. 3, pp. 461–470.

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