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Diatoms of the Macroalgae Epiphyton and Bioindication of the Protected Coastal Waters of the Kazantip Cape (Crimea, the Sea of Azov)

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Abstract: This article is about the diversity of diatoms in the benthos of the upper sublittoral near Kazantip Cape, located on the shore of the Sea of Azov in the northeastern part of Crimea. The study was conducted in 2022 and 2023 at a depth of 0.1 to 1 m at temperatures from 3.7 °C to 29 °C and salinity from 13.6 to 15.6 psu on the following 11 species of macroalgae: Phaeophyta of *Ericaria crinita*, *Gongolaria barbata*, and *Cladosiphon mediterraneus*; Chlorophyta—*Bryopsis hypnoides*, *Cladophora liniformis*, *Ulva intestinalis*, and *Ulva linza*; and Rhodophyta—*Callithamnion corymbosum*, *Ceramium arborescens*, *Polysiphonia denudata*, and *Pyropia leucosticta*. A total of 97 taxa of Bacillariophyta belonging to 3 classes, 21 orders, 30 families, and 45 genera were found. The highest number of diatom species was found on *U. linza* (61 species), *P. denudata* (45), *E. crinita* (40), the lowest number was recorded on thalli *P. leucosticta* (9). On macroalgae were found of 80% benthic diatoms, 50% marine species, 36% brackish-marine, 9% freshwater, 5% brackish, and 36% cosmopolites. The maximum abundance of the diatom community was 243.4 × 10^3 cells/cm^2 (*P. denudata* in September at 23.9 °C and 15.0 psu) with dominance by the diatom of *Licmophora abbreviata*, and the minimum was 3.8 × 10^3 cells/cm^2 (*P. leucosticta* in January at 3.7 °C and 15.0 psu). The presence in the epiphyton of diatoms—indicators of moderate organic water pollution (32 species), which developed in masse in late summer—indicate a constant inflow of organic matter into the coastal waters of the Kazantip Cape. The bioindicator and statistical studies indicate the effectiveness of the conservation regime, especially at stations within the IUCN reserve, despite relatively high saprobity rates at stations exposed to recreational pressure and poorly treated domestic wastewater.

Keywords: epiphyton diatoms; floristic; ecology; different indices; phytogeography; macroalgae; Kazantip Cape; the Sea of Azov

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1. Introduction

Seaweeds serve not only as a source of food and a habitat-forming component for many animals, but also as a substrate for colonization by different microalgae, among which diatoms are dominant [1,2]. It is known that diatoms create high primary production, make a significant contribution to the formation of microphytobenthos biodiversity, and can also be used as indicators of the quality of their habitat [1–3]. Together with floristic diversity, data on the abundance and biomass of diatoms from different ecotopes by season are important information [2].

The coastal waters of the Kazantip Cape of the Crimean coast of the Sea of Azov is one of the places of biological diversity of aquatic macrophytes due to a number of geomorphological features of the cape (for example, the presence of rocky territorial-aquatic complexes), as well as the influence of the more saline waters of the Kerch Strait, which unites the Sea of Azov and the Black Sea.

It should be noted that the water area of the Sea of Azov near the Kazantip Cape is part of the wetland of international importance "Kazantip Cape Aquatic Rock Complex", protected by the Ramsar Convention, (certificate No. 1393 dated 29 July 2004, Iran, Ramsar), and some bays of the Cape are part of the Kazantip Reserve [3].

In this respect, its waters are subject to relatively little anthropogenic influence, and can be considered as a reference [4]. The study of organisms, especially poorly studied ones, in anthropogenically undisturbed natural complexes is always of scientific interest. At the same time, an important component is the knowledge of the state of the basis of the trophic pyramid, macro- and micro-producers.

In the protected waters of Kazantip Cape, the focus has long been on the study of macrophytes. The first work on the study of the flora coastal waters of the Kazantip Cape was carried out in the 1920s and was reduced to determining the species composition of macrophytobenthic communities [5]. Currently, there is a lot of work in this area of research [6–10]. Since 2000, the study of cyanobacteria in the rocky supralittoral zone has begun [9].

Studies of benthic community's diatoms were first carried out in 2005 and covered several ecotopes, including the epilithon, epipsammon, and epiphyton of six species of macroalgae: Chlorophyta of genera *Blidingia* Kylin, *Ulothrix* Kützing, *Ulva* Linnaeus, Rhodophyta—*Ceramium* Roth, *Polysiphonia* Greville, and Phaeophyta—*Ericaria* Stackhouse [11]. In general, 95 diatom species were recorded in the microphytobenthos of the coastal Reserve and nearby bays, of which 79 taxa were recorded in the epiphyton. Together with data on floristic diversity, information on the abundance and biomass of diatoms from different ecotopes by season is presented [2,12].

To date, 69 taxa of macroalgae are indicated for the flora of benthic communities of coastal waters of Kazantip Cape: Chlorophyta—33 species, Ochrophyta—11, Rhodophyta—25 [10], as well as 184 taxa of microalgae: Cyanobacteria—83, Bacillariophyta—95, Dinophyta—2, Haptophyta—2, Chlorophyta, and Ochrophyta—1 of each [9,11].

However, communities of benthic microalgae, which are based on diatoms, have so far been poorly studied. It is known that species that are topically closely related to the substrate (benthos) are among the first to react to environmental changes, so they can be used for bioindication and assessment of the ecological situation, including in protected water areas. Therefore, it seems relevant to continue the study of the composition and quantitative parameters of diatom communities formed on different macroalgae of the Kazantip coast, as well as to expand the limited available information on the dominant species, their abundance and biomass, and to analyze the structure of the diatom community using a series of indices (species diversity, evenness, dominance, and saprobity), including for assessing the ecological situation of the study area.

The aim of this work is to study the diversity of diatom community in epiphyton of different species of macroalgae and bioindication of the protected coastal waters of the Kazantip Cape of the Sea of Azov based on the saprobity index.

2. Materials and Methods

2.1. Description of the Study Sites

The Kazantip Cape is located in the southern part of the Sea of Azov, and is a peninsula protruding into the sea for 2 km in the northeast of the Crimean Peninsula (Figure 1). We conducted a study of diatoms in four bays (stations) of Kazantip: Russkaya (st. 1), Shirokaya (st. 2), Kunushkay (st. 3), and Tatarskaya (st. 4). Shirokaya and Kunushkay bays are part of the Kazantip Reserve.

The Kazantip Cape is a fossil reef composed of briozoan limestone, consisting mainly of the skeletons *Membranipora lapidosa* Pallas, 1803 [13]. Alternating rocks of varying strength (limestones, clays, and marls) are destroyed by the sea at unequal rates, which determines the unique landscape of the Kazantip Cape (Figure 2). Its coastline is extremely rugged and consists of numerous small capes and bays [13].

Figure 1. Map of the sampling sites of the Kazantip Cape in bays 1—Russkaya, 2—Shirokaya, 3—Kunushkay, and 4—Tatarskaya.

Figure 2. Various views of the Kazantip Cape and its bays: (**a**,**d**,**e**)—rocky cliffs; (**b**)—sandy coast of Russkaya Bay; (**c**)—Kunushkay Bay; (**d**)—Shirokaya Bay; (**e**)—coastal ice cover.

The coastal waters of the cape have some features. For its shallow upper subtidal zone, the depth of which does not exceed 1.5 m, low salinity, varying in the range of 11–15 psu, as well as significant temperature changes, are noted. In July–August, coastal waters warm up to 28–30 °C, and in the winter months they cool to subzero temperatures, freezing already at minus 0.5 °C [11,14].

Ice can remain in the coastal area inclusive from December to March. Periodic strong storms in January–February break up the ice cover, leaving a pile of ice floes at the edge of the surf.

North-easterly and easterly winds prevail throughout the year. The windiest period is from October to June, with the highest number of storms, particularly in March. From July to September, storms are rare, the calmest month is August [14]. In general, unique ecological conditions have developed in the coastal waters of Kazantip Cape, which significantly distinguish it from other areas of Crimea.

2.2. Sampling and Material Processing

The material for this study was 108 samples of epiphyton from 11 species the macroalgae: Chlorophyta—*Bryopsis hypnoides* J.V. Lamouroux, *Cladophora liniformis* Kützing, *Ulva intestinalis* Linnaeus, and *Ulva linza* Linnaeus; Phaeophyta—*Ericaria crinita* (Duby) Molinari et Guiry, *Gongolaria barbata* (Stackhouse) Kuntze, and *Cladosiphon mediterraneus* Kützing; Rhodophyta—*Callithamnion corymbosum* (Smith) Lyngbye, *Ceramium arborescens* J. Agardh, *Pyropia leucosticta* (Thuret) Neefus et J. Brodie, and *Polysiphonia denudata* (Dillwyn) Grevillei ex Harvey. These species are predominantly annual forms (except *E. crinita* and *G. barbata*) and are widely represented in the shallow coastal waters of the Kazantip Cape. *P. leucosticta* is a seasonal winter species, selected for its dominance in the cold season. Samples of macroalgae with epiphyton were collected in four bays of the Kazantip Cape (Figure 1). Material was collected monthly from October 2022 to September 2023 (except for December) at a depth of 0.1 to 1.0 m, and water temperature varied from 3.7 °C in January to 29 °C in August with a salinity from 13.6 to 15.6 psu (Table 1).

Table 1. Temperature and salinity of the water in the bays of the Kazantip Cape in the different seasons 2022–2023.

Date	**13 October 2022**	**29 November 2022**	**31 January 2023**	**28 February 2023**	**29 March 2023**	**25 April 2023**	**31 May 2023**	**22 June 2023**	**27 July 2023**	**29 August 2023**	**25 September 2023**
Depth, m	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.1–1	0.1–1	0.1	0.1–0.5
Temperature, t °C	17.0	10.0	3.7	4.9	8.1	14.0	19.2	26.2	27.3	29.0	23.9
Salinity, psu	15.0	15.6	15	15.6	15.1	15.0	14.9	14.9	13.6	13.6	15.0

The bays of the cape are bound by bryozoan limestone cliffs, and their bottom, rocky in places, is formed by sand and shell sediments (Figure 2). The adjacent bays have a similar bottom, but their shores are flat, sandy, and shell-like [13].

To identify diatoms, preparations from living cells were used, as well as permanent preparations from cleaned valves prepared according to known methods [15] and in our modification [16]. Determination of the qualitative diatom composition was carried out in a light microscope (LM) of the Axioskop 40 type with AxioVision Rel. 4.6 (Zeiss, Jena, Germany). For the more accurate identification of diatoms, scanning electron microscopy (SEM, Hitachi SU3500, Tokyo, Japan) was applied. The diatom suspension was cleaned of organic matter by keeping it in $KMnO_4$ for 24 h, which was followed by adding HCl and heating this mixture to remove insoluble salts (e.g., carbonates). Then, the samples were washed with distilled water using repeated centrifugations to remove acid. Dried preparations of diatom valves were coated with gold-palladium for the SEM visualization.

In the classification of Bacillariophyta, we used the system of Round et al., 1990 [17]. Species identification of diatoms and determination of their ecological and phytogeographical characteristics were carried out by the following sources [3,12,18–28].

Quantitative counting of cells was carried out in a Goryaev chamber with a volume of 0.9 mm^3 in triplicate. The species richness (S), abundance (N), and biomass (B) of diatoms species were determined according to the method [1]. The species richness was determined as the number of species found in the counting chamber when viewing samples of macroalgae.

The analysis of the structure of the diatom community was carried out using indices of species diversity (H) [29], evenness (e) [30], and dominance (D_{BP}) [31]. When calculating the surface area of the macrophyte-basiphyte, we were guided by the method [32]. Statistical processing of quantitative data were carried out using Microsoft Office Excel 2007 software and a statistical analysis application for Windows Past 4.03 [33]. The Bray–Curtis similarity index was used for comparison of the relative abundances of species in a community in entire habitats and varied between 0 and 1. The network analysis in JASP (Jeffreys's Amazing Statistics Program), significant only, was doing on the botnet package in R Statistica package of [34]. The program conducts a Bayesian Pearson correlation analysis. The Pearson correlation coefficient is varied between −1 and 1, and measures the strength and direction of the relationship between each pair of variables. Bayesian analysis answers questions about the relationship of the parameters using probability statements.

3. Results

3.1. Fouling Species of Macroalgae

The following diatoms in the coastal waters of the Kazantip Cape in macroalgae epiphyton of 11 species have been studied: Phaeophyta—Ericaria crinita, Gongolaria barbata, and Cladosiphon mediterraneus; Chlorophyta—Bryopsis hypnoides, Cladophora liniformis, Ulva intestinalis, and Ulva linza; and Rhodophyta—Callithamnion corymbosum, Ceramium arborescens, Polysiphonia denudata, and Pyropia leucosticta (Figure 3a–k).

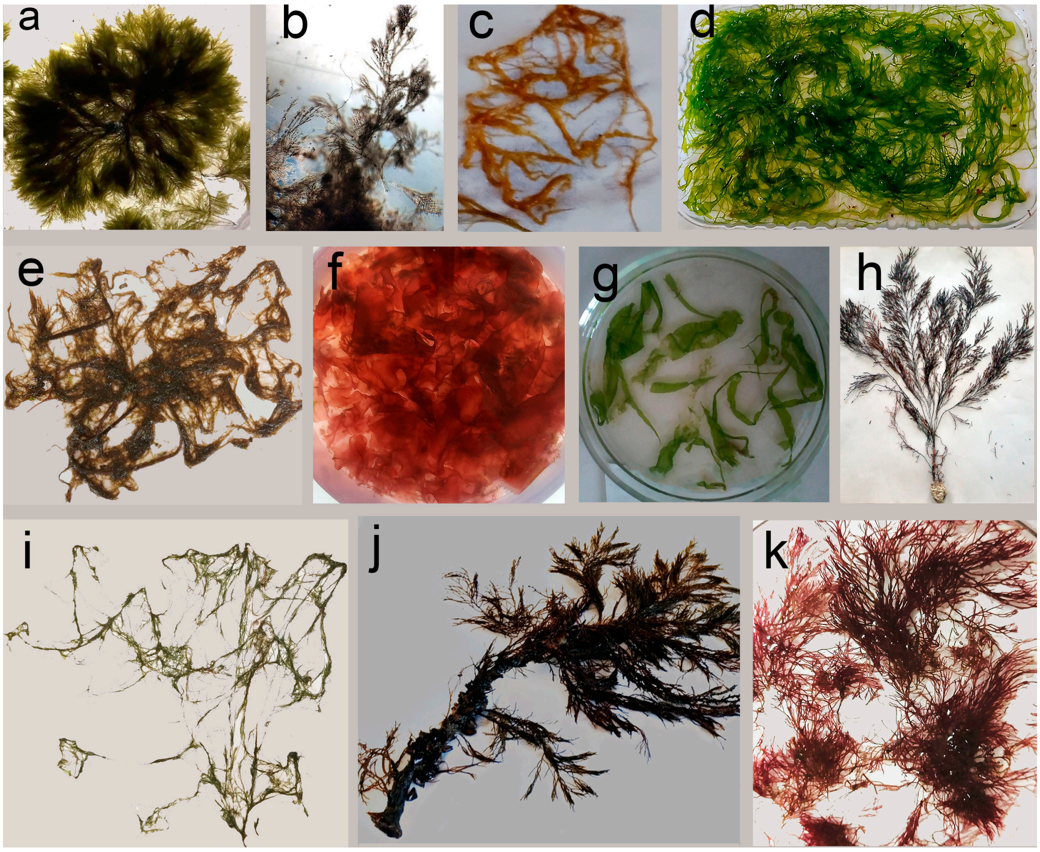

Figure 3. Samples of the macroalgae of the coastal waters of the Kazantip Cape: (**a**)—*Bryopsis hypnoides*, (**b**)—*Callithamnion corymbosum*, (**c**)—*Cladosiphon mediterraneus*, (**d**)—*Ulva intestinalis*, (**e**)—*Polysiphonia denudata*, (**f**)—*Pyropia leucosticta*, (**g**)—*Ulva linza*, (**h**)—*Ericaria crinita*, (**i**)—*Cladophora liniformis*, (**j**)—*Gongolaria barbata*, and (**k**)—*Ceramium arborescens*.

3.2. Species Composition, Ecology, and Distribution of Diatoms

A total of 97 Bacillariophyta taxa were found, belonging to 3 classes, 21 orders, 30 families, and 45 genera, of which 51 species were indicated the first time in the Kazantip Cape (Appendix A Table A1). The basis of their species composition is the class Bacillariophyceae, which is typical for microphytobenthos [1,2,18,35]. The highest number of diatom species was found on *U. linza* (61), *P. denudata* (45), and *Ericaria crinita* (40), and the lowest number of taxa was recorded on thalli of the red alga *P. leucosticta* (9) (Appendix A Table A1).

The diatom flora is represented by typical obligate fouling organisms—*Achnanthes brevipes* (Figures 4a,e, 5k and 6j), *Achnanthes longipes* (Figures 5o and 6t), *Gomphonemopsis* pseudexigua (Figure 5n), *Grammatophora marina* (Figure 4b,k), *Licmophora abbreviata* (Figures 5j and 6q,r), *Rhoicosphenia marina* (Figures 4c and 6n), *Tabularia parva* (Figure 6m), *Tabularia tabulata* (Figures 4f,j,n, 5q and 6u), and *Striatella unipunctata*—which are capable of adhesion with the help of mucopolysaccharides they secrete, and often form colonies. One of the colonial species of *Navicula ramosissima* (Figure 4g,h) was found in mucus tubes in March and April. The bentho-planktonic species of *Melosira jurgensii* (Figure 4d), *Melosira moniliformis* (Figure 4i), and *Melosira lineata* (Figure 4m) were met as well.

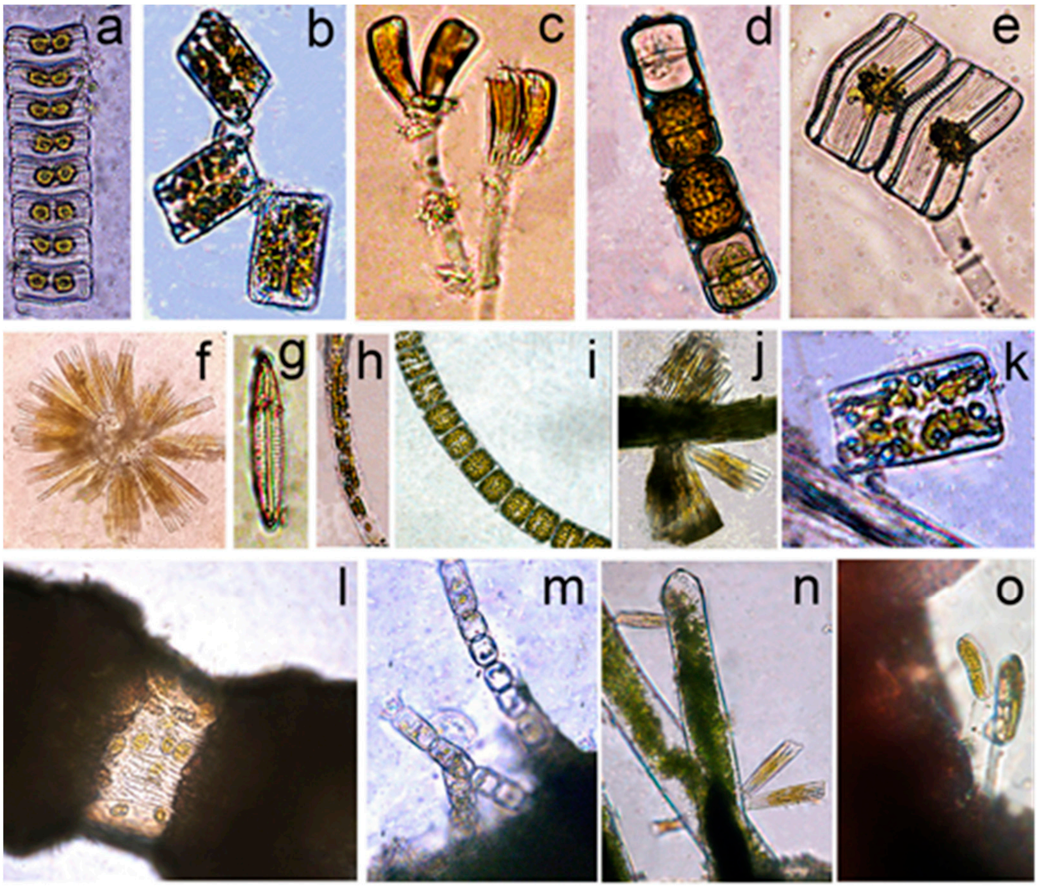

Figure 4. LM. Colonies of diatoms of various forms in the fouling of macroalgae in the Kazantip Cape: *Achnanthes brevipes* (**a**,**e**,**o**), *Grammatophora marina* (**b**,**k**), *Rhoicosphenia marina* (**c**), *Melosira jurgensii* (**d**), *Tabularia tabulata* (**f**,**j**,**n**), single cell of *Navicula ramosissima* (**g**) and its tube colonies (**h**), *Melosira moniliformis* (**i**), and *Melosira lineata* (**m**). A single living species of *Cocconeis scutellum* is inside of the red alga *Ceramium arborescens* (**l**).

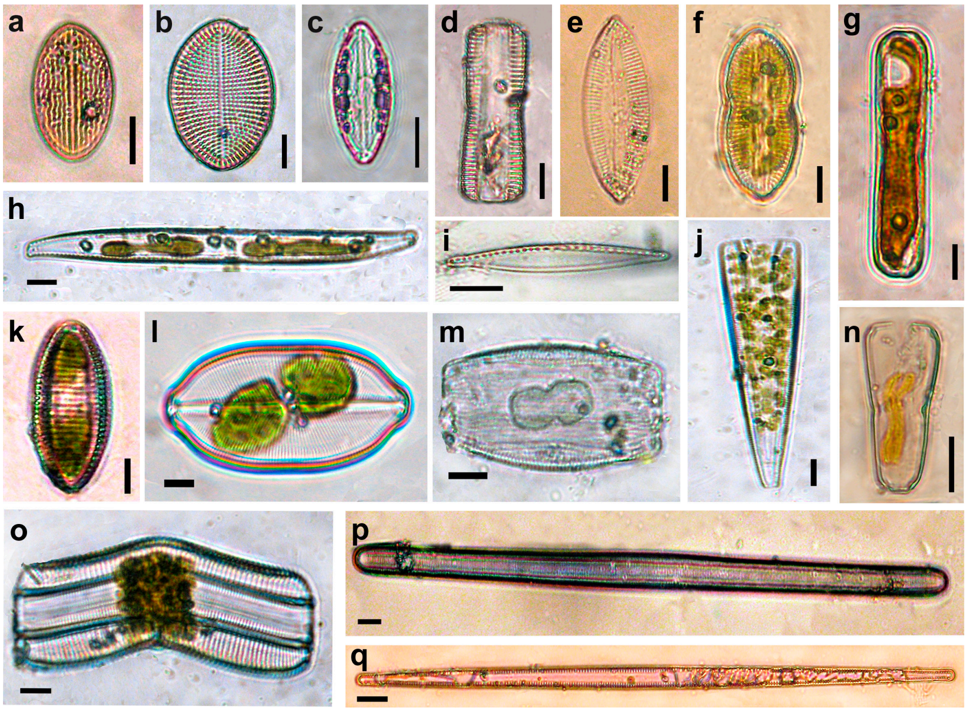

Figure 5. LM. Photographs of some diatom species frustules (**a**–**e**,**g**,**i**,**p**,**q**) and cells with chloroplasts (**f**–**h**,**j**–**o**) on macroalgae epiphyton: *Cocconeis placentula* var. *euglypta* (**a**), *Cocconeis scutellum* (**b**), *Mastogloia pumila* (**c**), *Navicula cancellata* (**d**), *Navicula palpebralis* (**e**), *Diploneis didyma* (**f**), *Caloneis liber* (**g**), *Nitzschia sigmoidea* (**h**), *Nitzschia lanceolata* var. *minor* (**i**), *Licmophora abbreviata* (**j**), *Achnanthes brevipes* (**k**), *Petroneis humerosa* (**l**), *Undatella lineolata* (**m**), *Gomphonemopsis pseudexigua* (**n**), *Achnanthes longipes* (**o**), *Synedrosphenia crystallina* (**p**), and *Tabularia tabulata* (**q**). Scale bar: 10 µm.

We also found the following benthic free-living species capable of moving along the substrate (Figures 5 and 6): *Cocconeis placentula* var. *euglypta* (Figures 5a and 6k), *Cocconeis scutellum* (Figures 5b and 6a), *Fallacia forcipata* (Figure 6i), *Lyrella atlantica* (Figure 6p), *Caloneis liber* (Figure 5g), *Mastogloia pumila* (Figures 5c and 6b,c), *N. cancellata* (Figure 5d), *N. perminuta* (Figure 6f), *Nitzschia lanceolata* var. *minor* (Figure 5i), *Rhopalodia musculus* (Figure 6e), and others.

When studying thalli of macrophytes, we noted that *Cocconeis scutellum* often forms close, sometimes numerous groups located on the surface of the thalli or inside them (Figure 4l). A similar phenomenon was described for the Black Sea [1] and other waters [36].

The species *Berkeleya rutilans*, *Cylindrotheca closterium*, *Grammatophora marina* (Figure 5b,k), *Licmophora abbreviata* (Figures 5j and 6q,r), *Navicula cancellata* (Figure 5d), *Nitzschia sigma*, *N. sigmoidea* (Fugure 5h), *Rhoicosphenia marina* (Figure 6n), *T. tabulata* (Figure 6u), and *Trachyneis aspera* are among the most frequently encountered. Some rare diatom species of the macroalgae epiphyton were found: *Amphora laevis*, *Grammatophora angulosa*, *Licmophora rostrata*, *Lyrella lyra*, *L. lyroides*, *Navicula cancellata* var. *gregoryi*, *Navicula dumontiae* (Figure 6d), *Nitzschia dissipata*, *N. inconspicua* (Figure 6g), *Planothidium delicatulum* (Figure 6h), *Petroneis humerosa* (Figure 5i), *Striatella unipunctata*, and *Tryblionella compressa*.

In addition to floristic analysis of diatom species, an analysis of ecological and phytogeographical characteristics was carried out, and average values of diatom abundance at the study stations were calculated (Appendix A Table A2). Ecological characteristics are represented by marines (50%) and brackish-marines (36%) as well as of freshwaters (9%) and brackish (5%). Of the 44 diatom species identified according to the saprobiont scale modified by [37], 32 were indicators of moderate organic pollution of waters or waters of Class 3 of water quality (species saprobity index varied from 0.7 to 3.6) (Appendix A Table A2). Betamesosaprobionts prevailed among this group (20 species). Of the phytogeographical elements of diatom flora, 36% species cosmopolites were found, of which *Cocconeis scutellum*, *Tabularia tabulata*, and

Licmophora abbreviata recorded almost on all species of macroalgae, as well as the colonial species *Achnanthes brevipes*, *Navicula ramosissima*, and *Rhoicosphenia marina*. Each group of ABT, BT, and boreal species counted as 20%.

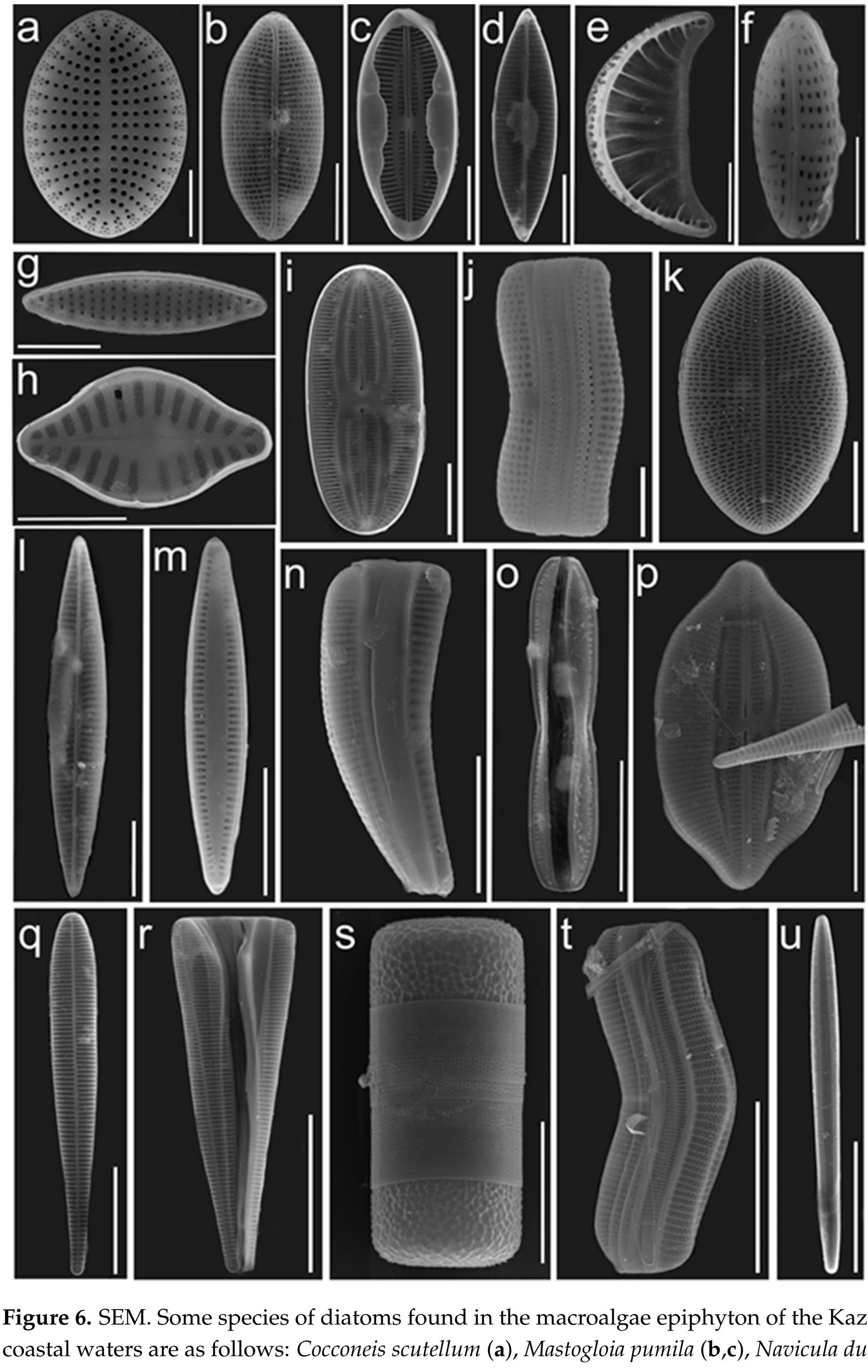

Figure 6. SEM. Some species of diatoms found in the macroalgae epiphyton of the Kazantip Cape coastal waters are as follows: *Cocconeis scutellum* (**a**), *Mastogloia pumila* (**b**,**c**), *Navicula dumontiae* (**d**), *Rhopalodia musculus* (**e**), *Navicula perminuta* (**f**), *Nitzschia inconspicua* (**g**), *Planothidium delicatulum* (**h**), *Fallacia forcipata* (**i**), *Achnanthes brevipes* (**j**), *Cocconeis placentula* var. *euglypta* (**k**), *Haslea subagnita* (**l**), *Tabularia parva* (**m**), *Rhoicosphenia marina* (**n**), *Nitzschia hybrida* f. *hyalina* (**o**), *Lyrella atlantica* (**p**), *Licmophora abbreviata* (**q**,**r**), *Melosira moniliformis* (**s**), *Achnanthes longipes* (**t**), and *Tabularia tabulata* (**u**). Scale bar: (**a**–**e**) = 5 µm; (**f**,**g**) = 3 µm; (**h**) = 4 µm; (**i**–**n**) = 10 µm; (**o**–**q**) = 20 µm; (**r**,**s**) = 30 µm; and (**t**,**u**) = 40 µm.

The calculation of species number, the average abundance of diatom cells on macroalgae at the study stations, and the calculation of the Saprobity Index S is shown in Table 2.

Table 2. Species number, averaged abundance (cells per cm^2) of diatoms on macroalgae, and Index saprobity S over the sampling stations in the coastal waters of the Kazantip Cape of the Sea of Azov.

Variable	St. 1	St. 2	St. 3	St. 4
Species number	89	97	97	42
Abundance averaged, cells/cm^2	15,394.98	45,112.88	20,169.29	28,443.75
Index S	2.21	2.26	2.25	2.19

Note. St. 1—Russkaya Bay; St. 2—Shirokaya Bay, St. 3—Kunushkay Bay, St. 4—Tatarskaya Bay.

The minimum number of species was noted at st. 4. At the same time, the abundance of diatoms was in the range of 15–45 thousand cells/cm^2 on average, and at st. 4, an average value of 28 thousand was observed, and the maximum value of 45 thousand was at st. 2. The saprobity indices of the station's community calculated based on species-specific saprobity indices and the number of cells of each indicator species (Appendix A Table A2) varied between 2.19 and 2.26, which corresponds to Class 3 of water quality. The highest index was at st. 2, and the lowest at st. 4, which, together with the reduced species number here, suggests a negative influence of the environment. The Pearson coefficients calculated for the data of Appendix A Table A2 show insignificant correlation between species number and cells abundance (0.03) and Index S and cells abundance (0.45), but the correlation between species number and Index S was 0.84. It can confirm the negative influence of the environment near station 4 on species' number of diatoms, as well as increasing the organic pollution load.

Statistical comparison of diatom communities on the different macroalgae and stations was conducted as a JASP network analysis (Figure 7a). It shows three different clusters of submerged macrophytes coded as in Appendix A Table A1.

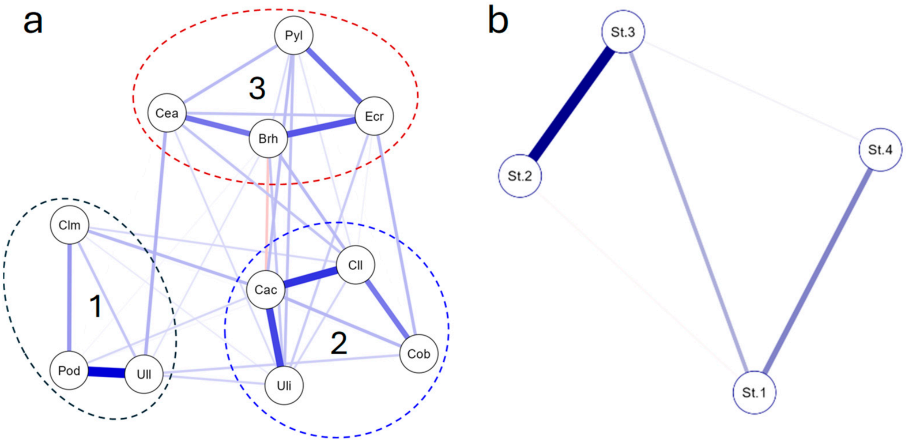

Figure 7. JASP plot of the full diatom community similarity in submerged macroalgae (**a**) and in four studied sites in the coastal waters of the Kazantip Cape of the Sea of Azov (**b**). Macrophyte names were coded as in Appendix A Table A1. The line thickness reflects the similarity coefficient value. The red lines are negative, and blue lines are positive correlations. Different clusters are numbered 1–3.

The highest similarity was between communities of cluster 1 on *P. denudata* and *U. linza* sampled mainly in Shirokaya Bay. Their epiphyton had the highest number of diatom species among other macroalgae. Cluster 2 brought together communities on *U. intestinalis*, *C. corymbosum*, *Cl. Liniformis*, and *G. barbata*. These macroalgae were sampled only in Shirokaya Bay during the summer period (with the exception *U. intestinalis*). The remaining diatom communities on macrophytes constituted the third cluster (*B. hypnoides*, *C. arborescens*, *E. crinita*, and *P. leucosticta*). Among them, the similarity was noticeably lower.

The listed macroalgae were sampled at four stations in different seasons of the year, which causes a wide variety of diatoms of their epiphyton.

The analysis of the similarity of diatom communities by stations (Figure 7b) also based on the abundance of species of the entire species composition (Appendix A Table A2) showed that the communities of stations 2 and 3 had the most similarity. These stations belong to the Kazantip Reserve, and are characterized by similar relief and underlying substrates. Among the diatoms, the following species prevailed here: *A. brevipes*, *C. scutellum*, *C. closterium*, *G. marina*, *L. abbreviata*, *L. flabellata*, *M. jurgensii*, *M. moniliformis* var. *moniliformis*, *M. moniliformis* var. *subglobosa*, *N. perminuta*, *N. ramosissima*, *T. parva*, and *T. tabulata*.

3.3. Structure of the Diatom Community in Different Seasons

The similarity of the species composition of diatoms of macroalgae by month, calculated using the Bray–Curtis index (BC) in the Past 4.03 program, turned out to be close to 0.45 (Figure 8). This indicated a certain similarity in the species composition on the epiphyton diatom community throughout the year. There were seven species (*Achnanthes brevipes*, *Berkeleya rutilans*, *Cocconeis scutellum*, *Grammatophora marina*, *Melosira moniliformis*, *Navicula ramosissima*, and *Tabularia tabulata*) that occur monthly on macroalgae.

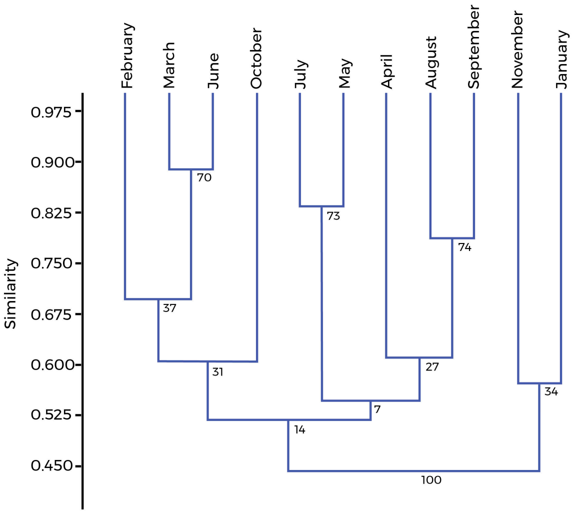

Figure 8. Dendrogram of the similarity of the diatom species composition in the epiphyton by seasons.

At the same time, the following two clusters were distinguished: one included a complex of diatom species in November and January, the other in the remaining months. The identification of the first cluster is most likely since only in these two months the species *Achnanthes brevipes* var *intermedia*, *Diploneis littoralis*, *D. didyma*, *Fallacia forcipata*, *Gomphonemopsis pseudexigua*, and some others were found.

Another cluster is formed by a complex of species, evenly represented in the remaining months. This distribution may be associated with the hydrodynamic regime in the coastal region. As a rule, from April to September, a minimum number of storms are usually recorded at the Kazantip Cape. During the study period, the most hydrodynamically turbulent months were November, December, and January.

Analysis of diatom community structure showed seasonality in their development, despite the similar species composition during the annual cycle.

In winter (January and February), the macroalgae fouling (*B. hypnoides*, *E. crinita*, *P. leucostica*, and *U. linza)* represented 32 species of diatoms. The epiphyton contained numerous colonial benthic species of *Tabularia* and *Navicula ramosissima*, as well as a single attached *C. scutellum*. Species of *Achnanthes*, *Grammatophora*, *Rhoicosphenia*, and benthoplanktonic *Melosira moniliformis* were often found in the epiphyton. Planktonic species, *Skeletonema costatum* and *S. subsalsum*, with a winter peak in their development, were often detected in fouling. The species richness varied from 9 to 13. The maximum abundance of diatoms was 26.9 × 10^3 cells/cm^2 on *E. crinita* in February, and the minimum was 3.8 × 10^3 cells/cm^2 on *P. leucostica* in January. The values of the indices varied between (D_{BP} = 18–53%), (H = 2.6–3.1), and (e = 0.7–0.9).

In spring (March, April, and May), 31 species of diatoms were recorded on the five species of macroalgae (*B. hypnoides*, *C. arborescens*, *E. crinita*, *U. intestinalis*, and *U. linza*). The above species, which are part of the winter complex, were more abundant in spring. The richness species varied from 7 to 18. The maximum abundance of diatoms reached 61.8 × 10^3 cells/cm^2 in the epiphyton of *E. crinita* in March, and the minimum was 6.3 × 10^3 cells/cm^2 on *U. intestinalis* in April. The indices varied within the following ranges: H = 1.6–2.9; D_{BP} = 21–67%; and e = 0.5–0.9. In March–April, *N. ramosissima* was found in colonies represented by long mucous tubes (Figure 4h). It should be noted that the high abundance of the diatom community is often due to the massive development of one, two, or less often three species, which is reflected in higher values of the dominance indices compared to the winter season.

From June to September, 74 species of diatoms were recorded in the epiphyton of different macroalgae (*B. hypnoides*, *C. corymbosum*, *Cl. liniformis*, *Cladosiphon mediterraneus*, *E. crinita*, *G. barbata*, *U. intestinalis*, *U. linza*, and *Polysiphonia denudata*). At this period, the diatom genera Licmophora (six species), Melosira (four), and Nitzschia (ten) are most diversely represented. Thus, in June–July, the species *C. scutellum* was dominant; *Navicula perminuta*, *N. ramosissima*, and *Rh. marina* were subdominantes; other species were noted as single. At the beginning of summer, many diatom colonies were destroyed and were found mainly in the form of single cells, fouling substrates to a lesser extent than in spring. The abundance of diatoms ranged from 4.3 × 10^3 cells/cm^2 (*G. barbata*, June) to 78 × 10^3 cells/cm^2 (*G. barbata*, July). The species richness varied from 3 to 18. During these months, low species diversity indices of (H = 1.1–2.6) and (e = 0.2) were noted. The Berger–Parker dominance index was maximum (D_{BP} = 87%). The abundant fouling of macroalgae by colonies of diatoms, mainly of the genera *Licmophora* spp., as also *Tabularia* spp., but less of *Achnantes* spp. and *Grammatophora marina*, were in August and September. Subdominant species *Cocconeis placentula* var. *euglypta*, *Odontella obtusa*, *Rhopalodia musculus*, and *Seminavis ventricosa* developed in mass. The richness species varied from 8 to 32, and the abundance ranged from 5 × 10^3 cells/cm^2 (*Cl. mediterraneus*, August) to 243.4 × 10^3 cells/cm^2 (*P. denudata*, September). The indices varied within the following ranges: H = 2.0–3.9, e = 0.7–0.9, D_{BP} = 14–58%; this indicates a more uniform distribution of the abundance of species in the community than in June–July.

In October and November, 43 species diatoms were recorded in the epiphyton of four macroalgae species (*B. hypnoides*, *C. arborescens*, *E. crinita*, and *U. linza*). The species *C. scutellum*, *G. marina*, *Tabularia fasciculata*, *T. parva*, *T. tabulata*, and *Melosira lineata* occur frequently. The fouling of macroalgae thalli with diatom colonies is less abundant. The species richness varied from 6 to 17. The maximum abundance of the diatom community was 18.8 × 10^3 cells/cm^2 on *C. arborescens* in October at 17 °C, and the minimum was 4.4 × 10^3 cells/cm^2 on *U. linza*. In the diatom epiphyton on *B. hypnoides* and *E. crinita*, minimum values of indices (H = 0.8 and 1.2) and (e = 0.3 and 0.5) were noted, which is due to the high abundance of the dominants species (D_{BP} = 61 and 67%). In the epiphyton of other macroalgae, the values indices varied between H = 2.4–3.3 and e = 0.7–0.8.

There were five cosmopolites of diatom species that dominated in different months of the year, as follows: *C. scutellum*, *G. marina*, *L. abbreviata*, *Rh. Marina*, and *T. tabulata*. The abundance of dominant diatom species during all seasons was as follows:

- *Cocconeis scutellum* dominated in March (*E. crinita*), May (*B. hypnoides*, *C. arborescens*, *U. linza*), June (*G. barbata*), and July (*C. corymbosum*) with the highest abundance (18.9 × 10^3 cells/cm^2) in May (*C. arborescens*) and the lowest (1.2 × 10^3 cells/cm^2) in July (*C. corymbosum*).

- *Grammatophora marina* dominated in October (*E. crinita*) with abundance of 15.3 × 10^3 cells/cm^2.
- *Licmophora abbreviata* (1004 cells/cm^2) dominated in August on *Cl. mediterraneus* and *U. linza*, where its minimum abundance was noted, as well as the maximum (N = 97.7 × 10^3 cells/cm^2) of *P. denudata* in September.
- *Rhoicosphenia marina* (N = 13.7 × 10^3 cells/cm^2) dominated on *E. crinita* in April.
- *Tabularia tabulata* dominated in October (*C. arborescens*), January (*U. linza*), February (*B. hypnoides*), March (*B. hypnoides, C. arborescens*), April (*B. hypnoides*), and August (*E. crinita*). The highest abundance (24.2 × 10^3 cell/cm^2) was recorded in the epiphyton of *B. hypnoides* in April, and the minimum (4.8 × 10^3 cell/cm^2) was recorded in the epiphyton of *E. crinita* in August.

4. Discussion

The epiphytic diatoms on aquatic vegetation in the upper sublittoral seas live in highly variable environmental conditions. Shallow coastal waters are characterized by significant temperature fluctuations throughout the year, season, and even within day; noticeable changes in salinity due to rain, melting snow, and seasonal influxes of fresh water; and the influence of the movement of water masses due to storms, surge phenomena in the seas, etc. In addition, macroalgae, as a substrate, are very variable during their life cycle.

Obviously, in such conditions, it is mainly species with broad ecological plasticity that can exist and flourish. Thus, cosmopolites and species with a wide geographical distribution dominate in terms of species richness and abundance. Therefore, the microphytobenthos diatoms from the coastal waters of different seas are characterized by significant similarities. Thus, 54 species registered at Kazantip Cape are indicated on green, brown, and red algae in the Crimean coastal waters of the Black Sea [1]. On 25 species of macrophytes from the Peter the Great Bay of the Sea of Japan, 112 species of diatoms were found, of which 47 taxa were common to the Sea of Azov [38]. Of the 85 species of diatoms found in the epiphyton of red, brown, and green algae of the Mediterranean Sea (coast of Israel), 45 taxa are also common [39]. In the epiphyton of 6 species of wetland macrophytes in southern Iraq, 74 species of diatoms were recorded [40], of which 10 species were found in the Sea of Azov.

Among the diatoms noted in our list of species, there are obligate foulers, *Achnanthes*, *Licmophora*, *Tabularia*, *Gomphonemopsis*, *Rhoicosphenia*, *Striatella*, etc., capable of adhesion with the help of mucopolysaccharides they secrete [41,42], as well as species that move freely along the substrate.

Many authors have noted that macrophytes represent an ideal substrate its colonization by diatoms [38,43–46]. According to the authors [47], the structure of epiphyton diatom communities can vary significantly depending from the macrophyte species; based on this, they hypothesized that it was due to an increase in colonization surface area by diatoms. This is also evidenced by data [35,48].

A wide variety of factors are known to influence the species composition and quantity of diatom algae: abiotic environmental conditions, biogeographic isolation, the nature of the underlying bottom substrates, and the physiological state of the basiphyte [3,35,45,46,49–53]. For diatoms from mountain lakes, the dependence of the diversity of their communities on altitude has been shown [54]. At the same time, some authors indicate that the degree of colonization of macroalgae by diatoms may depend on the taxonomic rank of the basiphyte [44,45,48,49], the structure of their thalli, and the season [1,11,38].

Previously, the diatom epiphyton *Bryopsis* was classified as nonfouling [52] and *Ulva* was classified as weakly fouling [55–58]. However, subsequent work showed that Chlorophyta algae, having an axial type of thalli, for example, *Cladophora*, *Chaetomorpha*, and *Bryopsis*, can be fouled by diatoms [55,57–59]. The abundance of diatoms on *Bryopsis plumosa* was 14.4 × 10^3 cells/cm^2 in May at depth up to 1 m in Koktebel Bay of the Black Sea [60]. The abundance of diatoms on *Bryopsis hypnoides* was 28 × 10^3 cells/cm^2 in May at the Kazantip

Cape. We noted that in the same months, the abundance of diatoms on *U. intestinalis* and *U. linza*, which have a lamellar thallus, was lower compared to the axial structures of the *Bryopsis*. In April, the abundance diatoms on *U. intestinalis* was 6.3×10^3 cells/cm^2 and on *B. hypnoides*—53.9×10^3 cells/cm^2. However, in September, at the Kazantip Cape, abundant development on *U. linza* and high (compared to other months) values of species richness (S = 24), the highest peaks of abundance (N = 17.7×10^3 cells/cm^2), and biomass (B = 0.31 mg/cm^2) diatoms were registered.

Cases of intensive colonization on *Ulva* have been recorded previously in the Crimean coastal waters of the Black Sea. For example, in the work, it was noted that, in certain seasons of the year, the thalli, and especially the rhizoids of *Ulva rigida*, were intensively overgrown with diatoms [57]. This may be due to a certain physiological state of the basiphyte at different stages of the life cycle, as indicated in the monograph [1].

The species Phaeophyta of *E. crinita* and *G. barbata* are well fouling with diatoms, as shown in this study and works [1,35,61,62]. These are perennial macroalgae, so the duration of existence of their thalli is longer compared to other studied species. It is indicated that the abundance of epiphyton on old plants was higher than in young ones [63].

Rhodophyta species with different thalli structures, sampled from the same depth, were colonized by diatoms differently. Thus, the lamellar thallus on *P. leucostica* had the lowest abundance of microphytes and the lowest species richness, while the epiphyton of *Polysiphonia denudata* had the highest number of all quantitative indicators. These macroalgae were selected in different seasons, but in comparison with other vegetation, *P. leucostica* thallus were practically not overgrown in winter, and in September the communities on *P. denudata* diatom epiphyton differed in the highest species richness, abundance, and biomass among other macroalgae. Therefore, there is a significant increase in the specific surface area of the thallus of axial-type macroalgae compared to the lamellar type [1,48,61]. At the same time, not only species diversity and species richness increase with increasing substrate area [64], but also the abundance of diatom populations and communities.

It should be taken into account that some macroalgae-basiphyte are overgrown with smaller macroepiphytes from the genera *Ceramium, Cladophora*, etc., which provide additional surface area for colonization by diatoms.

Let us note that an important factor influencing the development of epiphyton communities in coastal waters is hydrodynamics. Thus, according to the species composition, the diatom flora on macroalgae in different months of the year is divided into two clusters. One cluster unites a complex of species from November and January. During these months, strong stormy days were observed at Kazantip Cape, which made sampling impossible in December. The second cluster unites the diatom flora in the remaining months of the year, characterized by shorter and less severe storms. From October to March, the role of hydrodynamics increases significantly. By the beginning of summer, hydrodynamic activity decreases and in the calmest months, August, and September, we observed maximum species richness, species diversity, and evenness of species in diatom communities with abundant developments of macroalgae.

Some authors have noted a positive interaction between the organic matter content of natural habitats and the propensity of diatoms to heterotrophy [65–67]. The paper [68] indicates that the heterotrophic composition of microalgae is higher in the epiphyton than in the epilithon. Recent studies have shown that the beta diversity of producers is highest in the hypertrophic waterbody [69]. In conditions of increased nutrient content in water, there is a gradual replacement of the pioneer periphyton diatom community with green macroalgae [70]. Certain benthic diatoms of the genera *Amphora*, *Licmophora*, *Navicula*, *Striatella*, *Cocconeis*, *Tabularia*, and others prefer an environment enriched with dissolved organic matter and belong to heterotrophic (mixotrophic) species [1,65]. As a rule, such species are indicators of the trophic level of a water area and are abundantly represented in the organic-rich coastal area of the Sea of Azov.

In the coastal waters of the Kazantip Cape, we recorded the year-round presence of indicators of moderate organic pollution of waters, which develop en masse in late summer. This is probably due to the intake of organic substances with untreated sewage and domestic waters from adjacent settlements and recreation facilities near stations 1 and 4, with maximum load in summer period. Statistical comparison of diatom communities in terms of abundance and composition of bioindicators in JASP shows that the interaction between environment and biota is most similar at stations 2 and 3, and different at stations 1 and 4. It should be noted that stations 2 and 3 are located in the territory of the Kazantip Reserve, which indicates the effectiveness of the conservation regime, despite the relatively high saprobity indices (2.25–2.26). However, the ecosystems of stations 1 and 4 suffer significantly from anthropogenic load, although the saprobity indices here are lower (2.19–2.21) than in the protected part. This confirms our assumption of toxic pollution at the stations affected by recreational loads.

However, besides mesosaprobionts, oligosaprobionts were also observed, which were constantly present in the community, but with lower abundance, as it was previously noted in our work [3].

There are known works that show the role of benthic diatoms in the indication of other types of pollution, for example, metals [71]. Information on the floristic composition of diatoms and the structure of their communities in the Kazantip coastal area can be used to assess the ecological state of the intact environment or different types of impact, as indicated by the work carried out in other territories [72,73].

5. Conclusions

For the first time, data on the species composition, seasonal dynamics of abundance, biomass, and structural indicators of the diatom community of epiphyton of 11 species of red, brown, and green macroalgae were obtained for the protected waters of Kazantip Cape of the Sea of Azov represented by 97 taxa of Bacillariophyta were discovered, belonging to 3 classes, 21 orders, 30 families, and 45 genera, 51 species of which were indicated for the first time for the study areas. The number diatom species are the genera *Nitzschia* (12 species) and *Navicula* (11). Number of diatom species found by season: 32 in winter, 31 in spring, 74 in summer, and 43 in autumn, and 80% of benthic diatom species, 50% marine, 36% brackish marine, 9% freshwater, 5% brackish, 21% β-mesosaprobic species indicators of moderate organic pollution, and 36% cosmopolites were found.

Diatom communities are characterized by similar species composition throughout the year (except for November and January), with the highest similarity on macroalgae within the same station. The quantitative values of diatoms vary depending on the species of macroalgae and the season. The thalli of *B. hypnoides*, *G. barbata*, *E. crinita* и *P. denudata*, grow best, and the most abundant development of diatoms occurs in March and September. The maximum values of the abundance and biomass of diatoms for the entire study period were 243.4×10^3 cells/cm^2 и 2.82 mg/cm^2 on *P. denudata* in September. The minimum values ($N = 3.8 \times 10^3$ cells/cm^2, $B = 0.006$ mg/cm^2) were noted on *P. leucosticta* in January.

The presence in the epiphyton of diatoms—indicators of moderate organic pollution of water, which developed in masse in late summer—indicate a constant inflow of organic matter into the coastal waters of the Kazantip Cape. Our bioindicator and statistical studies indicate the effectiveness of the conservation regime, especially at stations within the IUCN reserve, despite relatively high saprobity rates at stations exposed to recreational pressure and poorly treated domestic wastewater. In whole, the waters of the Cape are mesotrophic. The bioindicator properties of the identified diatom species can be used in further monitoring the dynamics of anthropogenic load in the Sea of Azov.

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Appendix A

Table A1. Average abundance (cells per cm^2) of epiphytic macroalgae diatoms in the coastal waters of the Kazantip Cape in the Sea of Azov.

No.	Taxa	*Ericaria crinita*	*Gongolaria barbata*	*Cladosiphon mediterraneus*	*Bryopsis hypnoides*	*Cladophora liniformis*	*Ulva intestinalis*	*Ulva linza*	*Callithamnion corymbosum*	*Ceramium arborescens*	*Polysiphonia denudata*	*Pyropia leucosticta*
	Code	**Ecr**	**Cob**	**Clm**	**Brh**	**Cll**	**Uli**	**Ull**	**Cac**	**Cea**	**Pod**	**Pyl**
1	*Achnanthes brevipes* var. *brevipes* C. Agardh 1824	839	1	1	1309	2567	336.7	252	1	332.5	433	667
2	*Achnanthes brevipes* var. *intermedia* * (Kützing) P.T. Cleve 1895	83	0	0	0	0	0	0	0	0	0	0
3	*Achnanthes longipes* C. Agardh 1824	0	0	0	0	0	0	0.333	0	0.4	325	0
4	*Amphora laevis* * Gregory 1857	0	0	0	0	0	0	0.667	0	0	0	0
5	*Amphora marina* * W. Smith 1856	0	179	1	0	592.3	0	0.333	0	0	0	0
6	*Amphora ovalis* (Kützing) Kützing 1844	0	0	0	0	0	0	33	0	37.6	433	0
7	*Amphora proteus* * Gregory 1857	0	0	0	0	0	0	6.667	0	0	433	0
8	*Anaulus minutus* * Grunow 1880	0	1314	0	0	0	0	0	0	0	0	0
9	*Bacillaria paxillifer* (O.F. Müller) Hendey 1951	0	1	1	131.4	0	1	85	0	0	1	0
10	*Berkeleya rutilans* (Trentepohl ex Roth) Grunow 1880	1992	0	0	200	0	194.7	82.33	0	223.6	1300	303
11	*Caloneis liber* * (W. Smith) P.T. Cleve 1894	533	239	0	61	987.1	0	38.67	0	0	1	0
12	*Cocconeis neothumensis* * Krammer 1990	0	0	0	0	0	0	0	0	0.2	0	0
13	*Cocconeis placentula* var. *euglypta* * (Ehrenberg) P.T. Cleve 1884	0	0	0	0.125	0	0	18	0	0	2492	0
14	*Cocconeis scutellum* Ehrenberg 1838	4567	2747	89	4413	6318	4680	243.3	1162	4444	9424	667
15	*Coscinodiscus janischii* * A. Schmidt 1878	0	1	0	0	0	0.333	237	1	0	1083	0
16	*Cylindrotheca closterium* (Ehrenberg) Reimann et Lewin 1964	156	538	0	0	2172	0.333	6.667	109	0	758	0
17	*Diatoma tenuis* C. Agardh 1812	0	0	0	0	0	0.333	0	0	0	0	0
18	*Diploneis didyma* (Ehrenberg) Ehrenberg 1894	0.1	0	0	0	0	0	0	0	0	0	0
19	*Diploneis littoralis* * (Donkin) P.T. Cleve 1894	0	0	0	0	0	0	0	0	32.4	0	0
20	*Diploneis lineata* * (Donkin) P.T. Cleve 1894	101	0	0	0	0	0	0	0	0	0	0
21	*Diploneis smithii* * (Brébisson) P.T. Cleve 1894	0	0	0	0	0	0	0	0	0.2	0	0
22	*Entomoneis paludosa* (W. Smith) Reimer 1975	0	0	0	0	0	0	6.667	0	0	0	0

Table A1. *Cont.*

No.	Taxa	*Ericaria crinita*	*Gongolaria barbata*	*Cladosiphon mediterraneus*	*Bryopsis hypnoides*	*Cladophora liniformis*	*Ulva intestinalis*	*Ulva linza*	*Callithamnion corymbosum*	*Ceramium arborescens*	*Polysiphonia denudata*	*Pyropia leucosticta*
	Code	**Ecr**	**Cob**	**Clm**	**Brh**	**Cll**	**Uli**	**Ull**	**Cac**	**Cea**	**Pod**	**Pyl**
23	*Falcula media* var. *subsalina* * Proschkina-Lavrenko 1963	0	0	0	0	0	0	0.667	0	0	1	0
24	*Fallacia forcipata* * (Greville) A.J. Stickle et D.G. Mann 1990	0	0	0	0	0	0	0.667	0	0	1	0
25	*Fallacia pygmaea* * (Kützing) A.J. Stickle et D.G. Mann 1990	76	0	0	0	0	0	0	0	0	0	0
26	*Gomphonemopsis pseudexigua* * (Simonsen) Medlin 1986	76	0	0	74	0	0	0	0	0	0	0
27	*Grammatophora angulosa* * Ehrenberg 1840	0	0	0	0	0	0	0	0	0.2	0	0
28	*Grammatophora marina* (Lyngbye) Kützing 1844	5664	1	0	2143	0	0	480.7	0	800	6717	243
29	*Halamphora coffeiformis* (C. Agardh) Levkov 2009	86	239	1	0	0	0	7	0	0	867	0
30	*Halamphora hyalina* * (Kützing) Levkov 2009	0	0	1	0	0	0	28.33	0	37.6	1950	0
31	*Hantzschia marina* * (Donkin) Grunow 1880	0	0	0	40	0	0	0	0	32.4	0	0
32	*Haslea subagnita* * (Proschkina-Lavrenko) Makarova et Karajeva 1985	0.1	1	0	0	0	0	0	0	0	0	0
33	*Hyalosira delicatula* Kützing 1844	86	0	0	0.25	0	0	0	0	0	0	0
34	*Licmophora abbreviata* C. Agardh 1824	76	418	2920	0	789.7	170	1017	218	63	97,711	0
35	*Licmophora dalmatica* (Kützing) Grunow 1867	0	0	0	0	0	0	28.33	0	0	1	0
36	*Licmophora flabellata* * (Greville) C. Agardh 1831	0	1	775	0	0	0	235.3	1	0	9858	0
37	*Licmophora hastata* * Mereschkowsky 1901	0	0	179	0	0	0	0	0	37.6	0	0
38	*Licmophora paradoxa* (Lyngbye) C. Agardh 1828	0	0	0	0	0	0	11.33	0	0	0	0
39	*Licmophora rostrata* * Mereschkowsky, 1902	0	0	0	0	0	0	0	0	0	1	0
40	*Lyrella abrupta* * (Gregory) D.G. Mann 1990	0	0	0	0	0	0	0.333	0	0	0	0
41	*Lyrella atlantica* * (A. Schmidt) A.J. Stickle et D.G. Mann 1990	0	0	0	0	0	0	7	0	0	1	0
42	*Lyrella lyra* * (Ehrenberg) N.I. Karajeva 1978	0	0	0	0	0	0	0	0	0	325	0
43	*Lyrella lyroides* * (Hendey) D.G. Mann 1990	0	0	0	0	0	0	0.333	0	0	0	0
44	*Mastogloia pumila* * (Grunow) P.T. Cleve 1895	0	0	0	0	0	0	7	0	0	0	0
45	*Mastogloia pusilla* Grunow 1878	0	0	0	0	0	0	0.333	0	0	1	0
46	*Melosira jurgensii* * C. Agardh 1824	0	0	0	0	0	0	0	0	0	23,399	0
47	*Melosira lineata* * (Dillwing) C. Agardh 1824	0	0	0	0	0	0	81	0	753.9	5308	0
48	*Melosira moniliformis* var. *moniliformis* (O.F. Müller) C. Agardh 1824	882	1	0	374.8	1	0.333	728.7	0	0.4	10,183	0
49	*Melosira moniliformis* var. *subglobosa* * (Grunow) Hustedt 1927	468	0	0	310.4	0	0	530.7	0	84.6	19,065	0
50	*Navicula ammophila* var. *intermedia* Grunow 1822	114	0	0	0.25	0	43	9	0	85	2600	0
51	*Navicula cancellata* Donkin 1873 var. *cancellata*	89	239	0	0.125	987	0.333	0.333	145	63.4	1	0

Table A1. *Cont.*

No.	Taxa	*Ericaria crinita*	*Gongolaria barbata*	*Cladosiphon mediterraneus*	*Bryopsis hypnoides*	*Cladophora liniformis*	*Ulva intestinalis*	*Ulva linza*	*Callithamnion corymbosum*	*Ceramium arborescens*	*Polysiphonia denudata*	*Pyropia leucosticta*
	Code	**Ecr**	**Cob**	**Clm**	**Brh**	**Cll**	**Uli**	**Ull**	**Cac**	**Cea**	**Pod**	**Pyl**
52	*Navicula cancellata* var. *gregoryi* * Grunow 1880	0	0	0	0.125	0	0	0	0	0	0	0
53	*Navicula cryptocephala* * Kützing 1844	0	0	0	0	0	0	28	0	38	0	0
54	*Navicula directa* (W. Smith) Ralfs ex Pritchard 1861	177	239	0	0	0	0	0	0	32.4	0	0
55	*Navicula dumontiae* * Baardseth et Taasen 1973	0	0	0	0.125	0	0	0	0	0	0	0
56	*Navicula palpebralis* Brebisson ex W. Smith 1853	0	0	0	0	0	0	0.333	0	84.6	0	0
57	*Navicula pennata* var. *pontica* * Mereschkowsky 1902	0	0	0	0	0	0	9	0	0	1	0
58	*Navicula perminuta* * Grunow 1880	342	478	0	0.5	5331	870	283.7	109	127	3575	0
59	*Navicula perrhombus* * Hustedt ex Simonsen 1962	156	0	0	0	0	0	0	0	0	0	0
60	*Navicula ramosissima* (C. Agardh) P.T. Cleve 1895	2039	67,849	149	1073	4738	114.3	266.7	980	954.9	6825	485
61	*Neosynedra provincialis* * (Grunow) Williams et Round 1986	0.1	0	0	172.1	0	0	0	0	59.59	0	0
62	*Nitzschia dissipata* (Kützing) Grunow 1862	0	0	0	0	0	0	0.333	0	0	0	0
63	*Nitzschia distans* Gregory 1857	83	0	0	0	0	0.333	11.67	0	32.4	0	0
64	*Nitzschia hybrida* f. *hyalina* Proschkina-Lavrenko 1963	0	0	0	0.125	0	0.333	0.333	0	0	0	0
65	*Nitzschia inconspicua* * Grunow 1862	0	0	0	0	0	0	0.333	0	0	0	0
66	*Nitzschia lanceolata* var. *minor* Van Heurck 1880	0	0	0	211.8	1	0	0	0	0.2	0	0
67	*Nitzschia rupestris* * Proschkina-Lavrenko 1963	0	0	0	40	0	0	0	0	0	0	0
68	*Nitzschia sigma* (Kützing) W. Smith 1853	430	0	149	163.3	3356	259	67	254	60	1625	0
69	*Nitzschia sigmoidea* (Nitzsch) W. Smith 1853	0	0	1	0	0	0	186.7	0	0	2816	0
70	*Nitzschia spathulata* Brébisson ex W. Smith 1853	0	0	0	0	0	0	6.667	0	0	0	0
71	*Nitzschia tenuirostris* Mereschkowsky 1901	0	0	0	0	0	0	0	0	0	1	0
72	*Nitzschia vermicularis* (Kützing) Hantzsch ex Rabenhorst 1860	76	0	0	0	0	0	0	0	0	0	0
73	*Nitzschia vidovichii* * (Grunow) Grunow 1881	0	0	0	0	0	0	9	0	0	0	0
74	*Odontella obtusa* * Kützing 1844	0	0	0	0	0	0	0.667	0	0	867	0
75	*Parlibellus delognei* (Van Heurck) E.J. Cox 1988	111	1374	0	0	3554	0	0.333	1	0	1	182
76	*Petroneis humerosa* (Brebisson ex Smith) Sticle et D.G. Mann 1990	0	0	0	0	0	0	0	0	0	1	0
77	*Plagiotropis lepidoptera* * (Gregory) Kuntze 1898	0.1	179	0	0	0	0	195.2	0	37.6	1	0
78	*Planothidium delicatulum* * (Kützing) Round et Bukhtiyarova 1996	0	0	0	0	0	0	0.333	0	0	0	0
79	*Pleurosigma angulatum* (Queckett) W. Smith 1852	0	0	0	0	0	0	0.333	0	0	0	0
80	*Pleurosigma elongatum* W. Smith 1852	0	358	0	0	592	0	0.667	0	63.4	0	0
81	*Pleurosigma intermedium* W. Smith 1853	0	1	0	0	0	0	0	0	0	0	0

Table A1. *Cont.*

No.	Taxa	*Ericaria crinita*	*Gongolaria barbata*	*Cladosiphon mediterraneus*	*Bryopsis hypnoides*	*Cladophora liniformis*	*Ulva intestinalis*	*Ulva linza*	*Callithamnion corymbosum*	*Ceramium arborescens*	*Polysiphonia denudata*	*Pyropia leucosticta*
	Code	**Ecr**	**Cob**	**Clm**	**Brh**	**Cll**	**Uli**	**Ull**	**Cac**	**Cea**	**Pod**	**Pyl**
82	*Proschkinia poretzskiae* * (Korotkevich) D.G. Mann 1990	209	0	0	0	0	0	0	0	0	0	182
83	*Psammodictyon panduriforme* * (Gregory) D.G. Mann 1990	152	0	0	0	0	0	0	0	0	0	0
84	*Rhoicosphenia marina* (W. Smith) M. Schmidt 1889	2746	478	0	185.5	789.7	1447	6.667	109	1029	0	606
85	*Rhopalodia musculus* * (Kützing) O.F. Müller 1899	0	0	0	74	0	0	0.667	0	0	2383	0
86	*Skeletonema costatum* (Greville) P.T. Cleve 1878	1645	0	0	226.8	0	0	0	0	337.6	0	0
87	*Skeletonema subsalsum* (Cleve) Bethge 1928	1	0	0	0.125	0	0	0	0	0	0	0
88	*Seminavis ventricosa* * (Gregory) M. Garcia-Baptista 1993	356	0	0	0	0	0	126	0	0	1083	0
89	*Striatella unipunctata* * (Lyngbye) C. Agardh 1832	0.1	0	0	0.125	0	0	0	0	0	0	0
90	*Synedrosphenia crystallina* (C. Agardh) Lobban et Ashworth 2022	0	179	0	227.6	1	0	46.33	0	63	650	0
91	*Tabularia fasciculata* (C. Agardh) Williams et Round 1986	497	597	0	1204	0	0	1138	0	65	0	0
92	*Tabularia parva* (Kützing) Williams et Round 1990	475	0	626	911.4	2567	0	929.5	0	364.2	17,224	0
93	*Tabularia tabulata* (C. Agardh) Snoeijs 1992	2674	0	1	8086	6120	931.7	859.3	145	2984	11,049	425
94	*Trachyneis aspera* * (Ehrenberg) P.T. Cleve 1894	389	358	119	104.2	0	114.3	49	0	0	650	0
95	*Tryblionella compressa* * (Bailey) Poulin 1990	0	0	0	0.125	0	0	0	0	0	0	0
96	*Tryblionella hungarica* (Grunow) D.G. Mann 1990	0.1	0	0	0.25	0	0	0	0	0.2	0	0
97	*Undatella lineolata* (Ehrenberg) L.I. Ryabushko 2006	0	0	0	0	0	0	9.333	109	0	1	0
	No of Species	40	26	15	35	18	19	61	14	37	45	9
	Average Abundance, cells/cm^2	28,444	78,010	5013	21,739	41,462	9165	8418	3344	13,362	243,426	3760

Note. (*)—species recorded for the first time in the Kazantip Cape.

Table A2. Species composition of diatoms, their averaged abundance (cells per cm^2) by stations, ecological (Habitat, RS, SAPRO, s), and phytogeographical (PhG) characteristics in the coastal waters of the Kazantip Cape in the Sea of Azov.

No.	Taxon	St. 1	St. 2	St. 3	St. 4	Habitat	RS	SAPRO	Index S	PhG
1	*Achnanthes brevipes*	546.60	673.72	406.78	838.63	B	BM	β	2.00	C
2	*Achnanthes brevipes* var. *intermedia*	16.60	8.30	8.30	83.00	B	BM	-	-	C
3	*Achnanthes longipes*	0.15	32.57	10.91	0.00	B	M	β	-	ABT
4	*Amphora laevis*	0.13	0.07	0.07	0.00	B	M	-	-	BT, not
5	*Amphora marina*	0.27	77.16	25.81	0.00	B	M	-	-	BT, not
6	*Amphora ovalis*	14.05	50.33	21.46	0.00	B	BM	β	1.50	C
7	*Amphora proteus*	1.33	43.97	15.10	0.00	B	M	β	-	C
8	*Anaulus minutus*	0.00	131.40	43.80	0.00	B	M	-	-	BT, not
9	*Bacillaria paxillifer*	43.47	21.94	21.80	0.00	BP	BM	β	2.30	C
10	*Berkeleya rutilans*	499.62	429.58	309.73	1992.13	B	BM	-	-	ABT, not

Table A2. *Cont.*

No.	Taxon	St. 1	St. 2	St. 3	St. 4	Habitat	RS	SAPRO	Index S	PhG
11	*Caloneis liber*	126.43	185.93	104.12	532.50	B	M	-	-	C
12	*Cocconeis neothumensis*	0.04	0.02	0.02	0.00	B	FW	-	-	ABT, not
13	*Cocconeis placentula* var. *euglypta*	3.69	251.05	84.91	0.00	B	BM	β	1.30	ABT
14	*Cocconeisscutellum*	2751.35	3866.54	2205.96	4566.88	B	BM	β	2.00	C
15	*Coscinodiscus janischii*	47.47	132.27	59.91	0.00	P	M	-	-	BT, not
16	*Cylindrotheca closterium*	32.51	373.96	135.49	155.88	BP	BM	β	2.00	C
17	*Diatoma tenuis*	0.00	0.03	0.01	0.00	BP	FW	β	2.40	C
18	*Diploneis didyma*	0.03	0.01	0.01	0.13	B	BM	-	-	ABT, not
19	*Diploneis littoralis*	6.48	3.24	3.24	0.00	B	M	-	-	ABT, not
20	*Diploneis lineata*	20.25	10.13	10.13	101.25	B	M	o	0.70	BT
21	*Diploneis smithii*	0.04	0.02	0.02	0.00	B	BM	-	-	C
22	*Entomoneis paludosa*	1.33	0.67	0.67	0.00	BP	BM	β-α	2.50	C
23	*Falcula media* var. *subsalina*	0.13	0.17	0.10	0.00	BP	M	α-o	2.70	B
24	*Fallacia forcipata*	0.13	0.17	0.10	0.00	B	M	-	-	ABT, not
25	*Fallacia pygmaea*	15.20	7.60	7.60	76.00	B	BM	-	-	BT
26	*Gomphonemopsis pseudexigua*	30.00	15.00	15.00	76.00	B	M	-	-	ABT, not
27	*Grammatophora angulosa*	0.04	0.02	0.02	0.00	B	M	-	-	C
28	*Grammatophora marina*	1817.56	1604.88	1140.82	5664.25	B	M	β	-	C
29	*Halamphora coffeiformis*	18.70	119.85	46.18	85.50	B	M	o	1.30	C
30	*Halamphora hyalina*	13.39	201.59	71.66	0.00	B	BM	o	1.00	ABT, not
31	*Hantzschia marina*	14.48	7.24	7.24	0.00	B	M	o-α	1.80	BT, not
32	*Haslea subagnita*	0.03	0.11	0.05	0.13	B	BM	-	-	B
33	*Hyalosira delicatula*	17.15	8.58	8.58	85.50	B	BM	β	2.00	ABT, not
34	*Licmophora abbreviata*	815.28	10,046.31	3620.53	76.00	B	M	β	-	C
35	*Licmophora dalmatica*	5.67	2.93	2.87	0.00	B	M	-	-	B
36	*Licmophora flabellata*	202.07	1009.53	403.87	0.00	B	M	o-β	1.50	BT, not
37	*Licmophora hastata*	43.32	3.76	15.69	0.00	B	M	-	-	B
38	*Licmophora paradoxa*	2.27	1.13	1.13	0.00	B	M	-	-	C
39	*Licmophora rostrata*	0.00	0.10	0.03	0.00	B	M	-	-	B
40	*Lyrella abrupta*	0.07	0.03	0.03	0.00	B	M	-	-	BT
41	*Lyrella atlantica*	1.40	0.80	0.73	0.00	B	M	-	-	ABT, not
42	*Lyrella lyra*	0.00	32.50	10.83	0.00	B	M	o-β	1.50	BT, not
43	*Lyrella lyroides*	0.07	0.03	0.03	0.00	B	M	β	2.10	BT
44	*Mastogloia pumila*	1.40	0.70	0.70	0.00	B	BM	-	-	BT, not
45	*Mastogloia pusilla*	0.07	0.13	0.07	0.00	B	BM	-	-	BT, not
46	*Melosira jurgensii*	0.00	2339.90	779.97	0.00	P	BM	-	-	ABT, not
47	*Melosira lineata*	166.98	614.29	260.42	0.00	P	BM	o-β	2.00	ABT, not
48	*Melosira moniliformis* var. *moniliformis*	397.23	1217.15	538.13	882.25	BP	BM	o-β	2.00	C
49	*Melosira moniliformis* var. *subglobosa*	278.64	2045.82	774.82	467.50	BP	BM	-	-	B
50	*Navicula ammophila* var. *intermedia*	41.65	285.13	108.93	114.00	B	BM	-	-	AB
51	*Navicula cancellata* var. *cancellata*	30.55	152.51	61.02	88.88	B	M	-	-	C
52	*Navicula cancellata* var. *gregoryi*	0.03	0.01	0.01	0.00	B	M	-	-	B
53	*Navicula cryptocephala*	13.12	6.56	6.56	0.00	B	FW	β-α	2.40	C
54	*Navicula directa*	41.93	44.87	28.93	177.25	B	M	-	-	C
55	*Navicula dumontiae*	0.03	0.01	0.01	0.00	B	M	-	-	B
56	*Navicula palpebralis*	16.99	8.49	8.49	0.00	B	M	-	-	ABT, not
57	*Navicula pennata* var. *pontica*	1.80	1.00	0.93	0.00	B	M	β	1.00	BT
58	*Navicula perminuta*	150.67	1111.58	420.75	342.13	B	FW	-	-	C
59	*Navicula perrhombus*	31.18	15.59	15.59	155.88	B	M	-	-	B
60	*Navicula ramosissima*	896.59	8532.55	3143.05	2039.00	B	BM	β-α	2.40	ABT, not
61	*Neosynedra provincialis*	46.36	23.18	23.18	0.13	B	M	-	-	B
62	*Nitzschia dissipata*	0.07	0.03	0.03	0.00	B	FW	o	1.40	C
63	*Nitzschia distans*	25.41	12.74	12.72	83.00	B	BM	α	3.60	BT, not
64	*Nitzschia hybrida* f. *hyalina*	0.09	0.08	0.06	0.00	B	BM	β-α	2.50	B
65	*Nitzschia inconspicua*	0.07	0.03	0.03	0.00	B	FW	-	-	ABT, not
66	*Nitzschia lanceolata* var. *minor*	42.39	21.30	21.23	0.00	B	B	β	2.0	BT
67	*Nitzschia rupestris*	8.00	4.00	4.00	0.00	B	BM	-	-	B
68	*Nitzschia sigma*	173.85	621.48	265.11	430.00	BP	B	α	3.00	ABT, not
69	*Nitzschia sigmoidea*	37.53	300.27	112.60	0.00	BP	FW	β-α	2.50	B
70	*Nitzschia spathulata*	1.33	0.67	0.67	0.00	B	M	β-α	2.50	BT

Table A2. *Cont.*

No.	Taxon	St. 1	St. 2	St. 3	St. 4	Habitat	RS	SAPRO	Index S	PhG
71	*Nitzschia tenuirostris*	0.00	0.10	0.03	0.00	BP	B	β	1.70	B
72	*Nitzschia vermicularis*	15.20	7.60	7.60	76.00	B	B	β	2.20	BT, not
73	*Nitzschia vidovichii*	1.80	0.90	0.90	0.00	B	M	-	-	B
74	*Odontella obtusa*	0.13	86.77	28.97	0.00	BP	M	-	-	BT, not
75	*Parlibellus delognei*	22.19	522.26	181.49	110.63	B	M	-	-	C
76	*Petroneis humerosa*	0.00	0.10	0.03	0.00	B	M	-	-	C
77	*Plagiotropis lepidoptera*	46.59	41.29	29.29	0.13	B	M	-	-	ABT
78	*Planothidium delicatulum*	0.07	0.03	0.03	0.00	B	FW	o	1.00	ABT, not
79	*Pleurosigma angulatum*	0.07	0.03	0.03	0.00	B	M	-	-	C
80	*Pleurosigma elongatum*	12.81	101.41	38.07	0.00	B	BM	β	2.00	C
81	*Pleurosigma intermedium*	0.00	0.10	0.03	0.00	B	M	-	-	C
82	*Proschkinia poretzskiae*	41.70	39.05	26.92	208.50	B	M	-	-	B
83	*Psammodictyon panduriforme*	30.38	15.19	15.19	151.88	B	M	-	-	BT, not
84	*Rhoicospheniamarina*	793.32	739.67	511.00	2745.75	B	M	-	-	AB
85	*Rhopalodia musculus*	14.88	245.74	86.88	0.00	B	BM	β	1.00	BT
86	*Seminavis ventricosa*	441.82	220.91	220.91	355.88	B	M	-	-	C
87	*Skeletonema costatum*	0.23	0.11	0.11	1644.75	P	BM	-	-	C
88	*Skeletonema subsalsum*	96.38	156.49	84.29	1.00	P	BM	o	2.30	B
89	*Striatella unipunctata*	0.05	0.03	0.03	0.13	B	M	-	-	C
90	*Synedrosphenia crystallina*	67.39	116.69	61.36	0.00	B	BM	β-α	2.50	C
91	*Tabularia fasciculata*	580.89	350.14	310.34	497.38	B	BM	β-α	2.50	C
92	*Tabularia parva*	661.21	2247.06	969.43	475.00	B	BM	α	3.00	ABT, not
93	*Tabularia tabulata*	2920.89	3327.43	2082.77	2673.75	B	BM	-	-	C
94	*Trachyneis aspera*	132.26	166.46	99.58	389.13	B	M	-	-	C
95	*Tryblionella compressa*	0.03	0.01	0.01	0.00	B	M	-	-	ABT, not
96	*Tryblionella hungarica*	0.12	0.06	0.06	0.13	B	B	α-o	2.90	C
97	*Undatella lineolata*	1.87	11.93	4.60	0.00	B	BM	β	-	ABT

Note. (-)—data absent. Habitat: B—benthos, P—plankton, BP—bentho-plankton. RS—the relationship of species to the water salinity: M—marine species, FW—freshwater, BM—brackish-marine, B—brackish. SAPRO—self-purification zone: α—mesosaprobic, α-β—mesosaprobic, α-o—mesosaprobic, β—mesosaprobic, β-α—mesosaprobic, o—oligosaprobic, o-β—mesosaprobic. Index: S—species-specific index saprobity s according to [37]. PhG—phytogeographic elements: B—boreal species, AB—arctic-boreal, BT—boreal-tropical, ABT—arctic-boreal-tropical, C—cosmopolite. not = notal species also found in the southern hemisphere.

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