Diatom Algae of Sandy Spits of the Northwestern Part of the Black Sea (Ukraine)∗

A.A. Snigireva[1] & G.V. Kovaleva[2]

[1] *I.I. Mechnikov Odessa National University, Marine Research Station,*
2, Shampanskyi Lane, Odessa 65058, Ukraine
snigireva.a@gmail.com
[2]*Federal State Budget Institution of Science, Institute of Arid Zones*
of the Southern Sci. Center, RAS,
41, Chekhov St., Rostov-on-Don 344006, Russia
kovaleva@ssc-ras.ru

ABSTRACT: The species diversity of diatom algae of mezophytopsammon in three areas of the northwestern part of the Black Sea (Kinburn, Karolino-Bugaz, and Budakskaya sandy spits) has been studied. Fifty-one taxa of *Bacillariophyta* from 26 genera were identified. Five species were first recorded in this area, and one species is a new record for Budaki Lagoon. Most of the species found (17) are motile (epipelic), and only four species are attached to the sandy grains (epipsammic). With respect to salinity, the diatoms were equally represented by polyhalobes (35%), mezohalobes (35%), and oligohalobes (31%). The greatest number of species was represented by the alkaliphilic (88%). A high abundance of diatoms in mezophytopsammon (up to 12 million cells per cm^2) indicates their important role in productive processes of coastal ecosystems of the Black Sea.

KEY WORDS: *Bacillariophyta*, sandy spits, Black Sea, mezophytopsammon, epipelic, epipsammic algae, Ukraine.

INTRODUCTION

The total area of sandy spits and islands in Ukraine is about 200,000 ha (Dubyna et al., 2006). The uniqueness of such ecosystems is found in a specific combination of environmental factors in the contact zones. Due to the extremely high concentration of

∗ Originally published in *Algologia*, 2015, 25(2), pp. 148–173 ISSN 1521–9429

detritus and aquatic flora and fauna, sandy littoral is considered as a "hot spot" of environmental monitoring (Zaitsev, 2012). In addition, sandy spits are reservations of rich biological diversity: key habitats of great scientific and practical interest.

Until now, the study of sandy spits' flora was focused on the flowering plants (Dubyna et al., 2006). Information on the microflora of the habitat is fragmentary and sparse.

The results of the study of microphytobenthic communities inhabiting sandy substrates are given in the paper of Gusliakov and Kovtun (2000). Authors call such a community *mezophytopsammon*, defined as a group of algae that live in the spaces between grains of sand. Studies of this group are not finished yet, and so there is no final clarity of its main features. At present two clearly different ecological groups are known: *epipsammon* unites organisms attached to the sandy grains, and *epipelon* includes free-living forms. Microalgae from both groups are common in microphytobenthos (Vilbaste, 2001), showing a tendency to a specific substrate. Epipsammon diatoms prefer all kinds of grooves on the sand grains to which they are attached by valve surface, outgrowths (species of genera *Attheya* T. West, *Cocconeis* Ehrenb.), or by short mucous threads (species of genus *Licmophora* Agardh). Free-living species usually move in the spaces between the grains of sand filled with water (*Navicula* Bory, *Diploneis* Ehrenb., *Nitzschia* Hassall, *Cymbella* Agardh, *Pleurosigma* W. Sm. et al.). We consider mezophytopsammon as a transitional community from microphytobenthos to aerophytons, having its own characteristics. In addition, we propose gradation in the degree of hydration of the substrate: hydropsammon (sandy bottom to a depth of 0.5 m), hygropsammon (splash zone − 1.3 m from the water towards the land), and eupsammon (dry zone on the surface of the sand − from 3 to 20 meters above the water line) (Wishnievski, 1934, cit. Sakharova, 1963). This approach is necessary in the development of techniques for the sampling and study of the influence of environmental factors on the distribution and biodiversity of mezophytopsammon.

The aim of the present work was to study species composition of *Bacillariophyta* of sandy spits of the northwestern part of the Black Sea (NWBS).

MATERIALS AND METHODS

Material for the present work was collected in the lakes situated on the side of the sea at Kinburn and Karolino-Bugaz (Dniester) sandy spits, and on the side of Budaki Lagoon at the Budakskaya spit (Fig. 1). Quantitative algological samples were collected in the summer of 2007–2008. Qualitative samples were collected during summer–autumn of 2005, autumn of 2007, spring–autumn of 2010, summer of 2011, and summer–autumn of 2013.

Microalgae were studied in the 2-cm surface layer of the sand. Sampling of mezophytopsammon (hydropsammon, hygropsammon, and eupsammon) was carried out by

a tube. The water's edge is the line of intersection of the water surface of the sea and land surface (Chebotarev, 1978). To fix the samples 4% formaldehyde was used. The samples were free of sand and silt as described in the literature (Aleksandyrov and Tarasenko, 2006).

For the quantitative analysis and species identification of *Bacillariophyta,* permanent preparations were produced using aniline-formaldehyde resin (Eliashev, 1957). For burning of the cell's organic content, we used hydrogen peroxide (Algae, 1989; Kovtun et al., 2012). Identification of *Bacillariophyta* was carried out using a light microscope Mikmed-5, Leica DME and camera Leica EC3, as well as a scanning electron microscope (SEM) Carl Zeiss EVO 40 XVP at the Institute of Arid Zones of RAS Southern Scientific Center (Rostov-on-Don, Russia).

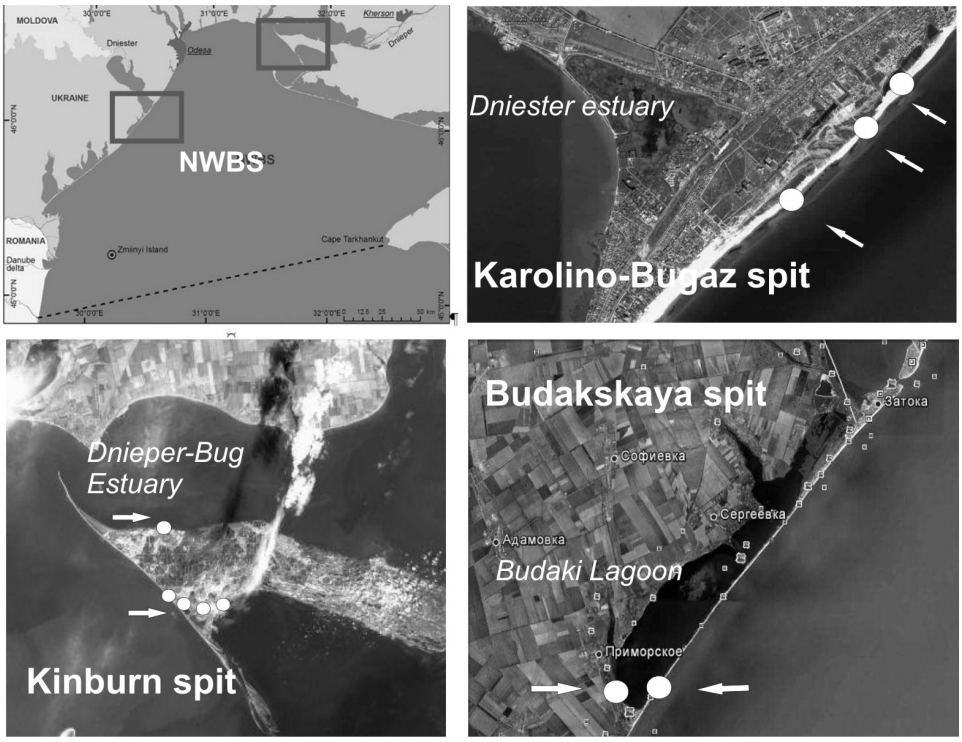

FIG. 1: Study area. O – sampling stations

For SEM study of *Bacillariophyta,* we developed an original method of cleaning and preparing the samples: the additional filtering of samples through the nuclear membrane filters Nucleopor (Track-Etch Membrane) with a pore diameter of 10 μm. Valves of

diatoms were purified from the organic content using standard methods (Diatoms ..., 1974). Since the samples of mezophytopsammon contained large amounts of pellet and silt particles, a thorough cleaning was necessary. For this purpose, samples were deposited on a filter and washed 3−4 times with distilled water. Subsequently, the filters were dried at room temperature and then fixed with an adhesive (based on colloidal silver) on a special table for studying samples in a SEM.

The nomenclature of *Bacillariophyta* is given according to Round et al. (1990) and AlgaeBase (www.algaebase.org). For identification, we used a number of publications: Zabelina et al., 1950; Krammer and Lange-Bertalot, 1991; Gusliakov et al., 1992; Snoeijs, 1993; Snoeijs and Vilbaste, 1994; Snoeijs and Potapova, 1995; Snoeijs and Kasperoviciene, 1996; Witkovski et al., 2000; Diatoms …, 2001; Levkov, 2009).

For the analysis of species diversity, we used Shannon (*H*) and Simpson (*D*) indices calculated by the following formulas:

$$H = -\Sigma\, n_i / N \cdot lg\, n_i / N;$$

$$D = 1 - (\Sigma\, n_i (n_i - 1)) / N (N-1),$$

where N – number of specimens, n_i – number of specimens of each species.

RESULTS AND DISCUSSION

In mezophytopsammon of the studied area 51 taxa of species and infraspecific ranks were revealed from 26 genera of *Bacillariophyta*. At the Kinburn spit 21 taxa were recorded, 23 taxa at Karolino-Bugaz, and 32 species and infraspecific taxa were found at the Budakskaya spit.

The most diverse genera in all studied sites were *Navicula* Bory, *Amphora* Ehrenb., *Cocconeis* Ehrenb., *Nitzshia* Hassall. Genera *Petroneis* Stick. et Mann, *Plagiotropis* Pfit., *Enthomoneis* Ehrenb., *Fallacia* Stick. et Mann and *Rhopalodia* O. Müll. were represented by single species, but, at the same time, dominant and subdominant species in the community were found. In mezophytopsammon the most abundant species were *Halamphora* aff. *salinicola, Navicula parapontica, Nitzschia frustulum, Planothidium delicatulum, Hippodonta* aff. *hungarica, Halamhpora coffeaeformis, Cocconeis placentula* var. *euglypta,* and *Anorthoneis hummii*. Species that were rarely found included *Astartiella bahusiensis*, *Delphineis minutissima*, *Caloneis liber*, *Pseudo-nitzschia pseudodelicatissima,* etc.

As a result of analyzing the literature data on taxonomic composition of benthic diatoms of the Black Sea (Wasser and Tsarenko, 2000; Nevrova and Gusliakov, 2006;

Nevrova and Liakh, 2006; Petrov and Nevrova, 2007; Microalgae …, 2008; Witkowski et al., 2010; Nevrova, 2013; Nevrova et al., 2013) five species first cited for the Northwestern part of the Black Sea were found (*Halamphora salinicola, Diploneis stroemii, Navicula viminoides* var. *cosmomarina*, *N. phylleptosoma*, and *Opephora minuta*) (Plates I, *6*; V, *2–4*, *8–9*; VI, *7*, *8*). Four species: *Achnanthes* cf. *lutheri*, cf. *Delicata* sp., cf. *Karayevia* sp., and *Hippodonta* cf. *hungarica* were not cited for the Black Sea, however, their precise identification needs additional studies.

The greatest species diversity of algae are observed in the interstitial areas of undisturbed sandy beaches (Gusliakov and Kovtun, 2000; Gusliakov, 2002; Kovtun, 2009). In such places sand "bloom" is commonly present, caused by abundant algal growth. Our study confirmed the presence of abundant sand "blooms" in the area of Kinburn, Karolino-Bugaz (Dniester), and Budakskaya spits. Microalgae actively develop on the surface and up to 2 cm in the sand depth in green or brown. Moisture and color of the sand varies depending on the distance from the water's edge.

In the splash zone (hydropsammone) sand is usually colorless, with a low number of microalgae due to the strong wave action. This zone is characterized by benthic and, to a lesser extent, adventive planktonic species from the pelagial: *Cylindrotheca closterium*, *Caloneis amphisbaena*, *Navicula parapontica*, *Halamphora coffeaeformis*, *Planothidium delicatulum*, *Hippodonta* cf. *hungarica*, etc.

At a distance of 2.3 m from the water edge (hygropsammon) sand is little moistened, greenish or brown in color. The most abundant taxa were *Cocconeis placentula* var. *euglypta*, *Halamphora coffeaeformis*, *H. salinicola*, *Navicula parapontica*, *Nitzschia frustulum*, *Planotidium delicatulum*, and *Amphora* sp. As it is seen from Fig. 2, in hygropsammon, we recorded the highest number of *Bacillariophyta* (12 million cells per cm^2). In eupsammon (dry on the surface, but moist at a depth of 0.5–2.0 cm sand where it has a greenish, yellow-brown coloring) at a distance of 5 m above the water line, the phytopsammon community was formed by *Achnanthes* cf. *lutheri*, and *Pinnularia* sp.

Along with the mobile species, such as representatives of the genera *Nitzschia*, *Rhopalodia*, *Mastogloia* Thw. ex W. Sm., *Navicula*, etc., inhabiting the interstitial portion of sand, the sand grains contain a large number of attached diatoms occurring on their surfaces, as well as in cracks and depressions. Kovtun (2009) has demonstrated that grains of sand are sometimes covered with a very small diatom (cells less than 10 µm) layer (species of *Nitzschia*, *Cocconeis*, *Amphora*, *Cymbella*, and *Fallacia*). Their identification is possible only using a SEM (Round and Bukhtiyarova, 1996). In the course of SEM study we revealed a number of small-celled diatoms previously not cited for this area, for example, *Astartiella bahusiensis*, cf. *Delicata* sp., *Delphineis minutissima, Fallacia cryptolyra*, *Navicula viminoides* var. *cosmomarina, Nitzschia ovalis,* and *Opephora* aff. *pacifica* (Table 1; Plates I–VIII).

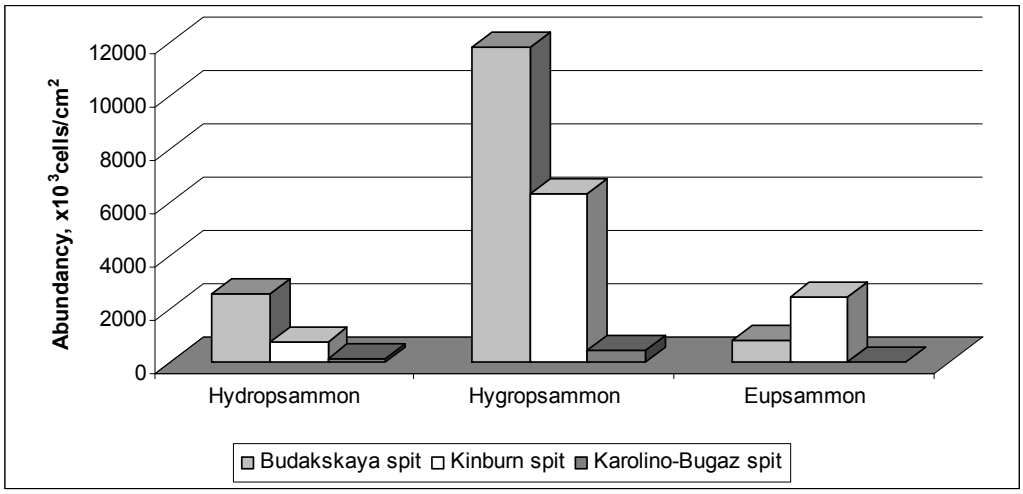

FIG. 2: Summer distribution of mesophytopsammon depending on the degree of sand hydration

The number of microalgae cells in the psammon communities depends on many ecological factors: the degree of moisture of the sand, its feed size distribution, wave action, temperature, etc. (Tarasenko and Aleksandrov, 2008). According to the data of 2007, number of mezophytopsammon at Budakskaya spit varied from 2.6 to 12 million cells per cm^2, at the Kinburn spit – 780–6330 thousand cells per cm^2, at the Karolino-Bugaz spit – 140–460 thousand cells per cm^2 (Fig. 2).

In the area of Budakskaya and Kinburn spits mass species were *Cocconeis placentula* var. *euglypta* (up to 3.8 million cells per cm^2), *Halamphora* cf. *salinicola* (up to 3.6 million cells per cm^2), *Nitzschia frustulum* (up to 1.8 million cells per cm^2), and *Halamhpora coffeaeformis* (up to 1.2 million cells per cm^2) (Table 2). In mezophytopsammon of the Karolino-Bugaz spit, the dominating species was *Navicula parapontica* (240 thousand cells per cm^2).

The data on the number of microalgae need further investigation, but at this stage it is possible to note the high number of *Bacillariophyta* cells in some biotopes yielding proof of their significant role in production processes of coastal systems of the Black Sea.

Quantitative assessment of species diversity was done using Shannon (*H*) and Simpson (*D*) indices (Fig. 3). The highest values of species diversity indices were noted in communities of hydropsammon and eupsammon of the Kinburn spit. This is understandable since it is part of the conservation area: Regional Landscape Park «Kinburn spit», where human influence is low. In this area, we identified the lowest number of taxa (21) compared to other studied sites. In the area of the Karolino-Bugaz spit, undergoing strong anthropogenic impact, species diversity of *Bacillariophyta* also were low. In the region of the Budakskaya spit, the greatest number of species were identified (32).

TABLE 1: Taxonomic composition, ecological and biological characteristics of *Bacillariophyta* on sand spits of the North-Western part of the Black Sea

Taxon	Location			Ecology			Saprobity	Distribution
	Kinburn spit	Karolino-Bugaz spit	Budakskaya spit	Biotope	Halobity	Relation to pH		
Achnanthes cf. *lutheri* Hust.			EU					
Amphora cf. *pediculus* (Kütz.) Grunow			HG	epipe, epili	i	alkf	χ	a-b
A. commutata Grunow		HG	HD, EU	epipe	mh	alkf		b
A. graeffeana Hendey		HG	HD	bn	mh	alkf		b-t
Amphora proteus Greg.		HG	HD	epipe	ph	alkf	β	b
Anorthoneis hummii Hust.	HG		HG	bn, epili	ph	alkf	β-α	b
Attheya decora West	HG			epips	mh			
Astartiella bahusiensis (Grunow) Witkowski, Lange-Bert. et Metzeltin		HG		epips				sh
Caloneis amphisbaena (Bory) Cleve			HD	epipe	hl	alkf	β	sh-b
C. liber (W. Sm.) Cleve			HD	bn	ph	alkf		sh-b
Cocconeis notata Petit	HG			bn	ph	alkf		sh-b
C. peltoides Hust.	HG			epips				sh
C. placentula var. *euglypta* (Ehrenb.) Grunow		HG	HD	epiph, epili	i	alkf	o	sh
C. scutellum Ehrenb.	HG		HD	epiph	ph	alkf	β	b
Cylindrotheca closterium (Ehrenb.) Reimann et J.C. Lewin				pl, epili, epiph, epipe	mh	alkf	β	sh
cf. *Delicata* sp.		HG						
cf. *Karayevia* sp.	HG		HG					
Delphineis minutissima (Hust.) Simonsen	HG		HD	litt	ph			sh

Continuation of Table 1

Diploneis aff. *smithii* (Bréb.) Cleve			EU	epipe	ph	alkf		b
Diploneis stroemii Hust.		HG		epipe				
Entomoneis alata (Ehrenb.) Reimer		HG		litt	mh			sh
Fallacia cryptolyra (Brockmann) Stickle et Mann (= *Fallacia phyllophorae* Gusl. sp. nov.)		HG		epipe	ph			
Halamphora coffeaeformis (Agardh) Levkov		HG	HD	epipe, epiph	mh	alkf	α	sh
H. salinicola Levkov et Díaz	HG	HG	HG		hl			
Hippodonta cf. *hungarica* (Grunow) Lange-Bert., Metzeltin et Witkowski	HG		HG		hl	alkf		sh
Mastogloia pumila (Cleve et Möller) Cleve	HG	HG		epipe, epili	hl	alkf		b
Navicula aff. *cryptocephala* var. *veneta* (Kütz.) Rabenh. (= *Navicula veneta* Kütz.)	HG	HG		epipe	hl	alkf	es	sh
N. cancellata Donkin	HG			bn				
N. viminoides var. *cosmomarina* Lange-Bert., Witkowski, Bogaczewicz-Adamczak et Zgrundo	HG		HG	epips				
N. parapontica Witkowski, Kulikovskiy, Nevrova et Lange-Bert.	HG		HG, HD	litt	ph			
N. phylleptosoma Lange-Bert.		HG	HG	epipe	mh	alkf		sh
N. pontica (Mereschk.) Witkowski, Kulikovskiy, Nevrova et Lange-Bert.		HG		litt	mh			e
Navicula salinarum Grunow	HD			epipe	mh	ind	α	sh
Navicula sp.			HG					
Navicymbula pusilla (Grunow) K. Krammer			EU	epipe-epili	hl		o	sh

End of Table 1

Nitszchia sp.	HG		HG					
N. frustulum (Kütz.) Grunow			HG	epili	hl	alkf	es	b
N. ovalis H.J. Arn.			HG		mh	alkf		b
N. paleacea Grunow			HG	epili	oh			
N. punctata var. *minutissima* Poretzky			EU		ph	alkf		sh
Opephora aff. *pacifica* (Grunow) Petit		HG			ph			
O. minuta (Cleve-Euler) Witkowski		HG		litt	ph			
O. mutabilis (Grunow) Sabbe et Vyvermann		HG	HD, EU		mh			
Petroneis humerosa (Bréb. ex W. Smith) A.J. Stickle et D.G. Mann		HG	HG	epipe	ph	alkf		b
Pinnularia sp.		HG	EU					
Plagiotropis lepidoptera (Greg.) Kuntze	HG	HG	HD	epipe	ph	alkf	o	sh-b
Planothidium delicatulum (Kütz.) Round et Bukht.	HG	HG	HD	bn	hl	alkf	β	sh
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle	HG							
Rhoicosphenia abbreviata (C. Agardh) Lange-Bert.	HG			epiph, epili	mh			
Rhopalodia musculus (Kütz.) O. Müll.	HG	HG	HD, EU	bn	mh	ind	β	b
Tabularia fasciculata (C. Agardh) D.M. Williams et Round	HG			epiph	mh	ind	α	sh

Ecological and biological characteristics are given according to Diatom ..., 1950; Gusliakov et al., 1992; Kovaleva, 2005; Krammer and Lange-Bertalot, 1991; Snoeijs, 1993; Snoeijs and Vilbaste, 1994; Snoeijs and Potapova, 1995; Snoeijs and Kasperoviciene, 1996; Witkovsky et al., 2000; Diatoms …, 2001; Vilbaste, 2001; Levkov, 2009.

Biotope: pl – plankton, bn – benthos , epiph – epiphyton, epili– epilithon, epipe – epipelon, epips – epipsammon, litt – littoral, HG – hygropsammon, HD – hydropsammon, EU – eupsammon.

Halobity: oh – oligohalobe: hl – halophylic, i – indifferent, mh – mesohalobe, ph – polihalobe.

Reaction on pH of environment: ind – indifferent, alkf – alcaliphylous.

Saprobity: α – α-mesosaprobe, β – β-mesosaprobe, β-α – mesosaprobe, o – oligosaprobe, χ – xenosaprobe, es – eurisaprobe.
Distribution: sh – widely distributed (cosmopolites), sh-b – widely-boreal, b – boreal, a-b – arctic-boreal, b-t – boreal-tropical, e – endemics.

TABLE 2: Number of *Bacillariophyta* (thousand of cells/cm^2) of sand spits in the North-Western part of the Black Sea depending on the degree of hydration of sand

Taxon	Hydropsammon	Hygropsammon	Eupsammon
Achnahtes sp.	34 (Ki)	–	–
Achnanthes cf. *lutheri*	–	–	199 (B)
Anorthoneis sp.	–	549 (Ki)	–
Caloneis amphisbaena	229 (B)	–	–
Caloneis sp.	–	–	182 (Ki)
Cocconeis placentula var. *euglypta*	–	3836 (B)	–
Cylindrotheca closterium	13 (K-B); 62 (Ki)	41 (K-B)	–
Delphineis minutissima	183 (B)	–	–
Halamhpora coffeaeformis	76 (B)	1189 (B)	182 (Ki)
Halamphora cf. *salinicola*	–	2302 (B), 3580 (Ki)	–
Hippodonta cf. *hungarica*	887 (B)	–	–
Navicula parapontica	49 (K-B)	241 (K-B); 652 (B)	–
Pinnularia sp.	–	–	38 (B);182 (Ki)
Navicula sp. 1	15 (K-B)	41 (K-B)	–
Navicula sp. 2	642 (B)	–	–
Nitzschia frustulum	–	648 (Ki); 1841 (K-B)	1182 (Ki)
Petroneis humerosa	6 (K-B)	–	–
Planothidium delicatulum	85 (Ki)	384 (B)	182 (Ki)
Pleurosigma sp.	23 (K-B)	–	–
Rhoicosphenia abbreviata	34 (Ki)	–	–
Tabularia fasciculata	68 (Ki)	–	–

L e g e n d : B – Budakskaya spit, Ki – Kinburn spit, K-B – Karolino-Bugaz spit.

Furthermore, a diversity of microalgae varies depending on the distance from the water edge. In the area of the Budakskaya spit, we observed a rise of *H* and *D* index values in hygropsammon with a further decrease in eupsammon (Fig. 3). In other areas, we observed loss of biodiversity in hygropsammon; that is not typical for phytopsammon.

An important question is whether there are specific species of mezophytopsammon *Bacillariophyta*. As mentioned previously (Gusliakov, 2002), many species regularly or occasionally inhabit space between sandy grains (interstitial). Some species are allochthonous, but some period of time they can occur in untypical for them biotope being in not active viable state (Kovtun, 2009). We may refer to typically psammophylic forms *Attheya decora* West., recently found in the Black Sea (Tarasenko and Terenko, 2008), *Astartiella bahusiensis* (Plate I, *2*), *Navicula viminoides* var. *cosmomarina* (Plate V, *2–4*), and *Cocconeis peltoides* (Plate II, *6*).

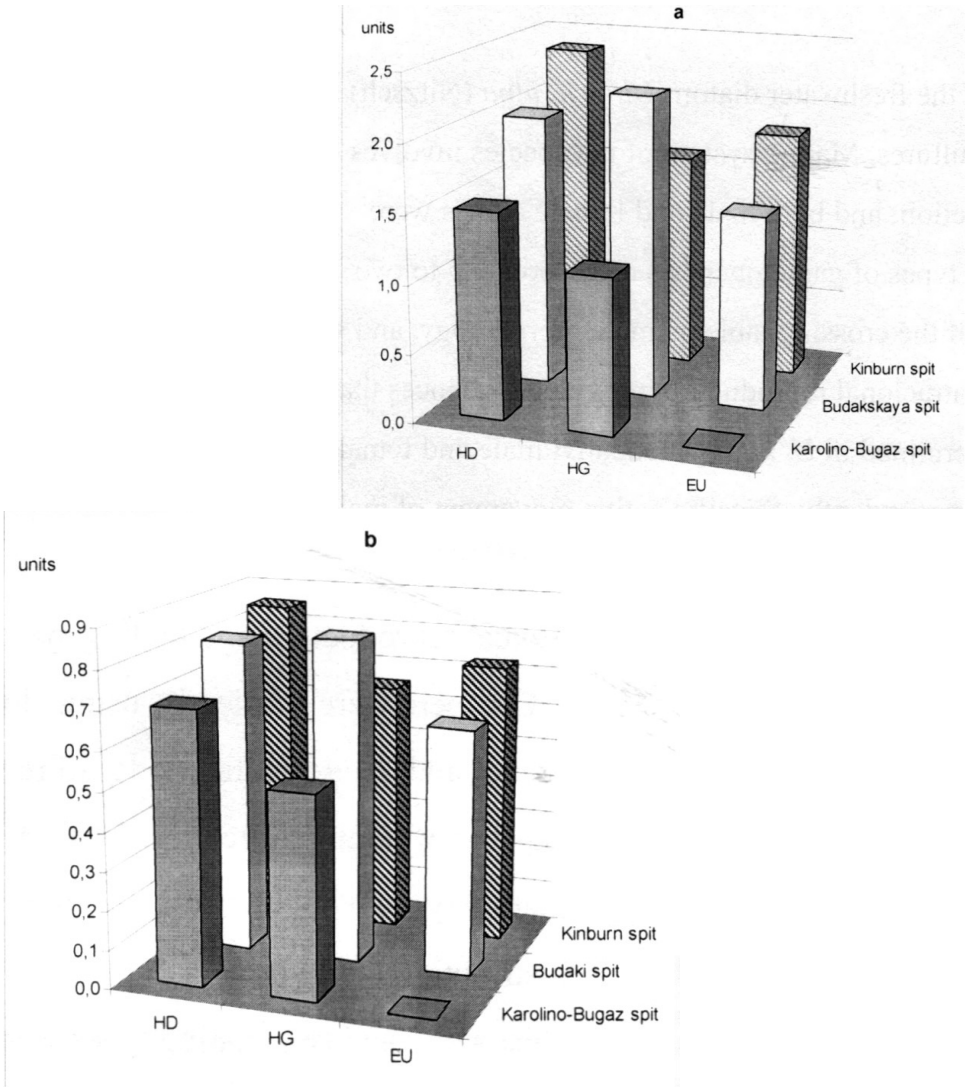

FIG. 3: Changing of Shannon (*a*) and Simpson (*b*) species diversity indices at the sand spits in hydropsammon (HD), hygropsammon (HG), and eupsammon (EU)

The highest number (35%) of detected species in the study area were freely moving, unattached species. Obviously, this is due to low activity of the waves at the sampling stations and a high degree of silting at some of them. Revealed species of *Bacillariophyta* also were represented by benthic (25%), epilithic (19%), and epiphytic (13%) forms (Table 1). Epipsammon made up 8% of species found.

TABLE 3: Morphological variability of some species of *Bacillariophyta* in study area

Taxon	Cell length, µm		Cell width, µm		Number of stria		Location	Biotope
Achnanthes cf. *lutheri*	9	8–15*	5	4.5–7*	20	12–16*	B	EU
	18		8		16		B	EU
	23–24		9		16		B	EU
Amphora proteus	37.5	56–83**	10	9–11**	15	11–13**	B	HD
	40		10		14		K-B	HG
Hippodonta cf. *hungarica*	21.5	10–30***	5.5	5–7***	11	8–10***	B	HG
	17.5		6		12–14		Ki	HG
Mastogloia pumila	25	20–30***	7.5	5–9***	26–27	25–30***	Ki	HG
	28		7.5		28		Ki	HG
	13		6		26–28		K-B	HG
Navicula parapontica	24	22–38****	5	5–6****	15	12–14****	Ki	HG
	28		5		14		B	HD
	17		5		13		B	HD
	21		4		15		B	HD
	15		5		13.5–14		B	HD
Opephora mutabilis	25	7–60***	5	2,5–7***	16–18	8–16***	B	EU
	9		4		14–16		K-B	HG
	11.5		2.5		14		B	HD
	10		7.5		14		K-B	HG
Planothidium delicatulum	10–11	7–20***	5–5.5	4–8***	15–18	14–16***	Ki	HG
	12.5		6		16		K-B	HG
Navicula pontica	52.5	34–70****	10	6–10****	10	7–10****	K-B	HG

R e m a r k s : * – after Krammer and Lange-Bertalot, 1991; ** – after Levkov, 2009; *** – after Witkowski, 2000; **** – after Witkowski et al., 2010. B – Budakskaya spit, Ki – Kinburn spit, K-B – Karolino-Bugaz spit. HG – hygropsammon, HD – hydropsammon, EU – eupsammon.

In terms of halobity, in the studied area, we revealed representatives of all known groups with some predominance of polihalobes (35%) and mesohalobes (35%) (Proshkina-Lavrenko, 1953). Oligohalobes included halophyles (20%) and indifferents (8%) (Table 1).

Several species of diatoms found in various parts of studied areas differed in their morphological characteristics (length and width of cells, the number of ribs and areola) (Table 3). For some of them, it is probably necessary to expand the description. For example, valves of *Amphora proteus* had some features similar to those of *A. marina*, but according to results of the SEM study (the presence of hyaline band) they should be referred to as *A. proteus* (Plate II, *3*). Cells of *A. greaffeana* were thinner than the previously mentioned (Gusliakov et al., 1992) (Plate II, *2*). Valves of *Mastogloia pumila* from Kinburn and Karolino-Bugaz spits differed in the number of chambers (Plate IV, *5*–7).

In Table 3 morphological parameters of certain species of mezophytopsammon are given. Species identification of some of them, such as *Achnanthes* cf. *lutheri* and *Hippodonta* cf. *hungarica* (Plate IV, *1–4*), need to be clarified, since the number of stria, to some extend, exceeds the data presented in the literature. However, according to other features (structure of areola, cell shape), they should probably be attributed to these species. Data on other species, such as *Navicula parapontica* and *N. pontica* (Plate V, *1*, *5*), are of interest because previously (Witkowski et al., 2010) both of them were described on the basis of the species *N. pennata* var. *pontica,* and information about their structure and distribution is extremely limited.

CONCLUSIONS

Flora of sandy spits of the northwestern part of the Black Sea is characterized by rich species composition of diatoms forming an independent ecological group, such as plankton or benthos. In mezophytopsammon of studied areas 51 taxa of species and infraspecific rank from 26 genera of *Bacillariophyta* were recorded. *Halamphora salinicola, Diploneis stroemii, Navicula viminoides* var. *cosmomarina, N. phylleptosoma,* and *Opephora minuta* are now sited for the NWBS area. The taxonomy of four more species requires clarification.

The most diverse composition of diatoms was recorded in the samples from the Budakskaya spit (32), the least – in the Kinburn area (21). With respect to the mode of life, mobile unattached diatoms dominated (35% of all identified microalgae); inhabitants of epipsammon made up 8%.

The number of mezophytopsammon can reach 12 million of cells/cm^3, which proves its significant role in the production processes of coastal systems of the Black Sea. Qualitative and quantitative characteristics of mezophytopsammon vary depending on the degree of hydration of sand: the greatest abundance and biodiversity of microalgae was observed in the area of moist sand at a distance of 1–2 meters from the water's edge.

Mezophytopsammon communities of sandy spits of the NWBS require further investigations. It is necessary to conduct a more in-depth analysis of the taxonomic composition and quantitative characteristics of their components.

ACKNOWLEDGMENTS

The work was performed as part of the Grant RFBR N 13-04-90941. The authors are grateful to Prof. of I.I. Mechnikov Odessa National University, Dr. B.G. Aleksandrov for valuable comments in the preparation of article, Senior Research Fellow of the A.O. Kovalevsky Institute of Biology of the Southern Seas., Ph.D. E.L. Nevrova for advice in the identification of species, and to Senior Research Fellow of the Institute of Arid Zones SSC RAS, Ph.D. K.V. Dvadnenko for help in the SEM study.

REFERENCES

Aleksandrov B.G. and Tarasenko A.A., On the problem of studying microalgae of sand supralittoral, in: *Mat. XII Ukr. Bot. Soc. Congr.* (May 15–18, 2006, Odessa), p. 186, 2006. [Rus.]

Algae: Reference book, Wasser S.P. (ed.), Nauk. Dumka Press, Kiev, 1989. [Rus.]

Chebotarev A.I., *Hydrological Dictionary*, Hydrometeoizdat Press, Leningrad, 1978. [Rus.]

Diatoms of Europe, Lange-Bertalot H. (ed.), Vol. 2, *Navicula* sensu stricto, 10 genera separated from *Navicula* sensu lato *Frustulia*, GFV, Stuttgart, 2001.

Diatoms of the USSR, Nauka Press, Leningrad, 1974. [Rus.]

Dubyna D.V., Tymoshenko P.A., and Sheliag-Sosonko Yu.R., Phytosystems of spits and islands of Azov-Black Sea region of Ukraine, *Ukr. Bot. J.,* **63**(1):3–1, 2006**.**

Eliashev A.A., Simple technique of preparation of highly refracting medium for diatom analysis, *Trudy NII Geol. Arctic,* (4):74–76, 1957.

Gusliakov M.O., *Diatoms in benthos of the Black Sea and adjacent water bodies* (*morphology, taxonomy, ecology, biogeography*), Abstr. Dr. Sci. (Biol.) Thesis, Kyiv, 2002. [Ukr.]

Gusliakov M.O. and Kovtun O.O., Algae of mesophytopsammon of the Black Sea, *Visn. ONU*, 5(1):129–134, 2000.

Gusliakov N.E., Zakordonets O.A., and Gerasimyuk V.P., *Atlas of diatoms of benthos of the northwestern Black Sea coastal and adjacent water bodies*, Nauk. Dumka, Kiev, 1992. [Rus.]

Kovaleva G.V., Microalgae of Lake Abrau (Krasnodar Region), *Bot. J.,* 90(5):681–695, 2005.

Kovtun O.O. *Ecological, biological, morphological and taxonomical chatacteristics of the Tiligul Estuary phytobenthos*, Abstr. Ph.D. (Biol.) Thesis, Odessa, 2009. [Ukr.]

Kovtun O.O., Snigireva A.O., and Bilous O.P., *Guidelines for the study of phytomicrobenthos and periphyton*, Odessa, 2012. [Ukr.]

Krammer K. and Lange-Bertalot H., *Bacillariophyceae*. 4. Teil: *Achnanthaceae*. Kritische Erganzungen zu *Navicula* (*Lineolatae*) und *Gomphonema* Gesamtliteraturverzeichnis, in: *Süßwasserflora von Mitteleuropa*, GFV, Stuttgart, 1991.

Levkov Z.l., *Diatoms of European Inland Waters and Comparable Habitats*, Vol. 5, Lange-Bertalot H. (ed.), A.R.G. Gantner Verlag K.-G., Ruggell, 2009.

Microalgae of the Black Sea: Problems of biodiversity conservation and biotechnological use, Tokarev Yu.N., Finenko Z.Z., and Shadrin N.V. (eds.), ECOSY-Hydrophysics Press, Sevastopol, 2008. [Rus.]

Nevrova E.L., Structure and taxonomic diversity of benthic diatoms from the mouth portions of Belbek and Chornaya rivers (South-Western Crimea, Ukraine), *Algologia,* **23**(4):471–492, 2013.

Nevrova E.L. and Gusliakov, N.E., *Bacillariophyta* species new for Crimea and rare for the Black Sea, *Mor. Ecol. J.*, **5**(4):64–71, 2006.

Nevrova, E. L. and Liakh A.M., New and noteworthy records of benthic diatoms (*Bacillariophyta*) from the Black Sea and estimation of their biomass using 3D modelling, *Ecol. Mor.,* 72:30–37, 2006.

Nevrova E., Witkowski A., Kulikovskiy M., Lange-Bertalot H., and Kociolek J.P., A revision of the diatom genus *Lyrella* Karayeva (*Bacillariophyta*: *Lyrellaceae*) from the Black Sea, with descriptions of five new species, *Phytotax*, 83(1):1–38, 2013. http://dx.doi.org/10.11646 /phytotaxa.83.1.1

Petrov A. and Nevrova E., Database on Black Sea benthic diatoms (*Bacillariophyta*): its use for a comparative study of diversity pecularities under technogenic pollution impacts, Proc. Ocean Biodiversity Informatics, Int. Conf. on Mar. Biodiversity Data Management, Hamburg, Germany (29 November – 1 December, 2004), *VLIZ*, Spec. Publ., 37:153–165, 2007.

Proshkina-Lavrenko A.I., *Diatoms – indicators of water salinity. Diatom collection*, LGU Press, Leningrad, 186–205, 1953. [Rus.]

Round F.E. and Bukhtiyarova L., Epipsammic diatoms – communities of British Rivers, *Diatom Res.*, 11(2):363–372, 1996.

Round F.E., Crawford R.M., and Mann, D.G., The Diatoms. Biology and morphology of the genera, Cambridge Univ. Press, Cambridge, 1990.

Sakharova M.I., Microbenthos of sandy beaches of Uchinsky Reservoir, in: *Uchinsky and Mozhaisk Reservoirs*, MGU Press, Moscow, pp. 39–55, 1963.

Snoeijs P., *Intercalibration and distribution of diatom species in the Baltic Sea*, Vol. 1, Opulus Press Upps. (Sweden), 1993.

Snoeijs P. and Kasperoviciene J., Intercalibration and distribution of diatom species in the Baltic Sea, Vol. 4, Opulus Press Upps. (Sweden), 1996.

Snoeijs P. and Potapova M., Intercalibration and distribution of diatom species in the Baltic Sea, Vol. 3, Opulus Press Upps. (Sweden), 1995.

Snoeijs P. and Vilbaste S., Intercalibration and distribution of diatom species in the Baltic Sea, Vol. 2, Opulus Press Upps. (Sweden), 1994.

Tarasenko A.A. and Aleksandrov B.G., The effect of physical and chemical factors on quantitative characteristics of microalgae on sandy beaches of Odessa, in: *Modern problem of algol*., Mat. Int. Conf. and VII School on Marine Biology (June 9–13, 2008, Rostov-on-Don), SSC RAN Press, Rostov-on-Don, pp. 347–350, 2008.

Tarasenko A.A. and Terenko L.M., Peculiarities of ecology and distribution of diatom *Attheya decora* West, 1860 in Odessa Bay (the Black Sea), *Visn. Odessa Nat. Univer.*, 13(14):111–117, 2008.

Vilbaste S., Benthic diatom communities in Estonian Rivers, *Boreal Environ. Res*. 6:191–203, 2001.

Wasser S.P. and Tsarenko P.M. (eds.), Diversity of algae in Ukraine, *Algologia*, 10(4):1–309, 2000.

Witkowski A., Lange-Bertalot H., and Metzeltin D., Diatom flora of marine coasts, Pt I, in: *Iconographia Diatomologica*, A.R.G. Gantner, Ruggell, Vol. 7, 2000.

Witkowski A., Kulikovskiy M., Nevrova E., Lange-Bertalot H., and Gogorev R., The genus *Navicula* in ancient basins. I. Two novelties from the Black Sea, *Plant Ecol. and Evol.*, 143(3):307–317, 2010.

Zabelina M.M. Kiselev I.A., Proshkina-Lavrenko A.I., and Sheshukova V.S., *Diatom analysis. Identification manual of fossil and modern algae*, Gosizdat Geol. Lit, Moscow, Vol. 3, 1950. [Rus.]

Zaitsev Yu., A key role of sandy beaches in the marine environment, *J. Black Sea/Mediter. Environ*., 18(2):14–127, 2012.

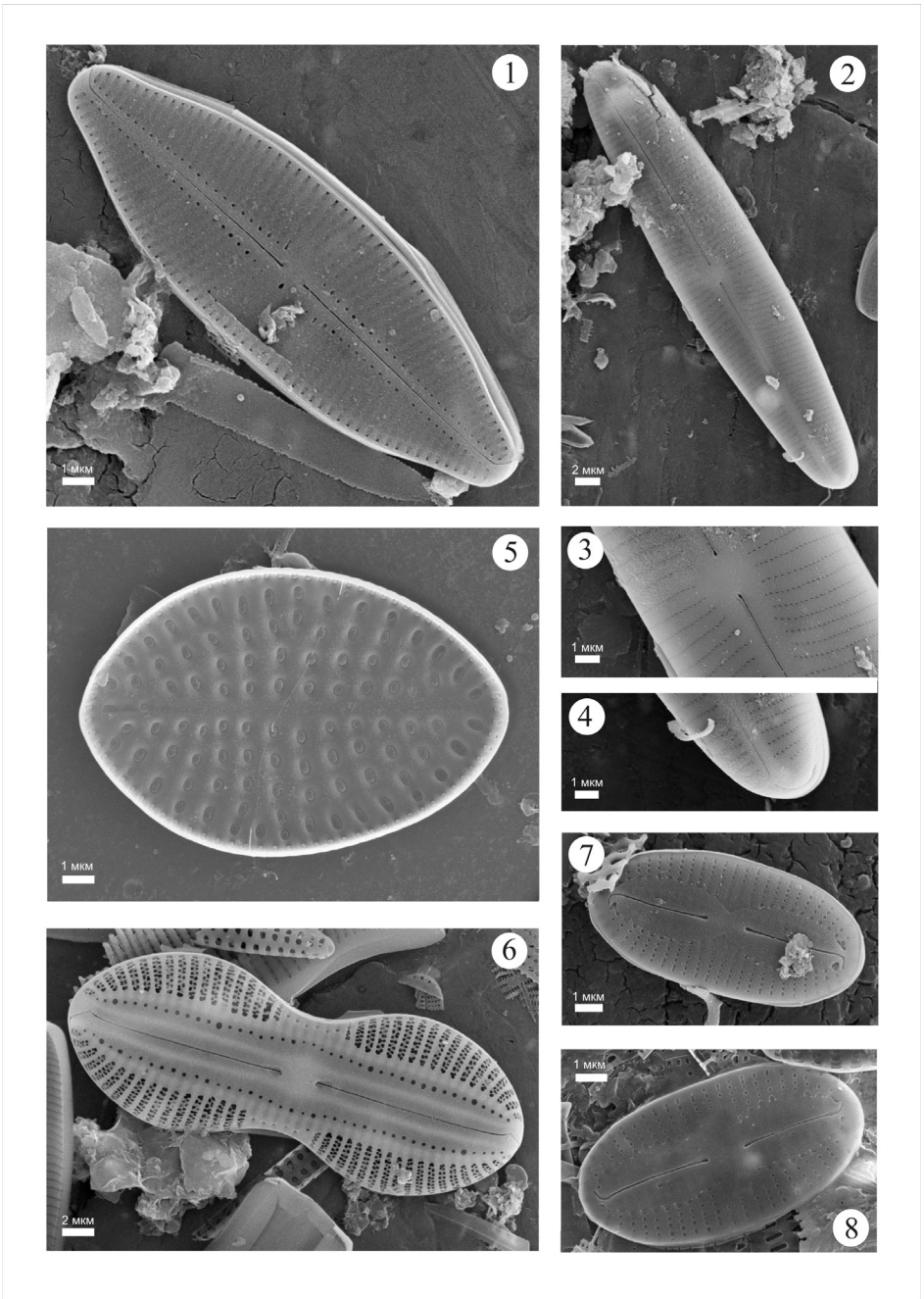

Plate I. *Bacillariophyta* of mezophytopsammon of the NWBS coast: *1 – Astartiella bahusiensis* (Karolino-Bugaz spit); *2–4 – Delicata* sp. (Karolino-Bugaz spit); *5 – Delphineis minutissima* (Kinburn spit); *6 – Diploneis stroemii* (Karolino-Bugaz spit); *7*, *8 – Fallacia cryptolyra* (*7* – Karolino-Bugaz spit, *8* – Budakskaya spit)

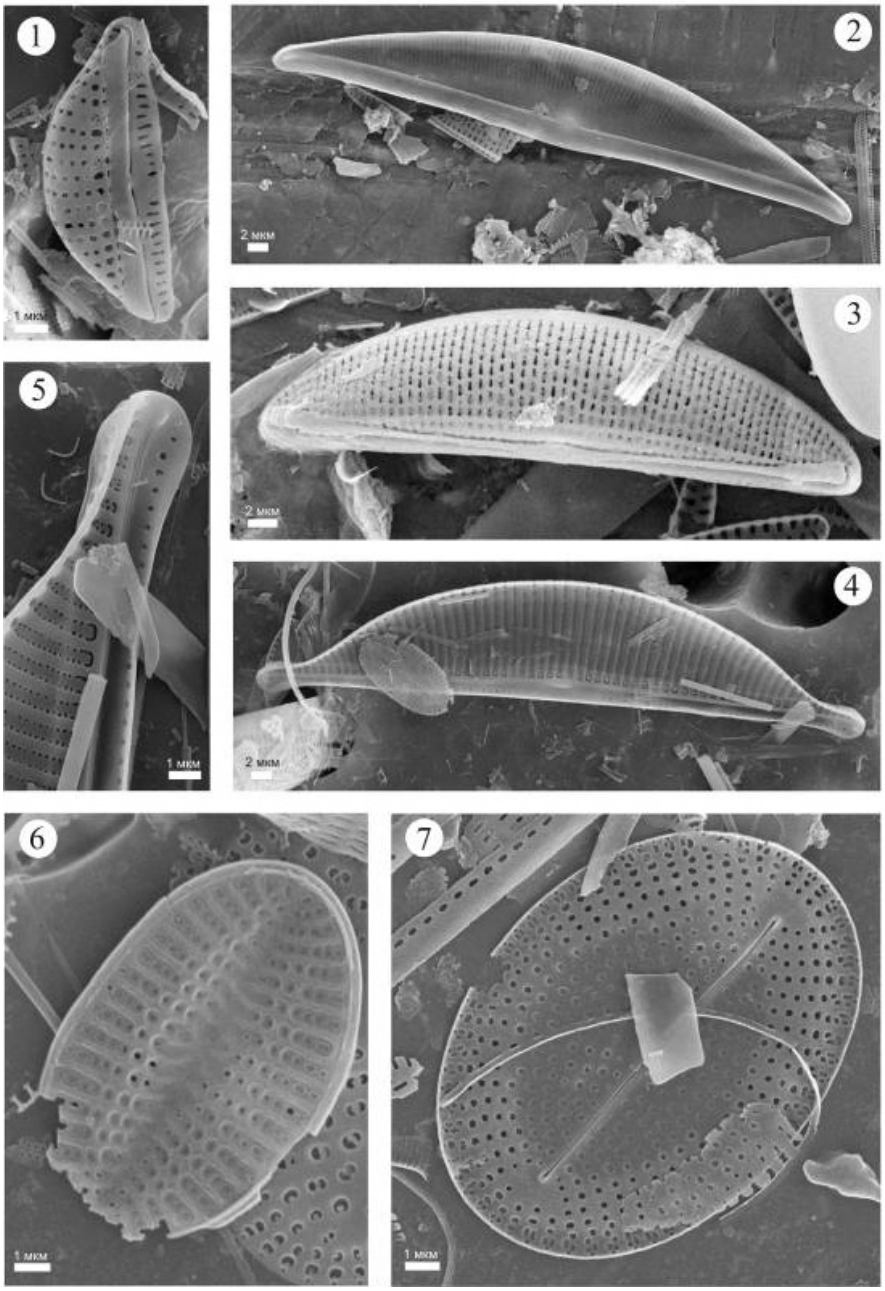

Plate II. *Bacillariophyta* of mezophytopsammon of the NWBS coast: *1* – *Amphora* cf. *pediculus* (Budakskaya spit); *2* – *Amphora graeffeana* (Karolino-Bugaz spit); *3* – *Amphora proteus* (Karolino-Bugaz spit); *4*, *5* – *Halamphora coffeaeformis* (Budakskaya spit); *6* – *Cocconeis peltoides* (Kinburn spit); *7* – *Anorthoneis hummii* (Kinburn spit)

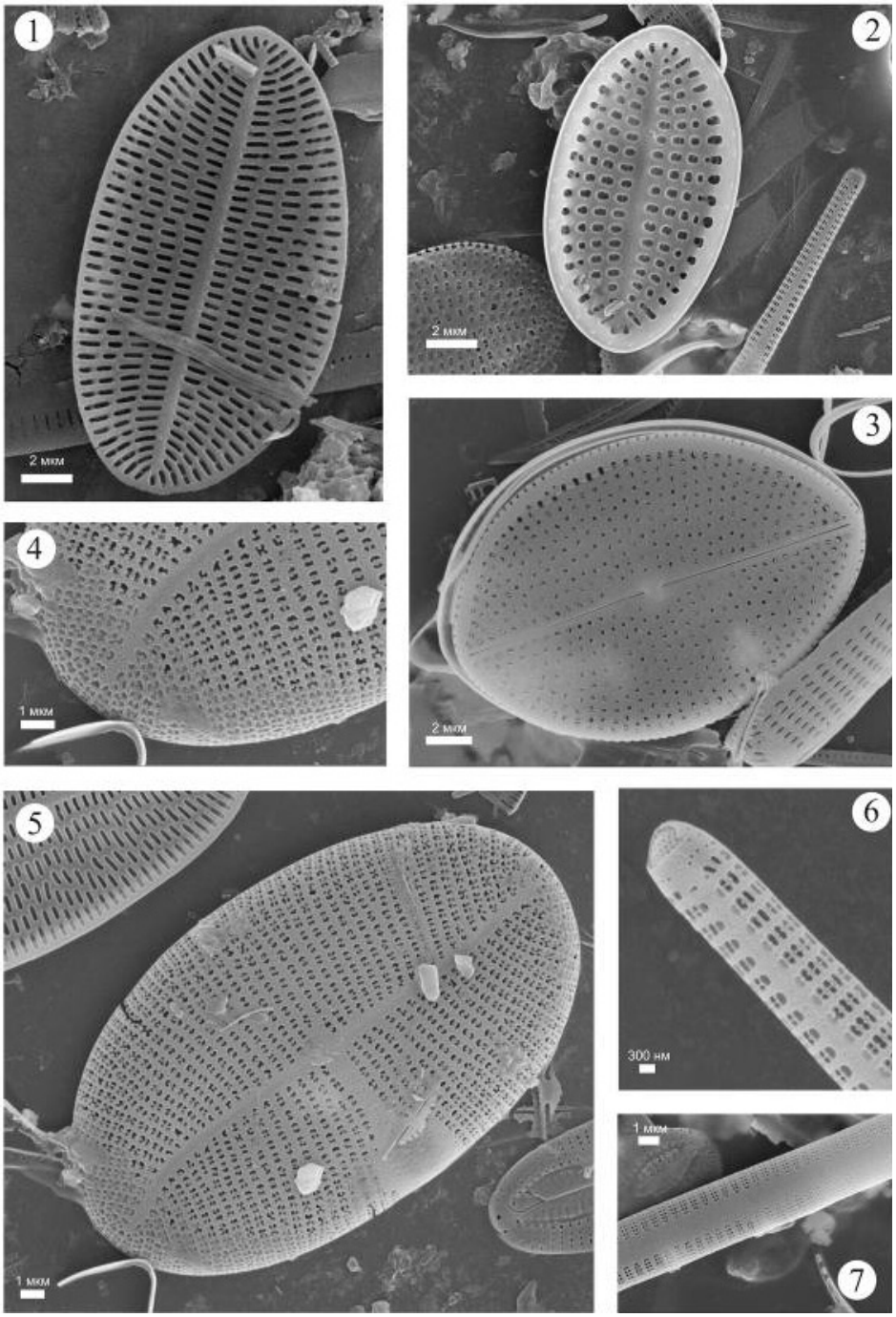

Plate III. *Bacillariophyta* of mezophytopsammon of the NWBS coast: *1 – Cocconeis placentula* var. *euglypta* (Karolino-Bugaz spit); *2*, *3 – Cocconeis scutellum* (Kinburn spit); *4*, *5 – Cocconeis notata* (Kinburn spit); *6*, *7 – Tabularia fasciculata* (Kinburn spit)

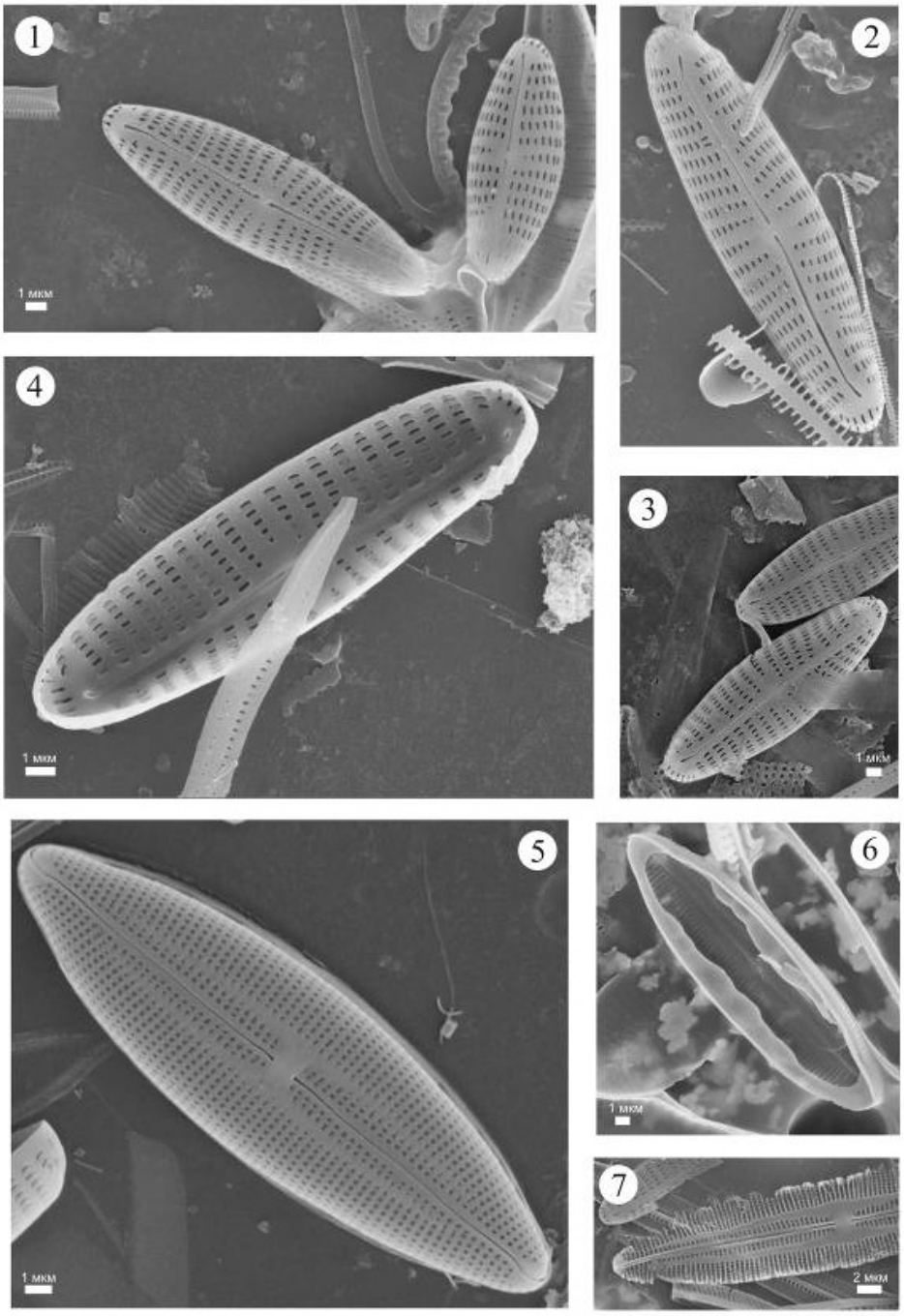

Plate IV. *Bacillariophyta* of mezophytopsammon of Kinburn spit: *1–4 – Hippodonta* cf. *hungarica* (*4* – internal side of valve); *5–7 – Mastogloia pumila*

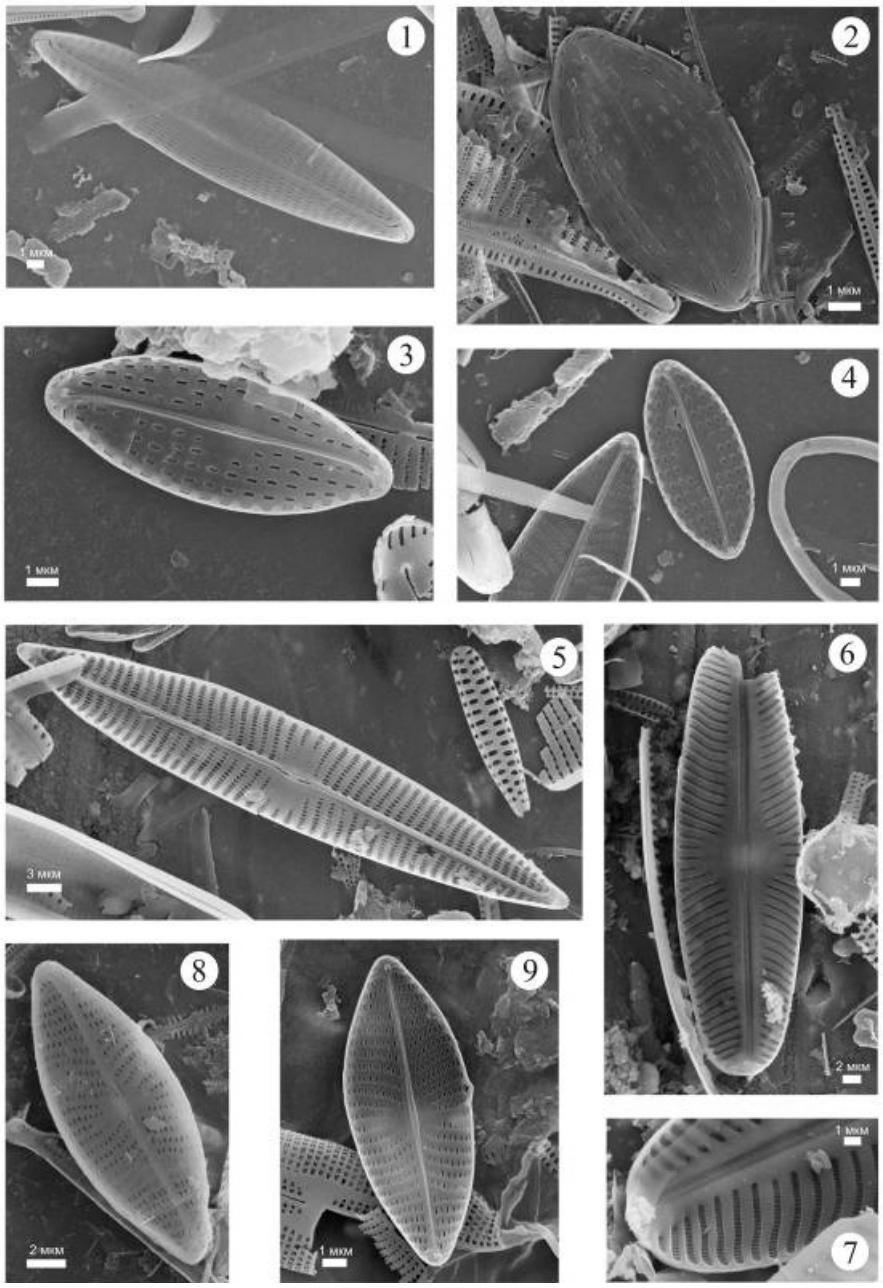

Plate V. Representatives of genus *Navicula* of mezophytopsammon of the NWBS coast; *1 –Navicula parapontica* (Kinburn spit); *2–4 – N. viminoides* var. *cosmomarina* (*2* – Budakskaya spit; *3*, *4* – Kinburn spit); *5 – Navicula pontica* (Karolino-Bugaz spit); *6*, *7 – Pinnularia* sp. (Karolino-Bugaz spit); *8*, *9 – Navicula phylleptosoma* (*8* – Budakskaya spit, *9* – Kinburn spit)

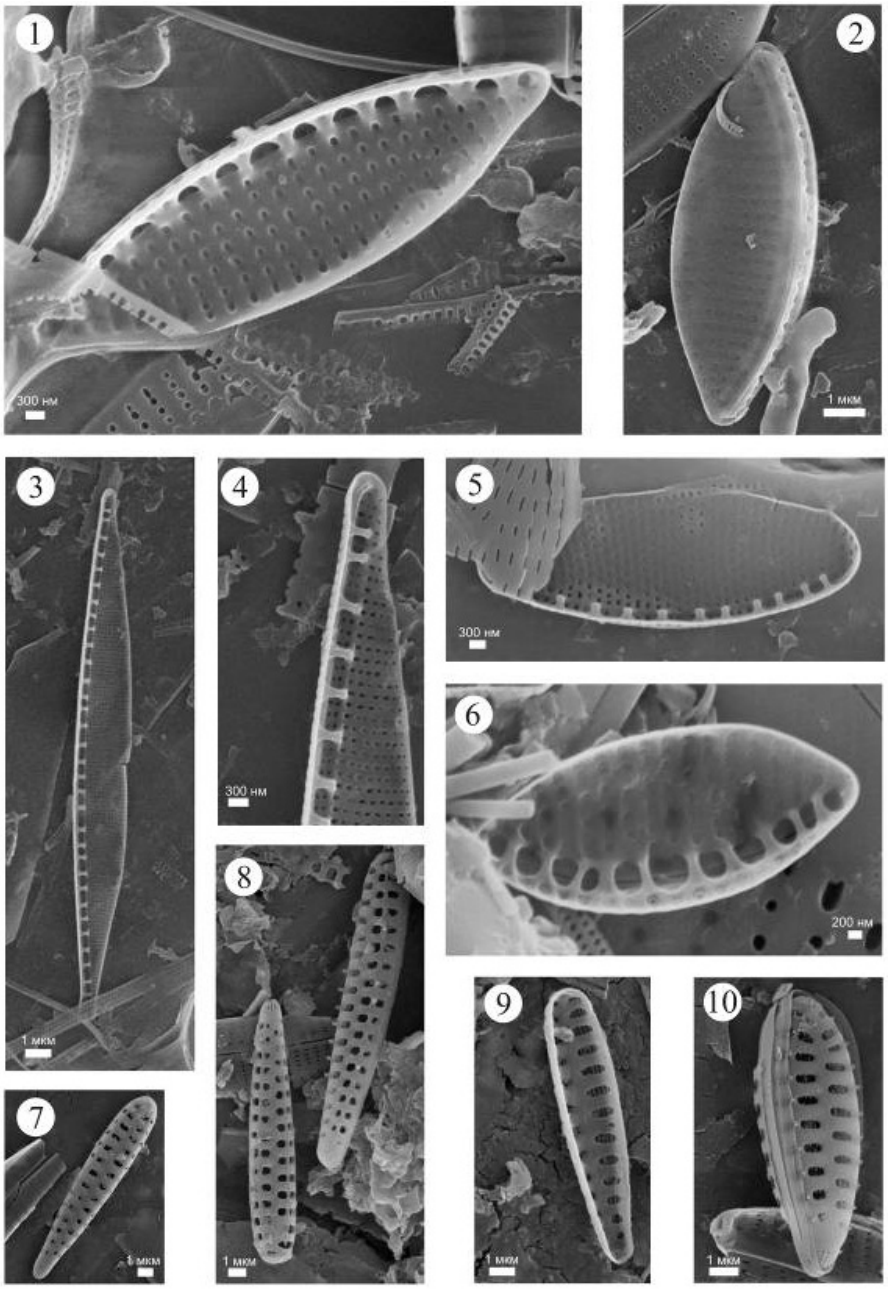

Plate VI. *Bacillariophyta* of mezophytopsammon of the NWBS coast: *1–2 – Nitzschia frustulum* (Budakskaya spit); *3–4 – Nitzschia paleacea* (Budakskaya spit); *5 – Nitzschia* sp. 3 (Budakskaya spit); *6 – Nitzschia ovalis* (Budakskaya spit); *7*, *8 – Opephora minuta* (Karolino-Bugaz spit); *9*, *10 – Opephora mutabilis* (Karolino-Bugaz spit)

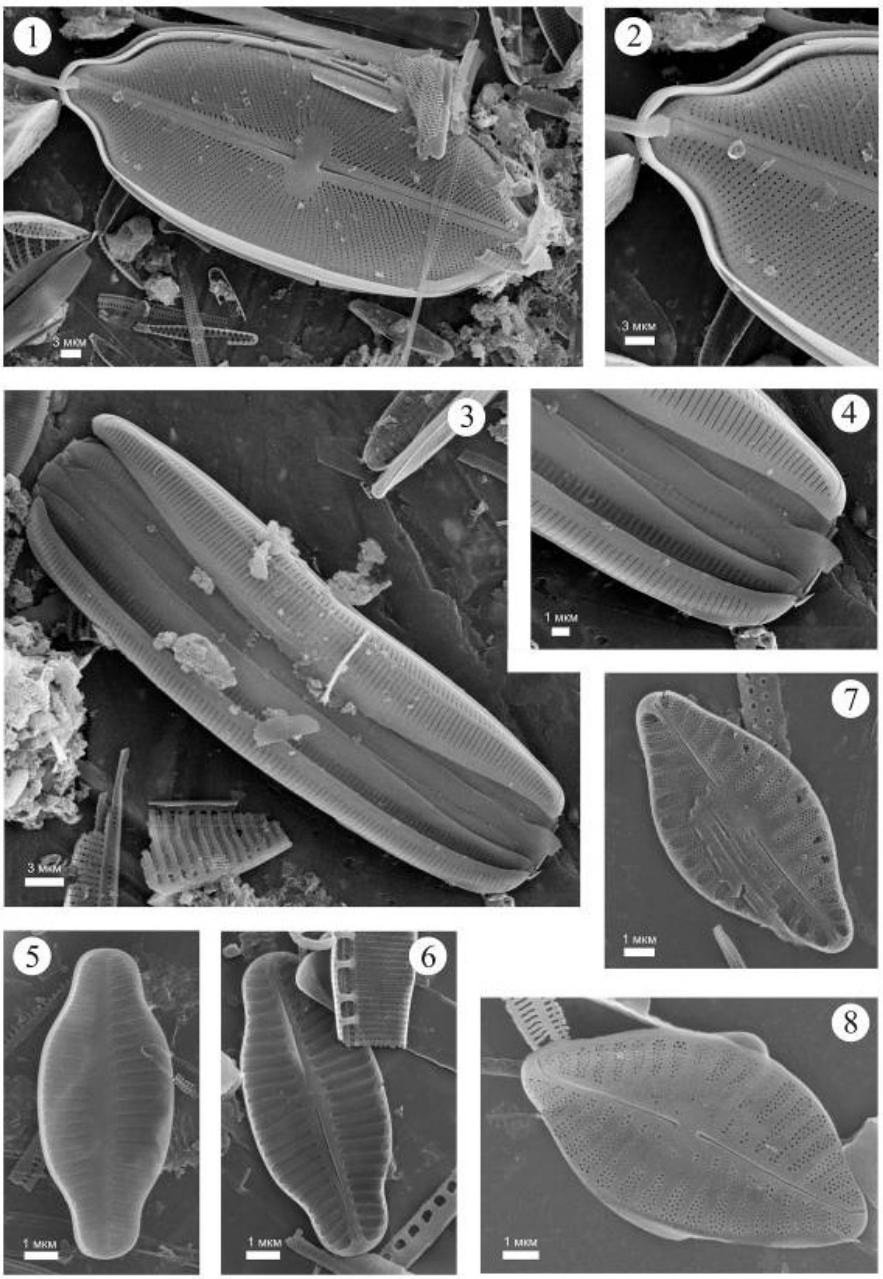

Plate VII. *Bacillariophyta* of mezophytopsammon of the NWBS coast: *1*, *2* – *Petroneis humerosa* (Karolino-Bugaz spit); *3*, *4* – *Amphora graeffeana* (Karolino-Bugaz spit); *5*, *6* – cf. *Karayaevia* sp. (Budakskaya spit); *7*, *8* – *Planothidium delicatulum* (Kinburn spit)

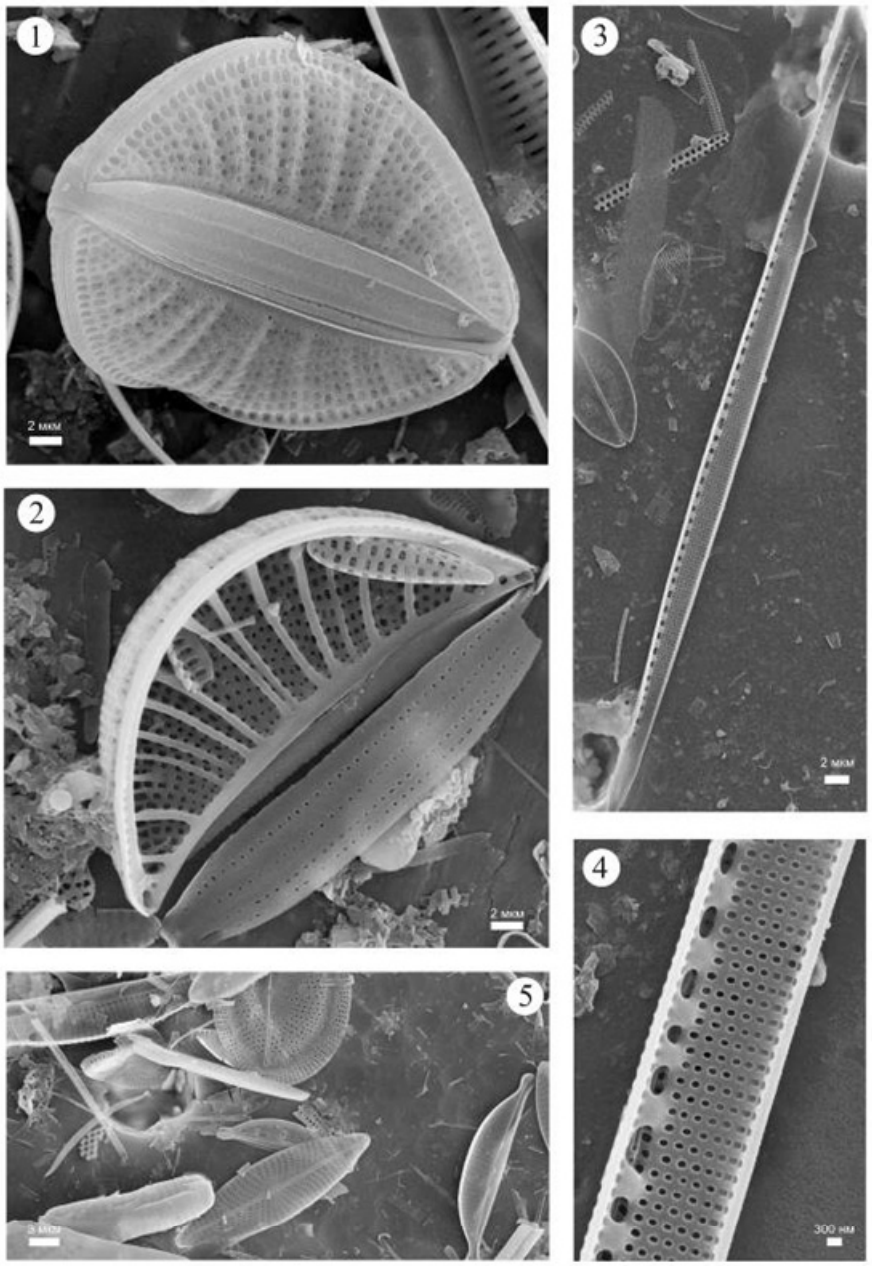

Plate VIII. *Bacillariophyta* of mezophytopsammon of the NWBS coast: *1–2* – *Rhopalodia musculus* (Karolino-Bugaz spit); *3–4* – *Pseudo-nitzschia pseudo-delicatissima* (Kinburn spit); *5* – general view of slide (Budakskaya spit)