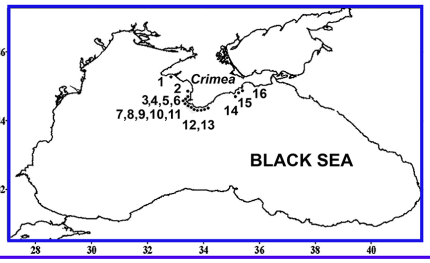
BENTHIC DIATOMS OFF CRIMEAN COAST (BLACK SEA): TAXONOMIC DIVERSITY AND STRUCTURE OF TAXOCENES AT THE LOCATIONS UNDER VARYING LEVELS OF TECHNOGENIC POLLUTION

NEVROVA ELENA, PETROV ALEXEI
A.O. KOVALEVSKY INSTITUTE OF BIOLOGY OF THE SOUTHERN SEAS RAS
2, NAKHIMOV AVE., 299011 SEVASTOPOL, RUSSIAN FEDERATION
el_nevrova@mail.ru, alexpet-14@mail.ru

Key role of benthic diatoms in functioning of coastal ecosystems determines the relevance of studying and preserving their biodiversity. Assessment of the taxocene structure of benthic Bacillariophyta is one of the most important task for the Black Sea. The coastal area of Crimea is subject to increasing anthropogenic impact. High species richness and complex structure of benthic diatom taxocenes in pristine water areas can rapidly change due to the disappearance of sensitive species and their replacement by ones which resistant to pollutants.
The work focused on assessment of the diversity and hierarchical structure of benthic diatom taxocenes along the Crimean coast in areas with varying degrees of anthropogenic pressure.
In ACCESS program, the database on benthic diatoms of the Black Sea was created, combining literary and own data. Updated inventory of Black Sea benthic diatoms includes 1094 species and IST pooled into 953 species, 149 genera, 61 families, 32 orders and 3 classes, according to taxonomic system (Round et al., 1990). Material for this study was sampled along the Crimea in 1984-2016 on 16 sites at depths range up 0.5 to 50 m. 380 samples were analyzed in total.



Sampling design along the Crimean coast:
1 – near vil. Marjino; 2 – near r. Belbek; 3 – referent site R3 near Sevastopol; 4, 5, 6 – Karantinnaya Bay, Sevastopol Bay, Inkerman Bay; 7, 8, 9, 10, 11 – Omega Bay, Golubaya Bay, Cape Feolent, Balaklava Bay, referent site R6 near Balaklava; 12 – Laspi Bay; 13 – Cape Sarych; 14 – near vil. Novyi Svet; 15 – Karadag Natural Reserve; 16 – Dvujakornaya Bay

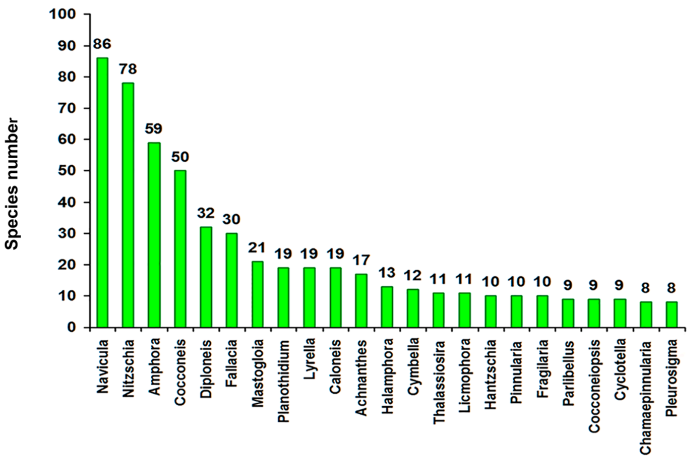
REPRESENTATIVENESS OF BACILLARIOPHYTA OFF CRIMEAN COAST

CLASS	ORDER	FAMILY	GENUS	SPECIES	INTRASPEC TAXA
COSCINODISCOPHYCEAE	11	17	28	72	80
FRAGILARIOPHYCEAE	8	9	26	68	74
BACILLARIOPHYCEAE	10	29	80	660	728
ВСЕГО	29	56	132	800	882

Taxonomic diversity and structure of benthic diatom taxocenes were investigated in Crimean nearshore habitats with varying levels of technogenic pollution. The highest diatom species richness ever registered in the Black Sea was recorded near the Crimean coast at 80.6% of the total number of Black Sea diatom flora.
When our own data was combined with literature, a total of 882 species and IST belonging to 132 genera, 56 families and 29 orders of Bacillariophyta have been registered. Only own data off the Crimean coast counted 793 species and IST pooled into 736 species, 130 genera, 53 families, 27 orders and 3 classes.
For most of the studied sites, parameters of key abiotic environmental factors were measured or taken from the literature, including the content of inorganic and organic contaminants in bottom sediments. According to the average values of pollutant concentration, the water areas were divided into three groups - heavily polluted, moderately polluted and conventionally clean.

MEAN CONCENTRATION VALUES OF TRACE METALS AND ORGANIC POLLUTANTS IN SOFT-BOTTOM SEDIMENTS FROM STUDIED SITES

Sites	Environmental variables, dry weight of bottom sediments									
	Metals, μg × g^{-1}							Organic pollutants, ng × g^{-1}		
	Cu (<20)	Pb (<15)	Zn (<80)	Ni (<40)	Cd (<0.5)	Mn (<10)	Hg (<0.04)	PCB (<50)	ChOP (<1)	PAH (<100)
Heavy polluted sites										
Near r. Belbek*	280	780	370	90	0,3	4890	43	78,9	14,2	0
Sevastopol Bay	97.9	96.1	167.2	34.0	0.33	364	1,12	310.5	15.93	2713
Inkerman*	1190	2800	400	320	16,2	5360	60	1014,3	19,8	1550
Karantinnaya Bay	26,2	18,2	26,9	25,1	-	178,3	0,3	155,0	64,2	1,3
Balaklava Bay*	161.4	338.7	232.2	30.8	0,31	333	0.81	121.8	18.80	7054
Conventionally healthy sites										
Referent site R3*	210	230	<20	30	0,1	330	30	22,2	1,9	0
Referent site R6*	10	29	6	9	0	140	0,1	0	0	0
Golubaya Bay*	16,8	121	<1,2	54,8	0,030	49,2	0,02	26,9	0,77	<3
Cape Fiolent*	22,8	21.8	124.3	5,5	0,05	244	0,02	16,3	1,10	<3
Laspi Bay**	7,4	3,7	12,0	1,9		6,3	0,042	5,4	2,8	0,1
Novyi Svet*	12,0	68,6	10,6	28,2	0,03	282	0,04	32,0	1,02	<3
Dvuyakornaya Bay*	13,4	45,2	98,4	<1,2	0,03	638	0,02	31,2	1,06	<3
Moderately polluted site										
Karadag Natural Reserve**	No data	Below average	Not exceed average	Not exceed average	High level	Below average	No data	151	9	No data



The most represented genera of Bacillariophyta along the Crimean coast were Navicula, Nitzschia, Amphora, Cocconeis, Diploneis, Fallacia, Mastogloia at al. These genera formed the most saturated poly-species branches in hierarchical tree of benthic diatom taxocenes off the Crimean coast.

It is impossible to access the species diversity of the Black Sea diatoms based on historical data using the traditional indices Shannon, Pielou, Margalef, *etc*. Taxonomic Distinctness indices (TaxDI, Δ+ and Λ+) were used to compare the hierarchical structure of diatom trees for studied sites [Warwick, Clarke, 1998, 2001]. This index calculate the average degree of phylogenetic distance between species based on the hierarchical structure of the taxocene.
Average taxonomic distinctness (Δ+) is the mean path length through the diatom assemblage taxonomic tree to phylogenetic common node, connecting every pair of species randomly selected from the list

$$\Delta+ = [\sum\sum i<j\ \omega ij] / [s(s-1)/2]$$

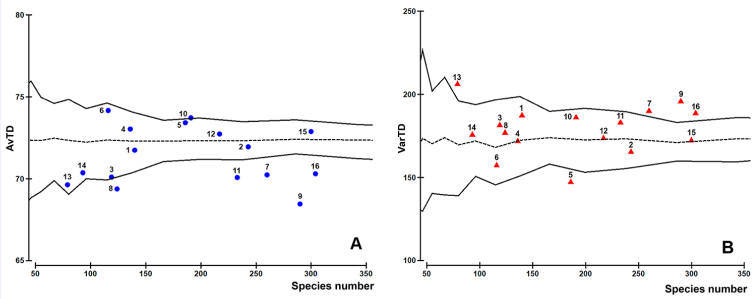
where ωij is the taxonomic path length between species i and j ; S is the number of species in assemblage.
Index Δ+ characterizes the vertical evenness of the regional taxonomic tree.

Index VarTD or Λ+ is the variability of these pairwise path lengths (ωij) between each pair of species i and j rating to its average value Δ+

$$\Lambda+ = [\{\sum\sum i<j\ \omega ij2\} / \{s(s-1)/2\}] - [\Delta+]2$$

Index Λ+ characterizes the horizontal unevenness of taxonomic tree from average level. Thus, VarTD characterizes various representativeness of lower taxa number to higher ones for each of branches composing the whole hierarchical tree.

ASSESSMENT OF TAXONOMICAL DIVERSITY OF BENTHIC DIATOMS OFF THE CRIMEAN COAST, BASED ON AvTD (A) AND VarTD (B) [WARWICK, CLARKE, 2001]



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The highest AvTD values are revealed for diatom taxocenes from highly polluted biotopes: Inkerman, Balaklavskaya, Sevastopolskaya, Karantinnaya bays and Belbek, for the moderately polluted area of Karadag and the conventionally clean Laspi Bay. The AvTD index for the above-mentioned areas on the graph is located much higher or close to the average expected level for the entire Black Sea flora of benthic Bacillariophyta (Δ+ = 82.09). The smallest values of AvTD index, located below the average expected level for the Black Sea diatom flora, correspond to conventionally clean areas: Maryino, Novy Svet, Dvuyakornaya and Omega bays, referent sites R3 and R3, c. Sarych, Golubaya bay and c. Fiolent.
Value of variability index VarTD for Belbek, Karantinnaya, Golubaya, Laspi bays, Novy Svet and Karadag are near the average expected level for the Black Sea flora (Λ+ = 316.827). For locations Maryino, referent sites R3 and R6, Inkerman, Balaklava bay the variability indices are located within 95% of the probability contour. For sites c. Sarych, c. Fiolent, Omega, Dvuyakornaya and Sevastopolskaya bays - VarTD indices are slightly outside the 95% probability contour.
Aappearance or elimination of a large number of closely related species has a less significant effect on taxonomical trees than that the finding or disappearing of a few species with a distant phylogenetic relationship. In summary, when the species richness of a taxocene based on poly-species branches formed by phylogenetically allied species is higher, while the average value of Δ+ is lower. Conversely, if the species richness of the taxocene based on oligo- or monospecies branches with a distant phylogenetic relationship is relatively low, the value of Δ+ will be higher.

EVALUATION OF TAXDI PROVIDES COMPREHENSIVE INSIGHTS INTO THE TAXONOMIC STRUCTURE. AVTD VALUES FOR DIATOM TAXOCENES FROM PRISTINE SITES WERE LOWER, AND VARIABILITY WAS GREATER THAN THE AVERAGE EXPECTED LEVELS FOR THE BLACK SEA BACILLARIOPHYTA. TAXONOMIC TREES WERE MAINLY FORMED BY POLY-SPECIES BRANCHES WITH A VARYING NUMBER OF SPECIES CLOSED AT GENUS LEVEL. STRUCTURE OF DIATOM TAXOCENES IN HEAVILY POLLUTED SITES DESCRIBED BY HIGHER AVTD VALUES IN COMPARISON TO THE AVERAGE EXPECTED LEVEL. IN SUCH CASE, OLIGOSPECIES BRANCHES WERE DOMINANT ALONGSIDE THE PRESENCE OF A LOWER NUMBER OF MONOSPECIES BRANCHES THAT CLOSED AT THE HIGHER TAXONOMICAL LEVELS OF FAMILY OR ORDER.
AVTD AND VARTD INDICES SHOULD BE RECOMMENDED AS RELIABLE QUANTITATIVE TOOLS FOR DIVERSITY ASSESSMENT UNDER THE CONDITION OF LONG-TERM ENVIRONMENTAL DISTURBANCES TO COASTAL MARINE HABITATS. THE OBTAINED RESULTS FOR TAXONOMICAL DISTINCTNESS PROVIDE A STATISTICALLY RELIABLE ASSESSMENT OF DIATOM TAXOCENE STRUCTURE AND COULD BE APPLIED FOR THE CONSERVATION OF MARINE FLORA DIVERSITY.

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