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OCEANOLOGY

Effects of Changes in the Hydrological and Hydrochemical Regime of the Caspian Sea on the Development of Microalgae in the Coastal Zone

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Abstract—This paper analyzes the composition and distribution of coastal phytoplankton in the western portion of the Middle Caspian in the context of changes in the hydrological and hydrochemical regime under the conditions of the rising level of the Caspian Sea. It has been demonstrated that the changes in the water regime led to an increase in the taxonomic diversity, the quantitative characteristics of phytoplankton, and the succession of the size groups.

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The Caspian Sea is a unique natural drainless brackish water body. The long term and annual fluctuations in the level typical of the Caspian Sea are regular processes reflecting the cyclic changes in the ambient environment [14, 15]. Due to this, the Caspian Sea can be a natural model for examination of the internal characteristics and environmental consequences of the global processes associated with the fluctuations in the level of the World Ocean.

Phytoplankton has a substantial significance in the biological productivity of the seas and is a sensitive indicator of all changes occurring in the ecosystem. The nature and degree of the development of phytoplankton govern the progress of production processes in the ecosystem as a whole. The short life span of microalgae and their ability to adequately react to changes in the quality of the habitat allow making an integral assessment of all natural and anthropogenic processes occurring in the water body.

As is well known, the current transgression of the Caspian Sea, biological invasions, and anthropogenic contamination, along with natural climate variations, led to a transformation of the autochthonous biota of the water body. These processes are particularly noticeable in the coastal shallow water zone. The rise of the level of the Caspian Sea that started in 1979 caused a flooding of the Caspian coast on a large territory. This was most manifest in the Terek-Sulak area (the northwestern portion of the Middle Caspian), where marine conditions have existed on the flooded territory for over 30 years [8].

A large number of studies have been dedicated to examination of phytoplankton in the Middle Caspian [2, 3, 7–10, 12, etc.]. However, all of them refer to the period when the level of the Caspian Sea was low. There are no data published in the last 25–30 years on the status of coastal algocenoses of the shallow portions within the western coast of the Middle Caspian. Given that such investigations would be of immediate interest, the authors examined the present-day status of phytoplankton in the coastal shallows within the western portion of the Middle Caspian, which is an extremely important fishing ground.

MATERIAL AND METHODS

This study presents data on examination of coastal shallows in the western portion of the Middle Caspian collected during the joint cruise organized by the Southern Scientific Center of the Russian Academy of Sciences and the Caspian Institute of Biological Resources of the Dagestan Science Center of the Russian Academy of Sciences during the period August 21–29, 2006, in the Kizlyar and Sulak gulfs and of the coastal water zones near the towns of Makhachkala, Izberbash, and Derbent using small vessels (Fig. 1).

Phytoplankton was collected using a Molchanov barometer and fixed with acid Lugol's solution. The fixed samples were settled under darkroom conditions for at least 15 days and were concentrated using the settling method [13, 1]. The number of cells was calculated in a Nageotte chamber (volume 0.1 mL) with three replications under a Micmed-6 light microscope (magnification ×400 and ×200). The biomass of the algae was calculated using the formulas of geometric

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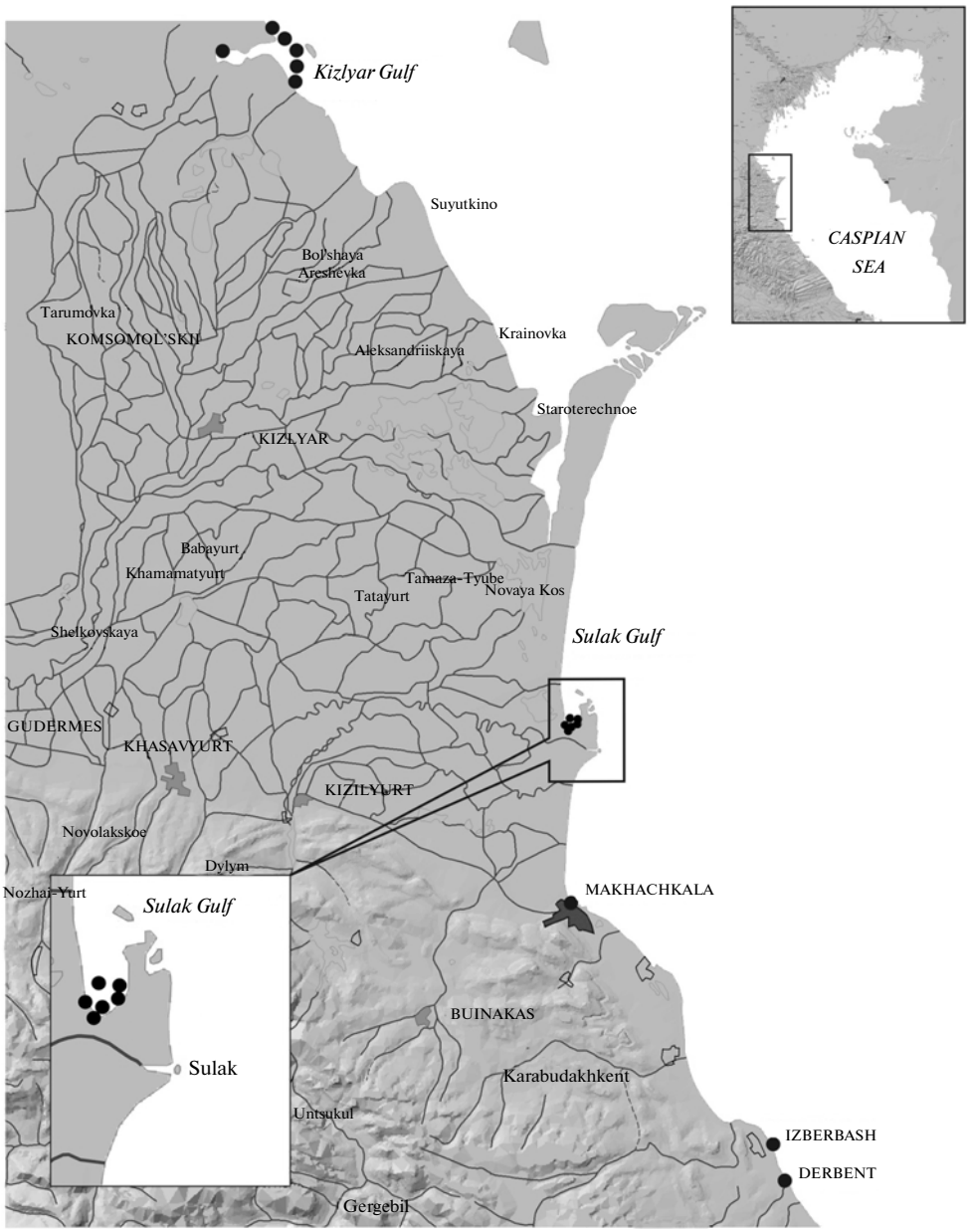

Fig. 1. Map showing phytoplankton sampling locations.

similarity of cells. The abundance of cells was expressed as mln cells/m^3, and the abundance of all phytoplankton and individual species was estimated from the wet weight in mg/m^3 and g/m^3.

RESULTS AND DUSCUSSION

The coastline of the water zone of the Middle Caspian, which is 530 km long, is characterized by a wide range of space–time variability of water salinity. The hydrological regime of the examined water zone was formed under the influence of the flows of the Volga, Terek, and Sulak rivers. While the average salinity of the Middle Caspian water is 12.84‰, the average salinity of the water on the beam of the Terek River is 6‰, in the Makhachkala area, 10‰, in the water zone of the town of Izberbash, 11.2‰, and in the southern portion of the coast, 12.85‰. The amplitude of synoptic and seasonal fluctuations in the salinity of the coastal waters is quite large. Despite the desalinating effect of the flow of the rivers of Dagestan and the water from the northern portion of the Caspian Sea, the salinity gradient between the extreme values is over 7‰. This is the reason for the uneven distribution of algal flora in different parts of the water zone of the Middle Caspian [4, 5].

The formation of the phytoplankton community during the period of the investigations occurred under

Spatial distribution of the principal taxons of microalgae of summer phytoplankton in the coastal shallow water zone within the western portion of the Middle Caspian in 2006

Area	Kizlyar Gulf		Sulak Gulf		Makhachkala		Izberbash		Derbent		Total	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Blue-green *Cyanophyta*	12	35.3	5	20.0	7	24.1	2	18.2	2	13.3	12	20.7
Diatoms *Bacillariaphyta*	10	29.4	8	32.0	8	27.6	6	54.5	7	46.6	22	38.0
Dynophytae *Dinophyta*	3	8.8	8	32.0	12	41.4	3	27.3	4	26.7	13	22.4
Euglena *Euglenophyta*	1	3.0									1	1.7
Green *Chlorophyta*	8	23.5	4	16.0	2	6.9			1	6.7	9	15.5
Other (small flagellate)									1	6.7	1	1.7
Total	34	100	25	100	29	100	11	100	15	100	58	100

sea transgression conditions. Desalinization of the water zone promoted an expansion of the species diversity and quite high values of the abundance and biomass of phytoplankton. During the investigations 58 species and varieties of microalgae belonging to five divisions were discovered. For comparison, the number of species encountered in the water zone of the entire Caspian Sea was 62 in 1976 and 37 in 1983 [11]. The maximum floristic diversity was observed for diatom algae (22 species), which is 38% of the total species diversity. The contribution of dynophyta and blue-green algae is 22.4 and 20.7%, respectively. The taxonomic structure of the phytoplankton is shown in the table.

The values of the biomass and abundance of microalgae in the examined water zone of the Middle Caspian were 2948.0 mg/m^2 and 568.5 mln cells/m^3, respectively (Fig. 2). An increase in the proportion of blue-green algae was observed (up to 68.8%), which were leaders in the abundance. The main contribution to the formation of the biomass was made by diatoms (74.1%).

An important feature of the development of phytoplankton in the coastal zone should be noted: against massive development of small-celled species, the leader of the previous years (the large-celled diatom *Pseudosolenia calcar-avis*) [2, 3] was not found.

The spatial distribution of phytoplankton in the sea zone was extremely uneven (see table, Fig. 2) and was governed by the salinity and inflow of biogenic elements. The spatial heterogeneity of these factors of the environment was responsible for the taxonomic composition, the production level, and the spatial behavior of the phytoplankton community. The most productive area during the period in question was the Kizlyar Gulf.

The Kizlyar Gulf is a natural water body located off the western shore of the Caspian Sea. The lythodynamics of its coasts is characterized by minimal slopes, whose values are a few decimals. The total length of the coastline is 115 km. The gulf intrudes into the continent for 20 km, is open on the east, and undergoes a desalinating influence of waters from the northern portion of the Caspian Sea. The Kuma, Prorva, Levyi Banok, and Talovka rivers fall into it. The gulf is shallow and is characterized by high hydrodynamic activity of the water mass and a large quantity of invading desalinized water [6]. The water salinity varies from 5 to 7‰. Passive flooding of the coast caused by marine transgression is observed there.

During the period of our investigations, high taxonomic diversity (see table) and the maximum values of the biomass and abundance of plankton microalgae (Fig. 2) were observed in the Kizlyar Gulf.

The number of species in the samples from the Kizlyar Gulf varied from 11 to 25. Fresh water and brackish water species primarily developed in phytoplankton. Blue-green algae were characterized by the maximum diversity in terms of the species composition (12 species); they accounted for 75% of the total abundance. The most frequently observed varieties were *Oscillatoria* sp., *Aphanothece clathrata* W. et G.S. West, *Gomphosphaeria lacustris* Chod., *Anabaena flos-aquae* (Lingb.) Breb., *A. bergii* var. *minor* Kissel., *Merismopedia punctata* Meyen, etc. Although *Aphanothece clathrata* prevailed in terms of the abundance, the

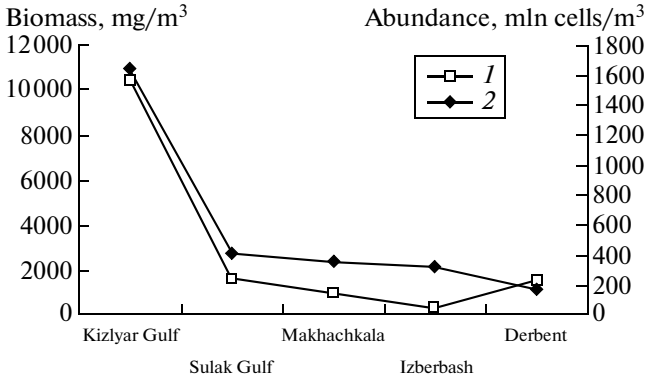

Fig. 2. Spatial distribution of the biomass (1) and abundance (2) of summer phytoplankton in the coastal shallows within the western portion of the Middle Caspian in 2006.

main contribution to the biomass of the blue-green algae was made by species of the genus *Oscillatoria*. Diatom and green algae were represented by 10 and 8 species, which is 29.4 and 23.5% of the species diversity, respectively. Over 87% of the biomass of phytoplankton in the Middle Caspian was formed due to the development of diatom algae. The diatoms were primarily represented by small celled species: *Nitzschia tenuirostris* Mer., *N. acicularis* W. Sm., *N. reversa* W. Sm., *Thalassionema nitzschioides* Grum., *Cerataulina pelagica* (Cl.) Hendey, *Rhizosolenia fragilissima* Bergon, *Actinocyclus variabilis* (Makar.) Makar. (= *Thassiosira variabilis* Makar.), *Thassiosira caspica* Makar., *T. parva* Pr.–Lavr., and *Thalassiosira* sp. *Actinocyclus ehrenbergii* Ralfs was dominant among diatoms in terms of the biomass; its biomass at some stations was up to 16.0 g/m^3, with the abundance being 361.8 mln cells/m^3. Massive vegetation of *A. ehrenbergii* was a reason for the high values of the total biomass of phytoplankton in the Kizlyar Gulf. Dynophyta were represented by only three species: *Prorocentrum scutellum* Schrod., *P. cordatum* (Ostf.) Dodge, and *Diplopsalis lenticola* f. *minor* (Pauls.) Pav. Their contribution to the total biomass and abundance was 9.4 and 0.3%, respectively.

The maximum quantitative characteristics of the development of phytoplankton (24 g/m^3 and 2924.5 mln cells/m^3) were observed at the stations located in the northern seaward portion of the Kizlyar Gulf, while the minimum values (252.9 g/m^3 and 728.8 mln cells/m^3), in its coastal part. In general, small-celled varieties prevailed in the plankton. The average biomass of phytoplankton in the water zone of the Kizlyar Gulf was 10.4 g/^{3}, and the abundance was 1653.1 mln cells/m^3.

The Sulak Gulf. Secular and long term variations of the level of the ocean, seas, and lakes is a very important factor that influences the evolution of deltas. During marine transgressions, deltas are normally filled up, narrow river valleys turn into gulfs, and broad river valleys, into estuaries or lagoons. The level of the Caspian Sea undergoes considerable fluctuations; the amplitude of the changes in the level was 15 m for the last 3000 years. The current transgression of the Caspian Sea affected the deltas of the rivers falling into it. Thus, the delta of the Sulak River was partly flooded and degraded by sea waves in 1979 [8]. The size of the delta decreased 38% from 70.6 to 43.7 km^2 in 1979–2000.

During the period in question, 25 species of phytoplankton were detected in the water zone of the Sulak Gulf, of which 8 species were diatoms; another 8, dynophyta; 5, blue-green; and 4, green algae. Blue-green algae dominated in terms of the abundance (62.1%); of these algae *Aphanothece clathrata* prevailed. The main contribution to the biomass was made by diatom and dynophyta algae (47 and 45.1%, respectively) from the genera *Actinocyclus, Thalassiosira, Diplopsalis,* and *Prorocentrum*. The maximum values of the biomass and abundance of phytoplankton (2.7 g/m^3 and 1628.4 mln cells/m^3) were recorded in the apical portion of the gulf.

In general, a reduction in the species diversity and abundance of diatoms in this portion of the water zone led to an almost 10 times reduction in the total biomass of phytoplankton compared with the Kizlyar Gulf (Fig. 2).

Coastal areas near the towns of Makhachkala, Izberbash, and Derbent. As one moves south, the water salinity increased, the quantity of the river flow decreased, and all vegetation characteristics of microalgae reduced (Fig. 2, table). The values of the biomass and abundance decreased over 10 times compared with the northern portion of the examined water zone. The minimum biomass (322.6 mg/m^3) and the lowest species diversity (11 species) were observed in the Izberbash area, and the minimum abundance, in the shallows near Derbent (169.7 mln cells/m^3).

In the Izberbash area, the main contribution to the formation of the biomass and abundance of phytoplankton is made by blue-green algae, 47.7 and 89.8%, respectively.

Oscillatoria sp. prevailed. The bulk of the taxonomic diversity of coastal phytoplankton in the Makhachkala area was made up by dynophyta, while in the shallow water zone of the towns of Izberbash and Derbent, by diatom algae (see table).

The key role in the formation of the biomass of coastal phytoplankton near Makhachkala and Derbent was played by dynophyta (61.5 and 58.0% of the total biomass, respectively), wit*h Diplopsalis lenticola* prevailing. *Prorocentrum cordatum* was also characterized by considerable development in this part of the water zone. Blue-green algae prevailed in terms of the abundance (51% in the Makhachkala area and 47.8% near Derbent); of these algae, the representatives of the genus *Oscillatoria* were most frequently observed. The average values of the biomass and abundance in the Makhachkala area were 934.9 mg/m^3 and 349.0 mln cells/m^3, and in the water zone near Derbent, 1560.7 mg/g^3 and 169.7 mln cells/m^3.

CONCLUSIONS

In conclusion, it should be noted that the present-day structure of summer phytoplankton in the coastal shallow water zone within the western portion of the Middle Caspian is characterized by high taxonomic diversity and high quantitative abundance. The maximum values of all characteristics in question were observed in the northern portion of the examined area. Shallowness, desalinization, and a constant inflow of biogenic elements imported by the Volga, Terek, and Sulak rivers created the most favorable conditions for vegetation of microalgae in this portion of the water zone.

In general, an increase in the proportion of small-celled blue-green algae in phytoplankton was observed;

algae of this type prevailed during the examined period in terms of the abundance. The bulk of the biomass was made up by large-celled diatom algae. A deterioration of the qualitative and quantitative characteristics of the development of phytoplankton was observed in the southern portion of the examined area (near the towns of Makhachkala, Izberbash, and Derbent).

It is important to note that the absolute year-round leader of the previous years (the nonfodder large celled diatom *Pseudosolenia calcar-avis*) was extruded by autochthonous small celled phytoplankton species (more valuable as fodder), which positively influences the development of zooplankton. The specific features of the organization of phytoplankton in different parts of the water zone influence the composition and productivity of the ecosystem. The favorable environmental conditions created by the rise of the level of the Caspian Sea promoted quite a high level of the development of coastal phytoplankton during the period in question.

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