ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 413, No. 2, pp. 297–299. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © G.G. Matishov, O.V. Stepan'yan, V.V. Povazhnyi, G. V. Kovaleva, K.V. Kreneva, 2007, published in Doklady Akademii Nauk, 2007, Vol. 413, No. 1, pp. 112–115.

OCEANOLOGY

Functioning of the Ecosystem in the Sea of Azov during Winter

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Received June 22, 2006

DOI: 10.1134/S1028334X07020377

Recent global climate changes are reflected at all organization levels of terrestrial and marine ecosystems. The most reliable indicators of climatic trends are marine ecosystems [2, 9]. Of particular interest are anomalously severe winters that occur against the background of progressive global warming and emphasize irregular temperature trends in the Northern Hemisphere. Drastic climatic anomalies, which influence the structure and productive characteristics of trophic chains, are essential for the functioning of marine ecosystems, including pelagic planktonic communities [7, 10].

The Sea of Azov is a relatively well-studied basin. Nevertheless, information on the functioning of its ecosystem during winter seasons, particularly those with severe conditions, is practically lacking [3]. The available data on the state of the pelagic zone in the Sea of Azov concern mild winters with relatively thin ice cover [11]. At the same time, the winter period is important for understanding regularities in functioning of the ecosystem and formation of productivity in the Sea of Azov.

The Murmansk Marine Biological Institute has been carrying out complex ecosystem observations along the Northern Sea Route, primarily in the Barents and Kara seas, using nuclear-powered icebreakers for more than ten years [1, 6, 8]. Since 2003, the practical experience obtained in the investigation of the Arctic seas has been used by scientists from the Azov Branch of the Murmansk Marine Biological Institute and the Southern Scientific Center of the Russian Academy of Sciences for complex studies of the Sea of Azov during winter seasons, including the anomalously severe winter of 2005/2006, on the diesel icebreaker *Kapitan Demidov* and R/V *Professor Panov* (Fig. 1). The works included hydrometeorological, hydrochemical, hydrobiological, and ornithological observations.

Hydrology. The studies shed light on the hydrological structure of the Sea of Azov during the winter season under conditions of pack ice cover. The results showed that the basin is characterized by well-developed lateral salinity gradients, particularly in mixing zones of sea and fresh waters, against the background of uniform temperature distribution. In the Taganrog Gulf, salinity varied from 0.3 to 6.7 g/l in 2003 and from 1.01 to 0.34 g/l in 2006. In general, salinity in the Sea of Azov ranged from 8.8 to 11.1 in 2003 and from 11.12 to 11.89 g/l in 2006. In the Kerch Strait, salinity amounted to 14.0 g/l.

The difference in the ionic composition of waters allowed us to discriminate fresh and seawater in the Sea of Azov with two stable frontal zones in the Taganrog Gulf. During mild winters (for example, in 2004/2005), the salinity distribution in the gulf and sea was characterized by significant spatiotemporal variability owing to intense wind-induced mixing and peculiarities in the hydrological regime of the basin. Anomalies defined in the salinity distribution throughout the Sea of Azov emphasize complex mechanisms of the transformation of different (riverine, drainage, snow melt, and sea) waters during the winter season.

Planktonic communities. We obtained the first data on the distribution and quantitative characteristics of winter plankton dwelling in the Sea of Azov under the ice cover. Planktonic pelagic communities are characterized by an intricate structure, species diversity, and high biomass values.

The *phytoplankton* biomass and abundance were 12–2424.4 mg/m^3 and 417–2115 · 10^6 cells/m^3, respectively. At the end of February 2003, the planktonic algal coenosis in the Taganrog Gulf consisted of more than 30 species of microalgae (largely, diatoms) [4]. In January–February of 2006, plankton in the Sea of Azov included 84 microalgal species of seven sections. The highest diversity was characteristic of diatomaceous, yellow-green, and green algae, while euglenic, cryptophytic, and blue-green algae were least diverse.

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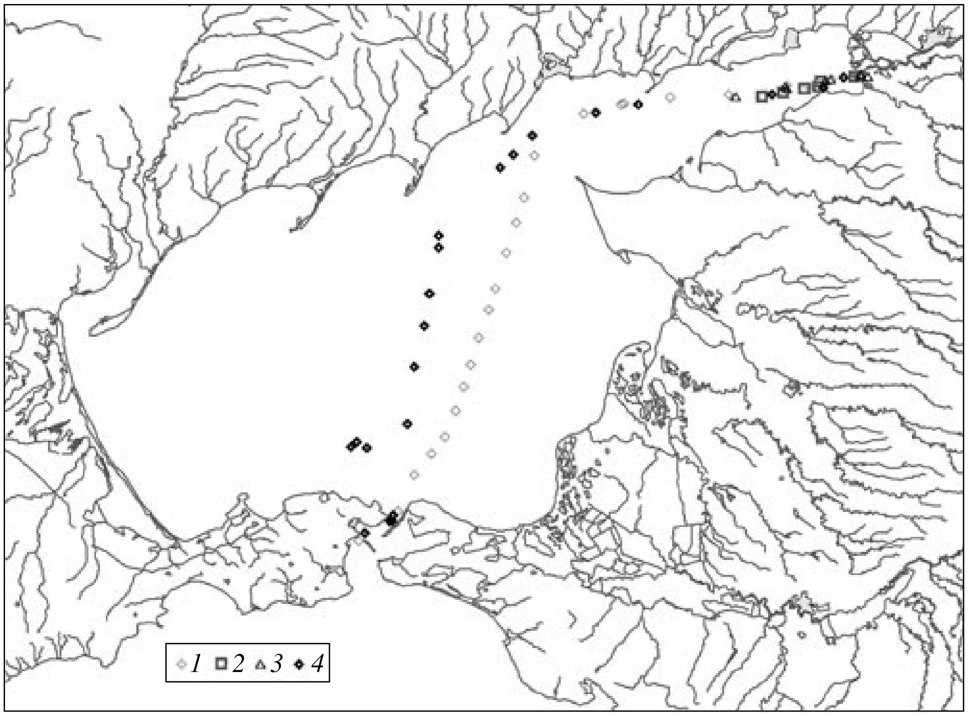

Schematic location of stations for the complex oceanographic and hydrobiological studies in the Sea of Azov during the winter season in 2003–2006. (*1*) 2003; (*2*) 2004; (*3*) 2005; (*4*) 2006.

The distribution of microalgal species diversity, biomass, and abundance through the sea and gulf was irregular. The entrance to the gulf and central part of the sea were characterized by the highest biomass and abundance of planktonic microalgae with distinct increase of these parameters from the end of the Taganrog Gulf toward its entrance. During the severe winter of 2006, when the ice thickness exceeded 0.5 m and its edge reached the entrance of the Kerch Strait, maximal values of the phytoplankton biomass in the Taganrog Gulf and Sea of Azov were as high as 1411.4 and 2424.4 mg/m^3, respectively, i.e., similar to their summer values. Such a development of microalgae indicates active bioproductivity under the ice.

The study revealed the main stages in succession of the phytoplankton community during the winter season and its similarity with production processes during the warm summer period. Phytoplankton development during the severe winter was confined to January. At the end of February and the beginning of March, the winter succession of phytoplankton ceases despite the fact that the pack ice can cover the sea for another one or two weeks. These observations imply complex mechanisms of regulation of the phytoplankton community. They also indicate that the development of phytoplankton is governed by not only exogenic factors (temperature, illumination, biogenic elements, and others), but also still poorly understood endogenic processes (relationships within and between populations). The combination of these factors determines the dynamics of the succession and production processes. It should be noted that similar phenomena are recorded in the Arctic seas marked by the existence of productive areas during the entire winter season.

It was established that *microzooplankton* in the Sea of Azov is active during the winter season as well. The species diversity (24 species in total) corresponded to a similar summer parameter. The spatial distribution of diversity and abundance characteristics of the microzooplankton community was relatively uniform. In January–February of 2003 and 2006, its abundance amounted to $1.1–2.2 \cdot 10^6$ specimens/m^3 ($0.9 \cdot 10^6$ specimens/m^3 on average) and $1.3–9.4 \cdot 10^6$ specimens/m^3 ($4.3 \cdot 10^6$ specimens/m^3 on average), respectively. The respective biomass value ranged from 8.6 to 64.3 mg/m^3 (34.3 mg/m^3 on average) and from 27 to 393 mg/m^3 (152 mg/m^3 on average). The trophic structure of the community was represented by microphagous organisms that were dominant in the Taganrog Gulf, as well as by algophagous and carnivorous organisms that prevailed in the remaining part of the Sea of Azov.

The dimensional structure of the microzooplankton community during the winter season demonstrates some peculiar features. Under the pack ice cover, it is largely represented by small species, while discontinuous ice cover stimulates the development of large infusorians. This phenomenon suggests the following conclusion. In winter, the water is characterized by a permanent pool of diverse infusorians and their potentially high reproduction rates. Therefore, microzooplankton retains the ability to reorganize the dimensional structure of the community rapidly and, thus, utilize more efficiently the available primary components of the trophic chain. This assumption is supported by the coincidence between areas with mass development and high production parameters of phyto- and ciliatoplankton in both the Taganrog Gulf and the central Sea of Azov.

In contrast to infusorians, *mesozooplankton* is characterized during the winter season by low species diversity and universal prevalence of marine rotifers with abundance equal to $5.3–27 \cdot 10^3$ specimens/m^3 and biomass equal to 1.25–46.77 mg/m^3 (21.32 mg/m^3 on average). Copepod naupliuses, calanids, and harpacticoids constituted a substantially lower share of the zooplankton community in the Sea of Azov. The highest mesoplankton diversity and abundance was noted in the Kerch Strait owing to its permanent influx with Black Sea waters. In our opinion, the Sea of Azov is lacking a typical winter mesoplankton community. The dominant eurybiontic species of the crawfish holoplankton are compelled to survive low-temperature periods at the stage of either resting eggs or older copepodites. This results in the replacement of calanoids by simpler rotifers.

Winter *meroplankton* in the Sea of Azov with a pack ice cover is represented by Cirripedia larvae and bivalve veligers. This fact indicates the reproduction of benthic organisms during winter season and availability of forage reserve for the zoobenthic community.

The described structure of the pelagic ecosystem implies that a productive planktonic community is actively functioning in the water column during the severe winter seasons when the Sea of Azov is covered by continuous ice. It is characterized by relatively high species diversity and biomass of phyto- and zooplankton assemblages, but by less intense development of mesoplanktonic groups with large organisms. The microbial trophic chain, some elements of which were observed during this study, probably plays a significant role during winter. At the same time, the prevalence of large forms among phytoplankton and the absence of corresponding zooplankton groups lead to incomplete utilization of the major part of the winter phytoplankton and elevated accumulation rates of detritus and organic matter in bottom sediments that are subsequently utilized by detritophagous organisms of different trophic levels.

The icebreaker-based study of the Sea of Azov covered by pack ice revealed previously unknown peculiarities in the development of biological communities: the high species diversity and biomass of phyto- and zooplankton assemblages, the subordinate role of mesozooplankton, and the presence of planktonic stages of benthic organisms. Thus, it can be inferred that plankton is particularly important for the formation and subsequent functioning of the detrital trophic chain in the Sea of Azov during winters with anomalously low air and water temperatures. Such an environment provides the prerequisites for the high biological productivity of the entire marine ecosystem, including high trophic elements (fishes and birds). Further field studies are needed to estimate the contribution of winter planktonic communities, which develop under extremely cold winter conditions, to the annual dynamics of production processes in the ecosystem of the Sea of Azov.

ACKNOWLEDGMENTS

We are grateful to all the participants of expeditions; to A.V. Ogarev, the chief of the Federal State Department of the Azov–Don State Management of Waterways and Navigation; and to the captain and crew of the diesel icebreaker *Kapitan Demidov* for help in these studies.

This work was supported by the Ministry of Industry, Science, and Technologies (Federal Purposeful Program “World Ocean,” Subprogram 7 “Complex Studies of Processes, Characteristics, and Resources of the Black and Azov Seas”) and the Presidium of the Russian Academy of Sciences (Program “Organization of Scientific Expeditions”).

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