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Formation of the Ecological Risk Zones in the Coastal Water Areas of the Kerch Strait

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Abstract
Purpose. The paper is aimed at studying the features of hydrological and hydrochemical structure of the bottom water layer and the distribution of geochemical parameters in the bottom sediments, and also at evaluating the basic factors in formation of the redox conditions in the bottom sediments of the Kerch Strait.
Methods and Results. The Kerch Strait ecosystem was comprehensively investigated in July and September, 2020. Hydrochemical studies of the water column were carried out using the standard hydrochemical methods. The profiles of the vertical distribution of oxygen, hydrogen sulfide, oxidized and reduced forms of iron in the pore waters were obtained, and also the geochemical characteristics of bottom sediments were defined. The features of their spatial and vertical distribution were considered. The sediment columns were sampled by a hand sampler and an acrylic soil tube (its internal diameter is 60 mm) with a vacuum seal. The pore water chemical profile was obtained by the polarographic method of analysis that included a glass Au-Hg-microelectrode. Hydrochemical structure of the surface horizon waters in July was noted to be conditioned by the Black Sea water contribution, and that of the bottom horizon waters – by the Azov Sea waters. It has been established that in a summer period in the Taman Gulf surface layer, an increased content of biogenic substances took place; and the increased water temperature and salinity, as well as active oxygen consumption in the bottom water layer decreased the degree of its saturation in the central part of the gulf. As a result, this favored the Taman Gulf silting, intensive oxygen consumption for oxidizing organic matter and the development of anaerobic conditions, and the hydrogen sulfide arising already in the surface layer of bottom sediments. In September, the main contribution was made by the Black Sea waters, that promoted the bottom water saturation with oxygen and the nutrient concentration decrease by 2–3 times. At that in September, oxygen penetrated into the sediment up to 2 mm, and the hydrogen sulfide content was 3 times lower than that in July.
Conclusions. It has been revealed that the hampered water exchange in the Taman Gulf region and the accumulation of organic matter in the bottom sediments due to the inflow of a significant amount of suspended matter, resulted in a limitation of the oxygen flow to the water bottom layer, whereas the fine-dispersion character of the sediments hampered penetration of oxygen into the bottom sediments. As a result, this contributed to the Taman Gulf silting, intensive oxygen consumption for oxidizing the organic matter and the development of anaerobic conditions, and to arising of hydrogen sulfide already in the surface layer of bottom sediments. The recorded at present anoxic conditions in the sediments upper layer can result in development of the oxygen deficiency in the bottom water layer and in formation of the ecological risk zones in the ecosystem of the Kerch Strait.

Keywords: hydrological parameters, hydrochemical parameters, currents, bottom sediments, pore waters, oxygen, voltammetry, granulometric composition, organic carbon, Kerch Strait

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Introduction

The water area of the Kerch Strait is an ecologically unfavorable area. Soil dumping and dredging are carried out here, a constant increase in the anthropogenic pressure on the marine environment takes place, which could not but affect various components of the strait's ecosystem – water exchange, vertical water stratification, hypoxia, migration of commercial fish, their mass death, etc. [1] [1–4]. At the same time, the Kerch Strait is an important commercial and tourist area, and the deterioration of water quality is reflected in its socio-economic attractiveness.

The main indicators for assessing the ecological state of marine ecosystems include the oxygen content as a key component that determines the redox environment and the very possibility of the existence of aerobic biological organisms. The main factors affecting the oxygen concentration are temperature, which controls the solubility of oxygen in water, as well as the organic matter content and reactivity, which determine the intensity of oxygen consumption [5]. In cases where the rate of oxygen consumption exceeds the rate of its supply, oxygen deficiency develops in the water column and bottom sediments [6]. This leads to a shift in the sequence of biogeochemical processes involving organic matter with a change from aerobic to anaerobic conditions [5]: when all oxygen is exhausted and other oxygen-containing components (nitrates/nitrites, manganese and iron oxides) are absent, sulfates act as the main oxidizer of organic matter in marine systems, and the product of their recovery is reduced forms of sulfur. As a result, anoxic zones are formed [5, 7]. Under these conditions, the respiratory activity of benthic organisms is suppressed and their species diversity decreases [8] with the predominance of species that survive in conditions of oxygen deficiency [9].

Thus, a constant increase in the anthropogenic load on coastal waters is manifested in an increase in the concentration of biogenic and organic substances. This leads to the accumulation of organic matter in bottom sediments and its involvement in biogeochemical processes. Therefore, the organic matter destruction is accompanied by oxygen consumption in the surface layer of bottom sediments and the bottom water layer, the extreme case of which is the development of hypoxia and anoxia, the appearance of reduced forms of sulfur and iron. This causes deterioration of living conditions, respiratory depression, death of benthic organisms and formation of ecological risk zones.

The characteristics of the water column in the Kerch Strait are determined by intense anthropogenic load, water dynamics, and are subjected to significant spatial and temporal variability [10, 11]. Bottom sediments, in contrast to the water column, are more conservative in their characteristics. This makes it possible to study the transformation of natural cycles and redistribution of various components, their transition from one form to another, more accessible one. In particular, determining the pollution level of bottom sediments is considered one of

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[1] Ivanov, V.A. and Shapiro, N.B., 2004. Modeling of Currents in the Kerch Strait. In: MHI, 2004. In: MHI, 2014. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 10, pp. 207-232 (in Russian); Lomakin, P.D., Panov, D.B. and Spiridonova, E.O., 2008. *Change of Major Components of Kerch Channel Ecosystem after Building of Tuzla Pier*. Sevastopol, 74 p. Preprint (in Russian).

the most convenient and objective methods for assessing the state of the marine environment in coastal areas [12], and the study of redox conditions provide forecasting of the development probability of oxygen deficiency zones and environmental risk zones.

The presence and reactivity of organic matter, as well as the granulometric composition of sediments, affect the oxygen concentration and redox conditions in bottom sediments to the greatest extent.

In the Kerch Strait, the main sources of organic matter are the Sea of Azov waters under northerly winds, the abrasion coasts of the Kerch and Taman Peninsulas, and anthropogenic activity [2] [13–15].

Recently, little attention has been paid to fundamental studies of the Kerch Strait bottom sediments. The employees of the Marine Hydrophysical Institute in 2008–2014 already carried out studies of the structure of currents in the Kerch Strait [3]. The main vectors for studying the system water – suspended matter – bottom sediments relate to such problems as the construction of a dam in the water area [4], accumulation and distribution of various pollutants (heavy metals [12, 16], aliphatic [17] and polycyclic aromatic hydrocarbons [18], chloroform-extractable substances [19]), as well as after ship accidents in the strait [20, 21]. At the same time, the effect of hydrological and hydrochemical characteristics of the near-bottom water layer and the geochemical characteristics of bottom sediments on the formation and dynamics of redox conditions in the bottom sediments of the Kerch Strait has not been practically studied.

The purpose of this work is to study the features of the hydrological and hydrochemical structure of the near-bottom water layer and the distribution of geochemical parameters in the bottom sediments; to evaluate the main factors in the formation of redox conditions in the bottom sediments of the Kerch Strait. The materials of the conference abstracts were used in the work [5].

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[2] Pasynkov, A.A., 2005. On Lithodynamics Processes in Kerchian Strait and Island Kosa Tuzla. *Geology and Mineral Resources of World Ocean*, (2), pp. 120-126 (in Russian).

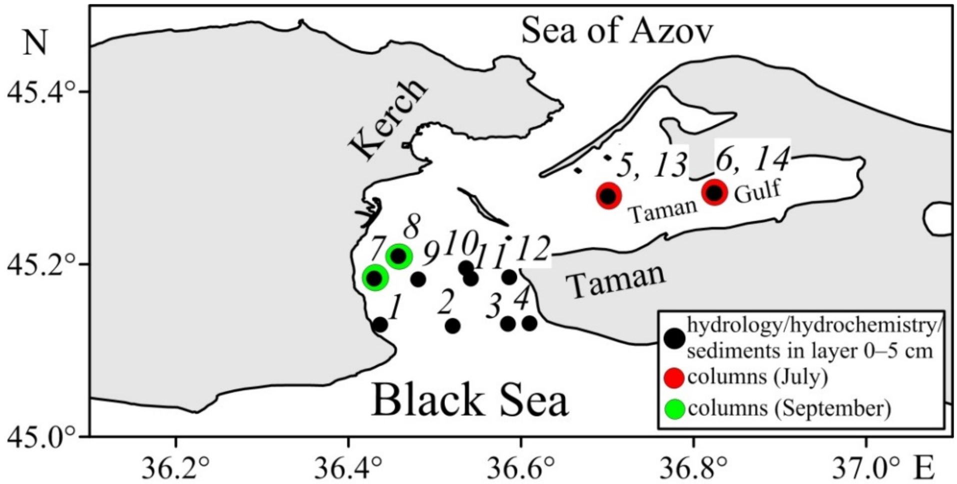
[3] Djiganshin, G.F., Motygin, A.S., Morozov, A.N. and Shutov, S.A., 2010. Hydrophysical Parameters of the Kerch Strait in December, 2009. In: MHI, 2009. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 23, pp. 153-158 (in Russian); Ivanov, V.A., Matishov, G.G., Kushnir, V.M., Berdnikov, S.V., Chepyzhenko, A.I., Povazhny, V.V. and Stepanyan, O.V., 2014. Kerch Strait in Autumn, 2011: Results of the Joint Complex Research Carried out in the Expeditions of MHI, NAS of Ukraine and SSC, RAS. *Morskoy Gidrofizicheskiy Zhurnal*, (1), pp. 44-57 (in Russian); Ivanov, V.A., Morozov, A.N., Kushnir, V.M, Shutov, S.A. and Zima, V.V., 2012. Currents in the Kerch Strait, ADCP-Observations, September 2011. In: MHI, 2012. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 26(1), pp. 170-178 (in Russian); Morozov, A.N., Lemeshko, E.M., Ivanov, V.A., Shutov, S.A. and Zima V.V., 2010. Currents in the Kerch Strait according ADCP Data in 2008-2009. In: MHI, 2010. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 22, pp. 253-267 (in Russian).

[4] Lomakin, P.D. and Spiridonova, E.O., 2008. Dynamics of Bottom Sediments in Kerch Strait before and after Tuzla Dam Building. In: MHI, 2008. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 17, pp. 215-224 (in Russian).

[5] Orekhova, N.A. and Konovalov, S.K., 2021. Developing Environmental Risk Zones in the Kerch Strait Area. In: SSC RAS, 2021. *Regularities of Formation and Impact of Marine and Atmospheric Hazardous Phenomena and Disasters on the Coastal Zone of the Russian Federation under the Conditions of Global Climatic and Industrial Challenges ("Dangerous Phenomena – III") in memory of Corresponding Member RAS D.G. Matishov.* Rostov-on-Don, pp. 320-324 (in Russian).

Materials and methods of the study

Comprehensive studies of the Kerch Strait ecosystem in July and September 2020 included hydrological and hydrochemical studies of the water column and analysis of the physico-chemical characteristics of bottom sediments. The scheme of stations for sampling water and bottom sediments is given in Fig. 1. Samples at stations 1–6 were sampled in July, at stations 7–14 – in September 2020.



F i g. 1. Scheme of the stations for hydrological, hydrochemical and geochemical studies in the Kerch Strait and the Taman Gulf water area in July and September, 2020

In order to obtain detailed (every 0.5 m) vertical profiles of temperature and salinity, a GAP-12 CTD probe was applied; to study water dynamics in the Kerch Strait, ADCP WHM1200 (operating frequency 1200 kHz) manufactured by RDI, USA was used. The device provides the measuring of the current velocity profile in a layer up to 10–15 m with a depth resolution of 1 m. The measurements were carried out in the mode of holding the device near the sea surface from the board of a drifting ship.

Seawater sampling from the surface and near-bottom horizons was carried out using a bathometer, then the samples were delivered to the laboratory on the shore.

The dissolved oxygen content in water samples was determined by the method of volumetric Winkler titration in the modification of Carpenter [22]. The technique enables us to obtain the results with an accuracy of ±0.010 ml/l (±0.4 μM). The degree of oxygen saturation (%) was calculated using the Weiss formula [23]

$$\ln C = A_1 + A_2\,(100/T) + A_3 \ln (T/100) + A_4\,(T/100) + \\ + S\,[B_1 + B_2\,(T/100) + B_3\,(T/100)^2], \qquad (1)$$

where C is oxygen solubility at total pressure of 1 atm with regard to the pressure of saturated water vapor, ml/l; $A_{(1,2,3,4)}$ and $B_{(1,2,3)}$ – constants ($A_1 = -173.4292$, $A_2 = 249.6339$, $A_3 = 143.3483$, $A_4 = -21.8492$; $B_1 = -0.033096$, $B_2 = 0.014259$, $B_3 = -0.0017$); T is an absolute temperature, K; S is salinity, ‰.

Mineral forms of nutrients (phosphates, silicic acid, ammonium nitrogen) were analyzed by the photometric method on a KFK-3KM spectrophotometer after seawater samples were filtered through a membrane filter with a pore size of 0.45 μm (except for the samples for determining the content of ammonium ions) [6]. When determining a silicic acid concentration, we have made a correction for salinity, calculated by the formula

$$C_{true} = C_{obs}(1+0.0045\,S), \quad (2)$$

where C_{true} is a true concentration of silicic acid; C_{obs} is an observed concentration of silicic acid; S, ‰ is a finite salinity of the analyzed sample [6].

Ammonium nitrogen was determined using a modified Sagi – Solorzano method for seawater, which is based on a phenol-hypochlorite reaction using sodium nitroprusside and sodium citrate [7]. To determine the sum of nitrates and nitrites on the AutoAnalyzer AA II flow analyzer (Bran+Luebbe), the method of reduction of nitrates to nitrites using copper-plated cadmium was applied.

The samples of the surface layer of bottom sediments of the Kerch Strait for studying the spatial distribution of physical (grain size distribution, humidity) and chemical (content of total, organic, carbonate carbon) characteristics were taken using a BG 0.025 bottom grab.

The grain-size composition of bottom sediments was determined by the mass content of particles of various sizes, expressed as a percentage, in relation to the mass of a dry soil sample taken for analysis. In this case, a combined method of decantation and sieving was applied. The separation of aleurite-pelitic fraction (≤ 0.05 mm) was performed by wet sieving, followed by gravimetric determination of the dry mass. The coarse-grained fractions (> 0.05 mm) were separated by a dry sieving method using standard sieves (GOST 12536-2014).

The carbon content (C_{org}, C_{carb}, C_{tot}) was determined coulometrically on an AN-7529 express analyzer according to a procedure adapted for marine bottom sediments [24].

The sampling of sediment columns (stations 5, 6, 7, 8, 13, 14) was carried out using a manual sampler and an acrylic soil tube with an inner diameter of 60 mm and a vacuum seal. The sampling was carried out in such a way as to preserve the fine structure of the sediment and the bottom water layer. On board, the columns were closed from below with a cork and transported to the shore.

To obtain the chemical profile of pore waters (the content of dissolved O_2, Mn(II), Fe(II, III), FeS, H_2S), a polarographic method of analysis with a glass Au–Hg microelectrode [25, 26] was applied. A silver chloride electrode was used as a reference electrode, and a platinum electrode – as an auxiliary one. Profiling of bottom sediment columns was carried out with a vertical resolution within the range of 1–10 mm. The method error was 10%.

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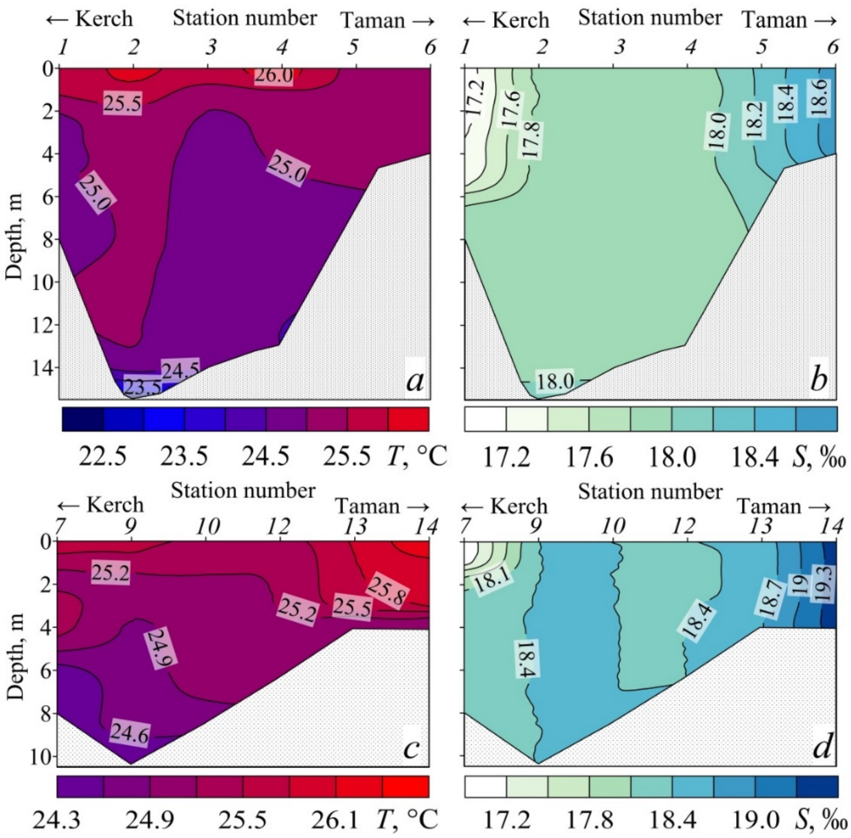
[6] Bordovsky, O.K., ed., 1992. *Modern Methods of Ocean Hydrochemical Investigations*. Moscow: IO AN USSR, 201 p. (in Russian).

[7] Unesco, 1987. *Thermodynamic of the Carbon Dioxide System in Seawater. Unesco Technical Papers in Marine Science, vol. 51.* Paris: Unesco, pp. 3-21.

Results and discussion

Hydrology and hydrodynamics of waters.

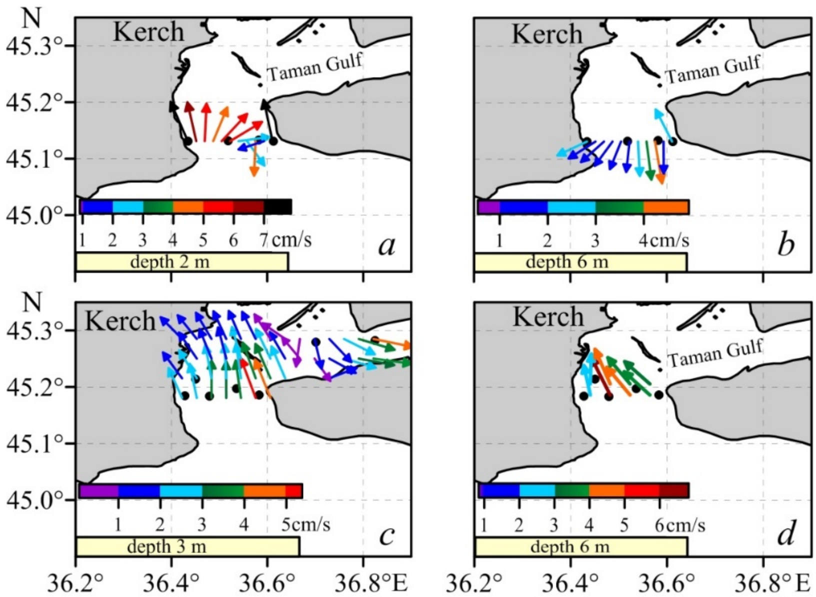
Based on the nature of the vertical profiles at the stations taken in July, the thermohaline structure in the southern part of the Kerch Strait and the Taman Gulf can be divided into three types. Features of the spatial and vertical distribution of hydrological parameters are given in Fig. 2. The waters of the first type are located near the western coast of the area under study (station 1), they are characterized by the minimum salinity (17‰) for the entire survey (Fig. 2, *b*). Apparently, the characteristics of the upper water layer (0 m) in this area were determined by meteorological conditions (northern wind (https://www.ventusky.com)) and the contribution of the Sea of Azov waters, while the reduced salinity in the subsurface layer was determined by the combined effect of the areal freshwater runoff from the shores of the Kerch Peninsula and the inflow of water from the Sea of Azov (Fig. 2, *a*, *b*) [10]. Salinity values slightly increase with depth, this can be explained by the inflow of the Black Sea waters, as indicated by the data of current vectors at a depth of 2 m (Fig. 3, *a*).



F i g. 2. Temperature and salinity distribution in the water columns of the Kerch Strait and the Taman Gulf in July (*a*, *b*) and September (*c*, *d*), 2020

The Taman Gulf waters (stations 5, 6) are evenly heated in depth (25.4 °C), they have a maximum salinity (18.6‰) (Fig. 2, *b*). The thermohaline structure of the gulf waters can be explained both by the pronounced stratification of waters and intensive evaporation in summer, and by the contribution of the Black Sea waters (Fig. 3, *a*).

In the central part of the studied section (stations 2–4) and near the shores of the Taman Peninsula, the water masses with a pronounced vertical temperature gradient (26.2–23.5 °C) and a salinity uniform in depth of 17.8–17.9‰ (Fig. 2, *b*) were observed. This is explained by the water inflow from the Sea of Azov. The obtained results are confirmed by the ADCP measurement data (Fig. 3, *b*).

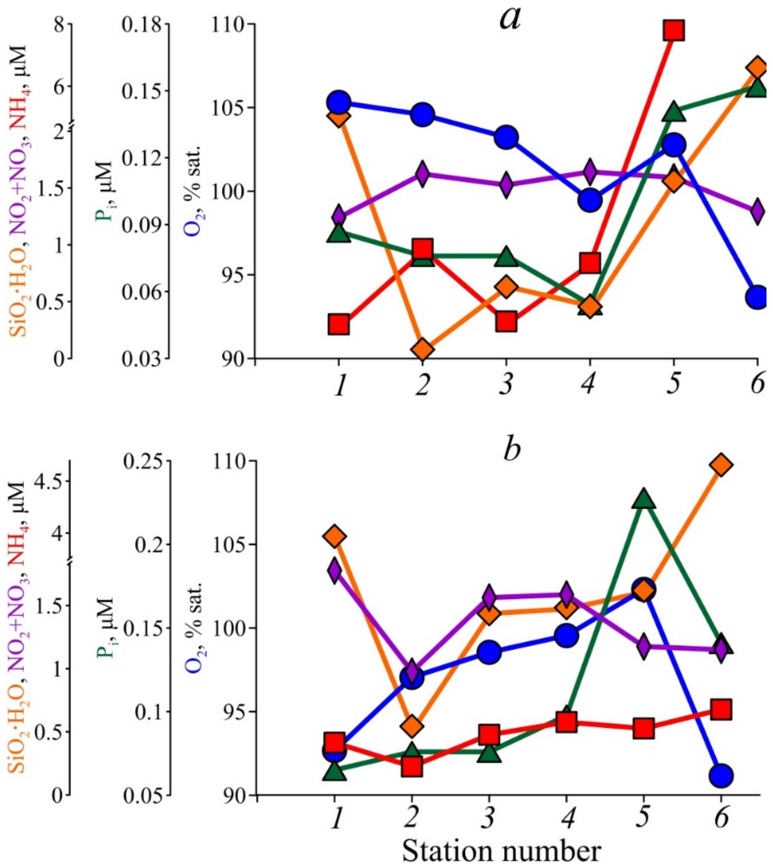


F i g. 3. Current profiles based on the ADCP data in July (*a*, *b*) and September (*c*, *d*), 2020

In September, the inflow of the Black Sea waters prevails throughout the entire water column (Fig. 3, *c*, *d*). As a result, the scale of freshening in the western part of the section is limited by the upper two-meter layer (Fig. 2, *d*). In the central part of the Kerch Strait, increased salinity values were noted, which in this period exceeded summer values (Fig. 2, *b*, *d*), which confirms the assumption about the contribution of the Black Sea waters (Fig. 3). The temperature gradient in the central part of the section was only ~ 1 ºC per 10 m of depth (Fig. 2, *c*). The maximum temperature (26.3 ºC) and maximum salinity (up to 19.4‰) were recorded in the waters of the Taman Gulf in September. The thermohaline characteristics observed in the Taman Gulf and weak water exchange (average current velocity of 2.2 cm/s) affected the hydrochemical characteristics of waters. The weakening of the water dynamics in Taman Gulf and the high probability of the formation of weak circular currents have previously been associated with the construction of the Tuzla dam [8] [1].

Hydrochemical analysis of waters.

As shown above, in July, the hydrochemical structure of waters in the surface horizon was determined by the contribution of the Black Sea waters, and in the near-bottom horizon – by the Sea of Azov waters (Fig. 3, *a*). It can be noted that a mixed type of effect of water dynamics prevailed in this period [11].



F i g. 4. Profiles of hydrochemical characteristics in the surface (*a*) and bottom (*b*) water layers in July, 2020

The concentrations of hydrochemical parameters in the surface and near-bottom water layers in July 2020 are demonstrated in Fig. 4. During this period,

[8] Ivanov, V.A. and Shapiro, N.B., 2004. Modeling of Currents in the Kerch Strait. In: MHI, 2004. In: MHI, 2014. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 10, pp. 207-232 (in Russian); Lomakin, P.D., Panov, D.B. and Spiridonova, E.O., 2008. *Change of Major Components of Kerch Channel Ecosystem after Building of Tuzla Pier*. Sevastopol, 74 p. Preprint (in Russian).

a slightly increased content of nutrients (except for silicic acid) was observed in the water column of the Kerch Strait: on average, the concentration of phosphates was 0.11 μM, ammonium ions 0.54 μM, and the sum of nitrates/nitrites 1.43 μM. The average oxygen concentration was 230 μM, and the degree of water saturation with oxygen reached 100%. The maximum concentrations of nutrients were noted in the surface layer of the Taman Gulf: the concentration of ammonium ions reached 7.79 μM, the sum of nitrates/nitrites was 1.59 μM, and silicic acid was 6.60 μM (Fig. 4, *a*). At the same time, the oxygen concentration decreased to 215 μM, and the degree of water saturation with oxygen – to 93%. In the bottom water layer of the Taman Gulf the concentrations of nutrients were significantly lower: 0.6 μM on average for ammonium ions, 1.16 μM for the sum of nitrate/nitrite, and 3.1 μM for silicic acid (Fig. 4, *b*). Elevated values of nutrients in the Taman Gulf water area, apparently, are determined by their supply with terrigenous runoff from agricultural enterprises located on the Taman Peninsula. Increased water temperature and salinity, as well as active oxygen consumption in the bottom water layer led to the fact that the degree of its saturation in the central part of the Taman Gulf (station 6) was 91%, which is 7% lower than the average value for the region.

In September, the Black Sea waters made the main contribution (Fig. 3, *c*, *d*). In addition to the contribution of the biogeochemical component (the photosynthesis process), the predominance of the Black Sea waters in the autumn period contributed to the decrease in the concentration of biogenic substances by 2–3 times relative to summer values. This also affected the oxygen concentrations: the values increased to an average of 245 μM (104% sat.), in the Taman Gulf – up to 251 μM (110% sat.).

In general, during the research period in the waters of the Kerch Strait, no significant deviations from the usual distribution of hydrochemical parameters were found [13–15]. However, the supply of an additional amount of nutrients contributes to the phytoplankton production in the surface waters and its further sedimentation and accumulation in bottom sediments. The intense influx of suspended organic matter into bottom sediments leads to an increase in the proportion of fine-grained sediment material and an increase in the content of organic carbon in them. The next step will be to change the redox conditions in bottom sediments.

Geochemical analysis.

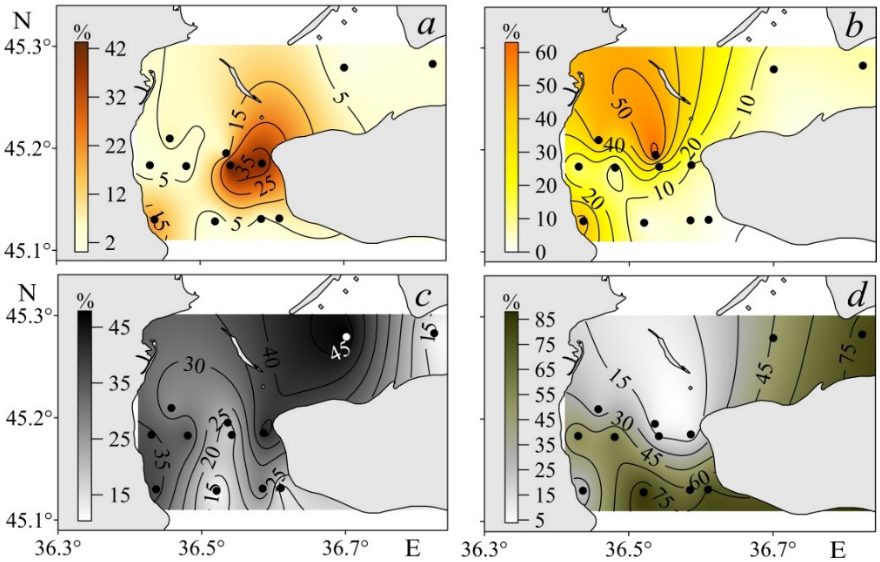
The surface layer of modern bottom sediments of the Kerch Strait has been studied in sufficient detail [9] [27]. In these works, it was noted that in the coastal zone of the strait in shallow water, sediments are represented by a complex of sand,

[9] Shnyukov, E.F. and Palansky, M.G., 1979. [Geological Significance of Some Geochemical Studies of Modern Bottom Sediments of the Kerch Strait]. In: E. F. Shnyukov, ed., 1979. *Lithological and Geochemical Conditions for the Formation of Bottom Sediments*. Kyiv: Naukova Dumka, pp. 3-17 (in Russian); Makarenko, D.E., ed., 1981. *Geology of the Shelf of the Ukrainian SSR. Kerch Strait.* Kyiv: Naukova Dumka, 158 p. (in Russian).

pebble and shell material. Shell fields are concentrated directly near the Kerch Peninsula shores. Sands, represented by quartz and organogenic-detrital varieties, extend down to 3–5 m depths. Fine-aleuritic and aleurite-clay silts are common in the places of depressions and topographic lows in the strait.

However, the data of early studies are objectively outdated, taking into account constantly increasing rates of sedimentation in the strait and especially in its innermost parts [27, 28]. In addition, the sediments of the Taman Gulf are little if at all studied in these works.

As a result of grain-size analysis of samples of the surface layer of the Kerch Strait bottom sediments, the features of the spatial distribution of the main fractions were identified: gravel (10–1 mm), sandy (1–0.1 mm), aleurite-pelitic (0.1–0.05 mm) and pelite-aleuritic (< 0.05 mm) (Fig. 5). The Kerch Strait sedimentary material is genetically heterogeneous, it is represented mainly by the products of massive material destruction of the Kerch and the Taman Peninsulas [10].

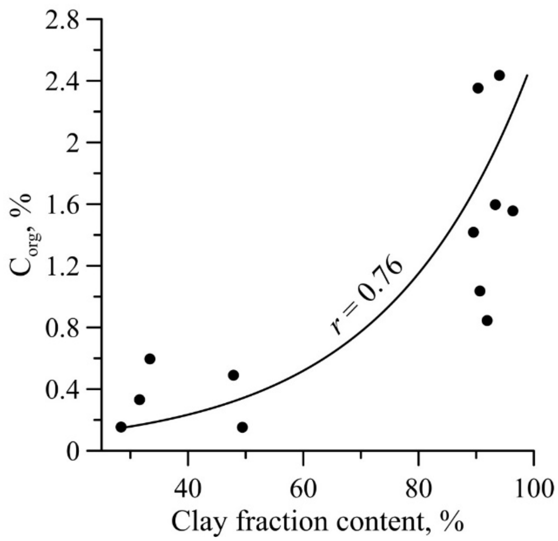


F i g. 5. Spatial distribution of the fractions of granulometric composition of bottom sediments in 2020: *a* – gravel; *b* – sandy; *c* – aleurite-pelitic; *d* – pelite-aleuritic

An analysis of the results obtained in this work revealed that the Kerch Strait bottom sediments are predominantly represented by pelite-aleuritic silts with inclusions of sandy material and separate inclusions of shell detritus near the shore.

[10] Shuisky, Yu.D., Vykhovanets, G.V., Khromov, S.S., Murkalov, A.B., Golodov, N.F., Bereznitskaya, N.A. and Chernyavskaya, A.N., 2003. [Morphology and Dynamics of the Abrasion Coasts of the Kerch Strait within Ukraine]. *Ecological Problems of the Black Sea*, (5), pp. 421-431 (in Russian).

On average, for all samples, the proportion of finely dispersed material was 70%; 44% of them fell to the pelite-aleuritic fraction and 26% to the aleurite-pelitic fraction. It was determined that an increased content of silty material, including the pelitic fraction (76–86%), is observed at stations in the southern, southwestern parts of the Kerch Strait (90–96%) and in the central part of Taman Gulf (90–94%) (Fig. 5, *c*, *d*). The content of sandy material varies within the range of 2–65%, the maximum values are noted near the western coast in the southern part of the strait, and the minimum values are noted near the eastern coast in the southern part of the strait and in the Taman Gulf (Fig. 5, *b*). Gravel material in the surface layer of sediments is fragmentary and mainly in the form of small and medium-sized shells and shell fragments. An increased content (41–45%) is noted at coastal stations near the eastern coast (Fig. 5, *a*).



F i g. 6. Relationship between the organic carbon content and the silt fraction proportion

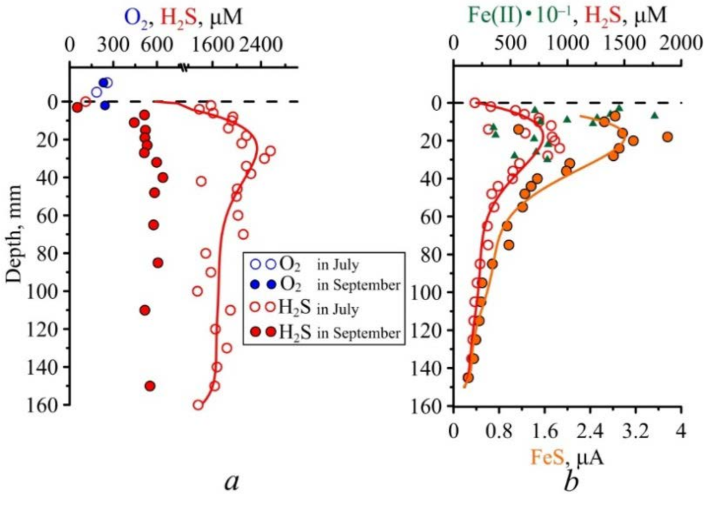
C_{org} content varies from 0.2–0.6% dry wt. in gravel-sand deposits of the southwestern part of the Kerch Strait up to 2.3–2.8% dry wt. in silt deposits of the Taman Gulf with an average value of 1.3% (n = 14). The obtained quantitative characteristics are in good agreement with the literature data [27]. Elevated C_{org} concentrations were observed for samples with the highest proportion (> 90%) of silty material (Fig. 6). The correlation between the content of C_{org} and the silt fraction was 0.76, which is primarily determined by the relationship with the content of pelite-aleuritic material (correlation dependence is 0.7), while the correlation with the aleurite-pelitic fraction is rather weak (0.3). This type of relationship between C_{org} content and granulometric fractions is "classical" for marine bottom sediments and, in particular, for coastal sediments of the Black Sea [27].

C_{carb} content in the surface layer of bottom sediments varies from 0.8–1.6% dry wt. in the Taman Gulf and in the southern deep-water part of the strait up to 4.6–6.0% dry wt. at shallow water stations near the western coast in the central part of the Kerch Strait. It was revealed that C_{carb} minimum values are accompanied by the maximum concentrations of silts (90–96%). The maximum correlation (0.6) is observed for gravel and sand material.

For the bottom sediments of the Taman Gulf and the southwestern part of the Kerch Strait, vertical profiles of C_{org} content were obtained and a trend towards a decrease in its concentration with depth was noted. The physicochemical characteristics of bottom sediments are also reflected in the characteristics of the pore water chemical composition in them.

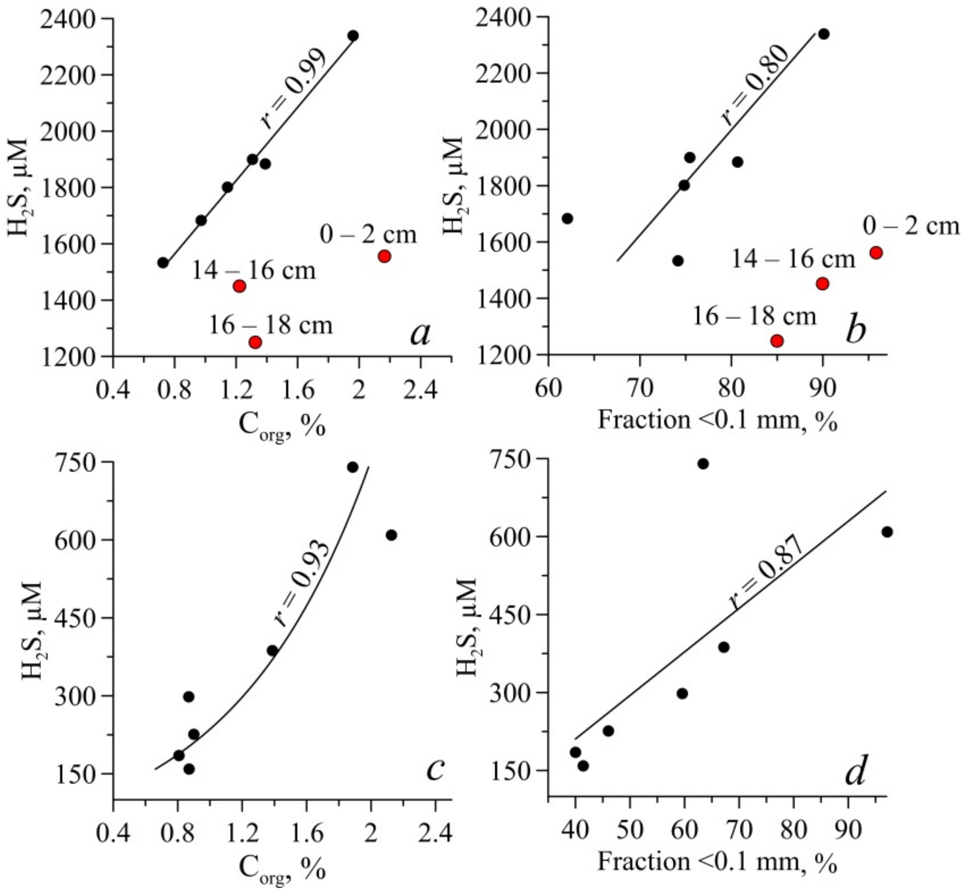
Chemical composition of bottom sediment's pore waters.

In the bottom sediments of the western part of the Taman Gulf (station 5), anoxic conditions were noted (Fig. 7, *a*). This was facilitated by the hampered water exchange in the water area of the gulf [3, 4], which led to the limitation of the oxygen flow to the bottom water layer, and the finely dispersed nature of the sediment, which hindered the oxygen penetration into the bottom sediments. In addition, an increased content of organic carbon (2.32–2.75%) contributed to the oxygen consumption for its oxidation. In July, the maximum concentration of hydrogen sulfide reached 2600 μM; by September, its content decreased significantly, although the nature of the distribution remained the same (Fig. 7, *a*). Perhaps this is due to the transition of dissolved forms of sulfides to the deposit (for example, the formation of pyrite).



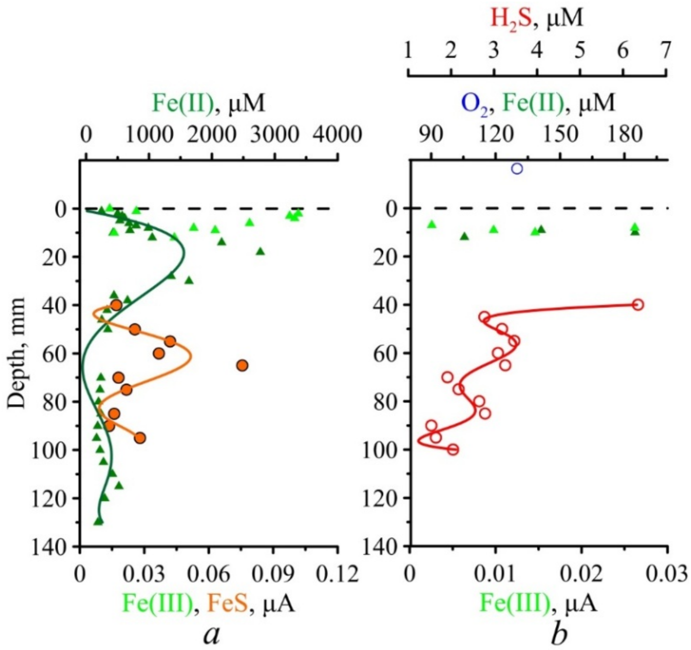
F i g. 7. Vertical profiles of the bottom sediments' pore waters in the Taman Gulf at stations 5 (*a*) and 6 (*b*)

At station *5* in the sediment layer of 2–14 cm, there is a decrease in the concentration of hydrogen sulfide, similar to a decrease in the C_{org} concentration (the correlation was 0.99), which indicates a direct dependence of the decrease in one concentration on another (Fig. 8, *a*). Then, in the sediment layer of 14–18 cm, the C_{org} concentration increases, while that of hydrogen sulfide decreases, as a result, a negative correlation dependence (–1) is noted. A similar situation was noted for the relationship between the concentration of hydrogen sulfide and the proportion of the silt fraction in the sediment (Fig. 8, *b*). Thus, we can conclude that the concentration of hydrogen sulfide in the deeper layers of the sediment is not related to its geochemical composition. The correlation dependence for the entire analyzed sediment layer was 0.36.



F i g. 8. Relationships between the concentration of H_2S in pore water and C_{org} at stations 5 (*a*) and 6 (*c*), and that of H_2S and the silt fraction content at stations 5 (*b*) and 6 (*d*) in bottom sediments

In the surface layer of bottom sediments in the Taman Gulf central part (station 6) oxygen was absent (Fig. 7, *b*). The chemistry of pore waters was determined by processes involving reduced forms of iron and sulfur, as well as by the products of their interaction. The predominant component of the pore waters was hydrogen sulfide with an average concentration of 465 μM. Its concentration increased with depth, reaching a maximum at 24 mm (933 μM), and then decreasing. The presence of iron monosulfide was also noted, the distribution of which is similar to the distribution of sulfides. Anoxic conditions were observed in bottom sediments. For station 6 a high correlation (0.93) is determined between the concentration of hydrogen sulfide and C_{org} content (Fig. 8, *c*), as well as between the concentration of hydrogen sulfide and the proportion of the silt fraction (0.87) (Fig. 8, *d*).



F i g. 9. Vertical profiles of the bottom sediments pore waters in the southwestern part of the Kerch Strait at stations 7 (*a*) and 8 (*b*)

Despite the fact that in the coastal areas of the Kerch Peninsula from the Black Sea, active hydrodynamic processes contributed to the supply of oxygen to the bottom water layer (Fig. 2, 3), in the surface layer of sediment at stations in the southwestern part (stations 7, 8) oxygen was absent. The main components of the pore waters here were reduced forms of iron (Fig. 9). The pore waters were distinguished by a high content of Fe(II), the maximum was noted at 18 mm (2769 μM), which is comparable to its concentration in the most anthropogenically loaded water areas of the Sevastopol region [29]; the concentration decreased with depth. The average concentration of Fe(II) was 626 μM. Thus, suboxic conditions were recorded in the upper layer of bottom sediments.

Conclusions

New comprehensive expeditionary data, including hydrological and hydrochemical characteristics of waters and geochemical characteristics of bottom sediments for the Kerch Strait water area, which is of priority importance for the development of the socio-economic potential of the region, were obtained. The obtained data on changes in the pore water chemical characteristics made it possible to identify areas where the formation of bottom sediments occurs under suboxic and anoxic conditions. Suboxic conditions were noted in the southwestern part of the Kerch Strait, and anoxic conditions – in the area of the Taman Gulf. Analysis of the effect of various factors (vertical profiles of temperature and salinity, oxygen concentration and degree of saturation of bottom waters with oxygen, currents, content of organic carbon and silty material) on the state of the marine ecosystem of the strait under anthropogenic load provided the assessment of the redox conditions in the thickness of bottom sediments. It was shown that the active exploitation of most coastal areas resulted in the main processes in the sediments being determined by reactions involving reduced iron and sulfur compounds. It was found that the difficult water exchange in the Taman Gulf area and the accumulation of organic matter in the bottom sediments due to the influx of a significant amount of suspended matter led to the limitation of the oxygen flow to the bottom water layer, and the finely dispersed nature of the sediments made it difficult for the oxygen penetration into the bottom sediments. As a result, a siltation of the Taman Gulf took place, as well as an intensive oxygen consumption for the oxidation of organic matter and development of anoxic conditions, appearance of hydrogen sulfide already in the surface layer of bottom sediments.

The absence of oxygen and the appearance of hydrogen sulfide causes respiratory depression and mass death of bottom organisms. Thus, it was determined that the currently recorded redox conditions in the upper layer of sediments led to the formation of ecological risk zones in the Kerch Strait ecosystem.

REFERENCES

1. Bryantsev, V.A., 2005. Possible Ecological Consequences of the Tuzla Damb Construction (Kerch Strait). *Morskoj Ehkologicheskij Zhurnal = Marine Ekological Journal*, 4(1), pp. 47-50 (in Russian).

2. Eremeev, V.N., Ivanov, V.A. and Ilyin, Yu.P., 2003. Oceanographic Conditions and Ecological Problems in the Kerch Strait. *Morskoj Ehkologicheskij Zhurnal = Marine Ekological Journal*, 2(3), pp. 27-40 (in Russian).

3. Lomakin, P.D. and Borovskaya, R.V., 2006. Characteristic of Modern Condition of Currents System of Kerch Strait on Base of Satellite and Contact Observations. *Issledovanie Zemli iz Kosmosa*, (6), pp. 65-71 (in Russian).

4. Fomin, V.V. and Ivanov, V.A., 2007. Coupled Modeling of Currents and Wind Waves in the Kerch Strait. *Physical Oceanography*, 17(5), pp. 253-268. https://doi.org/10.1007/s11110-007-0020-x

5. Orekhova, N.A. and Konovalov, S.K., 2018. Oxygen and Sulfides in Bottom Sediments of the Coastal Sevastopol Region of Crimea. *Oceanology*, 58(5), pp. 679-688. doi:10.1134/S0001437018050107

6. Diaz, R.J., 2001. Overview of Hypoxia around the World. *Journal of Environmental Quality*, 30(2), pp. 275-281. doi:10.2134/jeq2001.302275x

7. Meysman, F.J.R., Middelburg, J.J., Herman, P.M.J. and Heip, C.H.R., 2003. Reactive Transport in Surface Sediments. I. Model Complexity and Software Quality. *Computers & Geosciences*, 29(3), pp. 291-300. doi:10.1016/S0098-3004(03)00006-2

8. Zhang, J., Gilbert, D., Gooday, A.J., Levin, L., Naqvi, S.W.A., Middelburg, J.J., Scranton, M., Ekau, W., Peña, A. [et al.], 2010. Natural and Human-Induced Hypoxia and Consequences for Coastal Areas: Synthesis and Future Development. *Biogeosciences*, 7(5), pp. 1443-1467. doi:10.5194/bg-7-1443-2010

9. Losovskaya, G.V., 2011. On Indicator and Tolerant Species of Polychaetes (in the North-Western Black Sea). In: MHI, 2005. In: MHI, 2011. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 25(1), pp. 327-334 (in Russian).

10. Aleskerova, A.A., Kubryakov, A.A., Goryachkin, Yu.N. and Stanichny, S.V., 2017. Propagation of Waters from the Kerch Strait in the Black Sea. *Physical Oceanography*, (6), pp. 47-57. doi:10.22449/1573-160X-2017-6-47-57

11. Goryachkin, Yu.N., Kondrat'ev, S.I. and Lisichonok, A.D., 2005. Hydrological and Chemical Parameters and Water Dynamics in the Kerch Strait in March, 2004. In: MHI, 2005. In: MHI, 2014. *Ekologicheskaya Bezopasnost' Pribrezhnoy i Shel'fovoy Zon Morya* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: MHI. Iss. 12, pp. 108-119 (in Russian).

12. Kotelianets, E.A. and Konovalov, S.K., 2012. Trace Metals in Bottom Sediments of the Kerch Strait. *Morskoy Gidrofizicheskiy Zhurnal*, (4), pp. 50-60 (in Russian).

13. Sapozhnikov, V.V., Kumantsov, M.I., Agatova, A.I., Arzhanova, N.V., Lapina, N.M., Roi, V.I., Stolyarskii, S.I., Bondarenko, L.G., Panov, B.N. [et al.], 2011. Complex Investigations of the Kerch Strait. *Oceanology*, 51(5), 896. doi:10.1134/S0001437011050146

14. Zhugaylo, S.S., 2015. Monitoring of the Water Quality in the Kerch Strait and Pre-Strait Area of the Black Sea under Current Conditions. *Monitoring Systems of Environment*, 1, pp. 63-66 (in Russian).

15. Zhugaylo, S.S., Sebakh, L.K., Shepeleva, S.M., Zagayny, N.A. and Ivanyuta, A.P., 2011. Dynamics of the Main Hydrochemical Characteristics of the Kerch Strait Water Quality in Current Conditions. In: *Main Results of Complex Research in the Azov-Black Sea Basin and the World Ocean*. Kerch: YugNIRO, pp. 137-146 (in Russian).

16. Gurov, K.I., Kurinnaya, Yu.S. and Kotelyanets, E.A., 2021. Features of Accumulation and Spatial Distribution of Microelements in Bottom Sediments of the Crimea Coastal Regions. In: T. Chaplina, ed., 2021. *Processes in GeoMedia - Volume III*. Cham, Switzerland: Springer Geology, pp. 119-130. https://doi.org/10.1007/978-3-030-69040-3_12

17. Nemirovskaya, I.A., Zavialov, P.O. and Khramtsova, A.V., 2021. Hydrocarbons in Water and Bottom Sediments in Kerch Strait. *Water Resources*, 48(2), pp. 263-272. doi:10.1134/S0097807821020081

18. Nemirovskaya, I.A., Zavyalov, P.O., Konovalov, B.V. and Khramtsova, A.V., 2020. Content and Composition of Hydrocarbons in Water and Sediments in the Area of Kerch Strait. *Doklady Earth Sciences*, 492(1), pp. 387-391. doi:10.1134/S1028334X20050177

19. Tikhonova, E.A., Burdiyan, N.V. and Soloveva, O.V., 2017. The Chemical-Microbiological Characteristics of Sea Water and Bottom Sediments of the Kerch Strait and Adjacent Water Areas. *Marine Biological Journal*, 2(3), 75-85. doi:10.21072/mbj.2017.02.3.07 (in Russian).

20. Klenkin, A.A. and Agapov, S.A., 2011. Dynamics of Oil Product Distributions in Water and Bottom Sediments of the Sea of Azov and the Black Sea after Ship Accidents in the Kerch Strait. *Water Resources*, 38(2), pp. 220-228. doi:10.1134/S0097807811020060

21. Matishov, G.G., Inzhebeikin, Yu.I. and Savitskii, R.M., 2013. The Environmental and Biotic Impact of the Oil Spill in Kerch Strait in November 2007. *Water Resources*, 40(3), pp. 271-284. doi:10.1134/S0097807813020048

22. Eremeev, V.N., Konovalov, S.K. and Romanov, A.S., 1998. The Distribution of Oxygen and Hydrogen Sulfide in Black Sea Waters during Winter-Spring Period. *Physical Oceanography*, 9(4), pp. 259-272. https://doi.org/10.1007/BF02522712

23. Weiss, R.F., 1970. The Solubility of Nitrogen, Oxygen and Argon in Water and Seawater. *Deep Sea Research and Oceanographic Abstracts*, 17(4), pp. 721-735. doi:10.1016/0011-7471(70)90037-9

24. Ljutsarev, S.V., 1986. The Determination of Organic Carbon in the Sea Bottom Sediments by means of Dry Oxidation. *Oceanology*, 26(4), 704-708 (in Russian).

25. Brendel, P.J. and Luther III, G.W., 1995. Development of a Gold Amalgam Voltammetric Microelectrode for the Determination of Dissolved Fe, Mn, O_2, and S(-II) in Porewaters of Marine and Freshwaters Sediments. *Environmental Science & Technology*, 29(3), pp. 751-761. doi:10.1021/es00003a024

26. Luther III, G.W., Brendel, P.J., Lewis, B.L., Sundby, B., Lefrançois, L., Silverberg, N. and Nuzzio, D.B., 1998. Simultaneous Measurement of O_2, Mn, Fe, I^-, and S(-II) in Marine Pore

Waters with a Solid-State Voltammetric Microelectrode. *Limnology and Oceanography*, 43(2), pp. 325-333. doi:10.4319/lo.1998.43.2.0325

27. Ovsyanyi, E.I., Konovalov, S.K., Mitropol'skii, A.Yu. and Kotel'yanets, E.A., 2015. Organic Carbon and Carbonates in the Recent Bottom Sediments of the Kerch Strait. *Geochemistry International*, 53(12), pp. 1123-1133. doi:10.1134/S0016702915120071
28. Khrustalev, Yu.P. and Denisov, V.I., 2001. Features of Distribution of Suspended Matter and Intensity of Its Sedimentation in the Kerch Strait Region of the Black Sea. *Oceanology*, 41(6), pp. 907-916.
29. Kurinnaya, Yu.S., Gurov, K.I., Zabegaev, I.A. and Orekhova, N.A., 2022. Redox Conditions and Characteristics of Bottom Sediments in the Bays of the Sevastopol Region. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 42-54. doi:10.22449/2413-5577-2022-1-42-54

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