Трансформация экосистем
Ecosystem Transformation

ISSN 2619-0931 Online
www.ecosysttrans.com

DOI: https://doi.org/10.23859/estr-240506
EDN: https://elibrary.ru/qyguqj
UDC 57.04: 574.3: 574.5

Article

Monitoring long-term changes in the environment and macrobenthos of the Vostok Bay, the Sea of Japan

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Abstract. The changes of the macrobenthos and environmental characteristics in the Vostok Bay, the Sea of Japan, have been analyzed for the periods starting from the 1970s and 2000s to the present, respectively. Anthropogenic impact on the Vostok Bay has been ongoing for over 150 years: recreational load is rapidly increasing, fishing industry and ship repair enterprises are operating, and the coastline is being actively developed. The water temperature in spring and autumn have increased over the past 20 years, indicating an increase in the heating rate and a decrease in the cooling rate of the bay's water mass at present. This fact contributes to the deterioration of oxygen indicators and stimulates the restructuring of production-destruction processes, affecting the balance of nutrient compounds. The abundance of heterotrophic microorganisms indicates a high content of organic matter in the aquatic environment. Anthropogenic pollution is confirmed by high abundance of enterobacteria (including *E. coli*), as well as a high number of bacteria that degrade oil, diesel fuel, and phenols. The abundance of metal-resistant bacteria reflects the high concentrations of heavy metals in the bay. Macrobenthos community is currently stable. However, the biomass of the Gray mussel and the Kuril horse mussel has significantly decreased over the past 50 years. Cadmium levels exceeding toxicological standards were detected in the soft tissue of Gray mussels. Assessing the human health risk, based on the combined cadmium and lead levels, revealed a significant risk of cancer from continuous consumption of mussel soft tissue during the recreational season and beyond. The ongoing transformation of the Vostok Bay ecosystem requires continuous environmental monitoring and relevant environmental management decisions.

Keywords: marine environment, hydrological parameters, hydrochemical parameters, microbiological assessment, benthic organisms, heavy metals, human health risk, anthropogenic impact, ecosystem transformation

Funding. This work was supported by the Ministry of Education and Science of the Russian Federation, project no. FZNS-2023-0011 "Technologies for monitoring the sustainability of ecosystems of inland and marginal seas of Russia under conditions of global climate change and anthropogenic impact."

Acknowledgements. Our teacher, Nadezhda K. Khristoforova, Doctor of Biological Sciences, Professor, and Honored Scientist of the Russian Federation, began working on this article with a team of authors. This work is dedicated to her memory.

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To cite this article: Galysheva, Yu.A. et al., 2025. Monitoring long-term changes in the environment and macrobenthos of the Vostok Bay, the Sea of Japan. *Ecosystem Transformation* **8** (4), 93–119. https://doi.org/10.23859/estr-240506

Received: 06.05.2024
Accepted: 20.09.2024

DOI: https://doi.org/10.23859/estr-240506

EDN: https://elibrary.ru/qyguqj

УДК 57.04: 574.3: 574.5

Научная статья

Мониторинг долгосрочных изменений среды и макробентоса залива Восток Японского моря

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Аннотация. В статье представлен анализ изменения макробентоса и характеристик среды залива Восток соответственно с 1970-х и 2000-х гг. по настоящее время. Антропогенное воздействие на залив Восток продолжается уже более 150 лет: интенсивно увеличивается рекреационная нагрузка, работают предприятия рыбной промышленности и судоремонта, активно застраивается береговая линия. Весенние и осенние значения температуры воды за последние 20 лет увеличились, что свидетельствует о нарастании скорости прогрева и уменьшении скорости охлаждения водной массы залива в настоящее время. Данный факт способствует ухудшению кислородных показателей и стимулирует перестройку продукционно-деструкционных процессов, отражающихся на балансе соединений биогенных элементов. Численность гетеротрофных микроорганизмов свидетельствует о высоком содержании органического вещества в водной среде. Антропогенное загрязнение подтверждается высокими уровнями энтеробактерий (в том числе кишечной палочки), а также высокой численностью бактерий-деструкторов нефти, дизельного топлива и фенолов. Численность металл-резистентных бактерий отражает высокий уровень содержания тяжелых металлов в водной среде залива. Макробентос на современном этапе стабилен. Однако биомасса мидии Грея и модиолуса курильского за последние 50 лет достоверно снизилась. В мягких тканях мидии Грея из залива обнаружено превышение допустимых токсикологических норм в отношении кадмия. Расчет риска здоровью человека по совокупному содержанию кадмия и свинца показал существующую опасность возникновения онкологических заболеваний при непрерывном потреблении мягких тканей мидий в течении рекреационного сезона и более длительного времени. Происходящая трансформация экосистемы залива Восток требует постоянного экологического мониторинга и управленческих решений в области природопользования.

Ключевые слова: морская среда, гидрологические параметры, гидрохимические параметры, микробиологическая оценка, донные организмы, тяжелые металлы, риск здоровью человека, антропогенное воздействие, трансформация экосистем

Финансирование. Работа выполнена при поддержке Минобрнауки России, проект FZNS-2023-0011 «Технологии мониторинга устойчивости экосистем внутренних и окраинных морей России в условиях глобального изменения климата и антропогенного воздействия».

Благодарности. Над статьей вместе с коллективом авторов начинала работать д.б.н., профессор, Заслуженный деятель наук РФ Надежда Константиновна Христофорова – наш учитель. Работа посвящается ее памяти.

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Для цитирования: Галышева, Ю.А. и др., 2025. Мониторинг долгосрочных изменений среды и макробентоса залива Восток Японского моря. *Трансформация экосистем* **8** (4), 93–119. https://doi.org/10.23859/estr-240506

Поступила в редакцию: 06.05.2024
Принята к печати: 20.09.2024

Introduction

Vostok Bay is located in the Sea of Japan southwest of Nakhodka city (Primorsky Krai, Russia); it is bounded by the capes Podosyonov and Peshchurov. The bay is relatively small, its area is approximately 36 km^2; it intrudes into the coastline by ~8 km; the maximum depth is 31 meters.

The development of the Vostok Bay began in the mid-19th century, with anthropogenic impact steadily increasing and continuing for over 150 years. Detailed hydrographic descriptions of the bay and its inlets were first conducted in 1861–1863 by Russian sailors led by A. Peshchurov, commander of the clipper ship "Gaidamak"[1]. Subsequent development of the bay and the establishment of settlements along its shores were associated with coastal fishing and fish processing.

In the mid-20th century, shipyards and agar production plants were built on the coast. By the mid-1970s, the population of the settlements along the bay's shores had grown significantly, and municipal infrastructure had developed. The fishing collective farm and ship repair yard expanded their capacity and became the town's mainstays. In 1992, the Gaidamak Ship Repair Yard was converted into a joint-stock company, significantly reducing production, and ultimately ceasing operations for several years. In March 2001, the yard resumed operations under a new name, LLC RPK Poseidon, which retained its core business (ship repair).

In addition to the industrial cluster, a scientific research centre was also developed at the Vostok Bay in the second half of the 20th century. In 1971, construction[2] of the Marine Biological Station of the Institute of Marine Biology of the Far Eastern Scientific Centre "Vostok" (Kashenko, 1976) has started in Tikhaya Zavod' Inlet. It has since become a modern scientific centre. The biological station is designed for marine research in various fields. Since the early 1970s, comprehensive marine research has been conducted in the Vostok Bay.

In 1989, the Marine Reserve "Zaliv Vostok" was established; it became part of the Far Eastern Branch of the Russian Academy of Sciences (Tyurin, 1996). The reserve is bounded by a line connecting capes Pushchino and Elizarova, with a 50-m-wide sanitary zone. The reserve purpose is to preserve and restore the natural complexes of the Vostok Bay to their natural state, to maintain the ecological balance and rational use of natural resources, mariculture plantations, and recreational areas[3].

In 2016-2017, construction of a petrochemical complex of the Eastern Petrochemical Company (EPCC) was planned on the eastern shore of the bay (Cape Elizarova), which could lead to the changes in the chemical composition of seawater and also impact negatively the ecosystem and biodiversity. Scientists were concerned about the emerging problem; they formulated a rationale for locating the EPCC and its terminal east of Wrangel Inlet in Nakhodka Bay (Barysheva et al., 2019; Vyshkvartsev, 2010). In 2021, the project was approved, and the EPCC will be built in the port of Nakhodka. However, land plots on the eastern coast of the Vostok Bay between Cape Elizarova and Cape Podosenov are still considered as a part of the port; the project is planned to be completed by 2030, despite criticism from environmental scientists (Vyshkvartsev, 2010).

Poaching is also present in the study area. In just four months (January–April, 2020), inspectors conducted more than 50 raids and seized approximately 1.6 km of fishing nets[4] in the Marine Reserve "Zaliv Vostok".

According to official statistics, the permanent population of the settlements on the coast of the Vostok Bay is currently over 10000: 973 people in Avangard settlement; 134, in Livadia; 2903, in Volchanets; 695, in Novo-Litovsk; 6000, in Yuzhno-Morskoy. The Dushkino settlement, located upstream along the Volchanka River, also influences the bay with a population of 563 people[5]. The number of people on the

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[1] Vostok Bay. Web page. URL: http://territoriya.nakhodka-lib.ru/geografy/zaliv%20vostok.htm (accessed: 09.03.2022).

[2] Marine biological station "Vostok". Web page. URL: http://www.mbsvostok.ru/ (accessed: 23.12.2021).

[3] Primorye Nature Reserve: Marine Energy of the Vostok Bay Nature Reserve. Web page. URL: https://primamedia.ru/news/502737/ (accessed: 14.11.2021).

[4] Online version of the 'Vladivostok' newspaper, no. 4675 (6380) dated April 24, 2020. More than 1.5 kilometers of nets were confiscated in the marine reserve. Web page. URL: https://vladnews.ru/ev/vl/4675/126624/bolee_kilometra (accessed: 09.03.2022).

[5] Territorial body of the Federal State Statistics Service for Primorsky Krai. Population. Web page. URL: https://25.rosstat.gov.ru/folder/27118 (accessed: 09.03.2022).

shores of the bay varies significantly by season, reaching a maximum from early July to late September due to intense recreational pressure (Galysheva et al., 2022).

Today, the Vostok Bay remains one of the cleanest coastal waters in Primorye, attracting numerous tourists to its picturesque shores. A ship repair and fish processing plant, as well as the "Pacific Ocean" fishing collective farm, continue to operate in Gaydamak Inlet, and virtually the entire coastline of the bay is being actively developed and built upon. Long-term environmental management in the coastal and offshore zones of the Vostok Bay has inevitably affected its ecosystem, manifesting itself both as the changes in environmental components and in the bay's biota. Therefore, the study aims to analyze long-term changes in the characteristics of seawater and macrobenthos in the Vostok Bay, based on data obtained during the entire period of scientific observations, conducted here from the early 1970s to the present (a total of ~50 years), and to assess the environmental risk.

Materials and methods

The original data were obtained in the scientific expeditions performed in 2020 (July, October) and 2021 (May, July), each covering 21 stations (Fig. 1). Archive data included that obtained previously by the authors of this article and published data from other authors; the pooled dataset was used for comparative analysis.

Hydrological analysis

The parameters of the water column (temperature, salinity, dissolved oxygen and chlorophyll *a* concentrations) were determined using an autonomous ASTD102 10-Hz CTD-probe (JFE Advantech Co Ltd., Japan). Based on the results of primary processing of CTD-data, performed using original software products (Lazaryuk and Kosheleva, 2014), series of measured hydrological parameters were obtained with a depth lag of 0.5 m (z), optimal for subsequent analysis.

Microbiological analysis

Water samples were collected in July 2020 and May 2021 from the subsurface layer (10–20 cm), placed in sterile plastic containers and transported to the laboratory for analysis in accordance with GOST R 31861-12[6] and GOST R 31942-12[7]. Samples were analyzed in triplicate, observing sample storage periods. The quality of surface waters in the Vostok Bay was assessed by the abundance of several ecotrophic groups of microorganisms (MO): colony-forming heterotrophic microorganisms (HM), hydrocarbon-oxidizing microorganisms (ORB, oil-resistant; DRB, resistant to diesel fuel), phenol-resistant microorganisms (PRB), coliform bacteria (CB), and metal-resistant bacteria (MRB).

The total number of HM was analyzed on the medium for marine microorganisms (MMOM) with the addition of 1.5% agar (Nalivaiko, 2006; Yochimizu and Kimura, 1976). The abundance of oligotrophs (per 1 mL of water) was assessed on solid Mills medium modified for marine microorganisms (Ilyinsky et al., 2010). The most probable number of bacteria of the ecophysiological groups ORB, DRB, and PRB was estimated based on the tenfold dilution method using elective media. Yeast extract (0.005%) with mineral salts was used as a basis for the preparation of elective media, to which oil, diesel fuel, or phenol were added at a final concentration of 0.1% as the only carbon source for bacterial development (Rukovodstvo..., 1980). The number of MRB forms in the community of heterotrophic cultured MO was determined by the plate method using meat-peptone agar (MPA) with the addition of metal salts in concentrations inhibiting the growth of sensitive forms of bacteria. Chlorides of Zn, Cu, Cd, Ni, Pb were used as the additives (Dimitrieva and Bezverbnaya, 2002). Resistance testing was performed element by element for all collected samples (in triplicate). CB was detected using Endo's selective medium. Catalase-positive and oxidase-negative gram-negative bacteria were identified (Rukovodstvo..., 1980). Arithmetic means with standard deviations were calculated for all parameters. A total of 29 surface water samples were collected, and 870 cultures were performed.

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[6] GOST R 31861-2012. Water. General requirements for sampling.

[7] GOST R 31942-2012 (ISO 19458:2006). Water. Sampling for microbiological analysis.

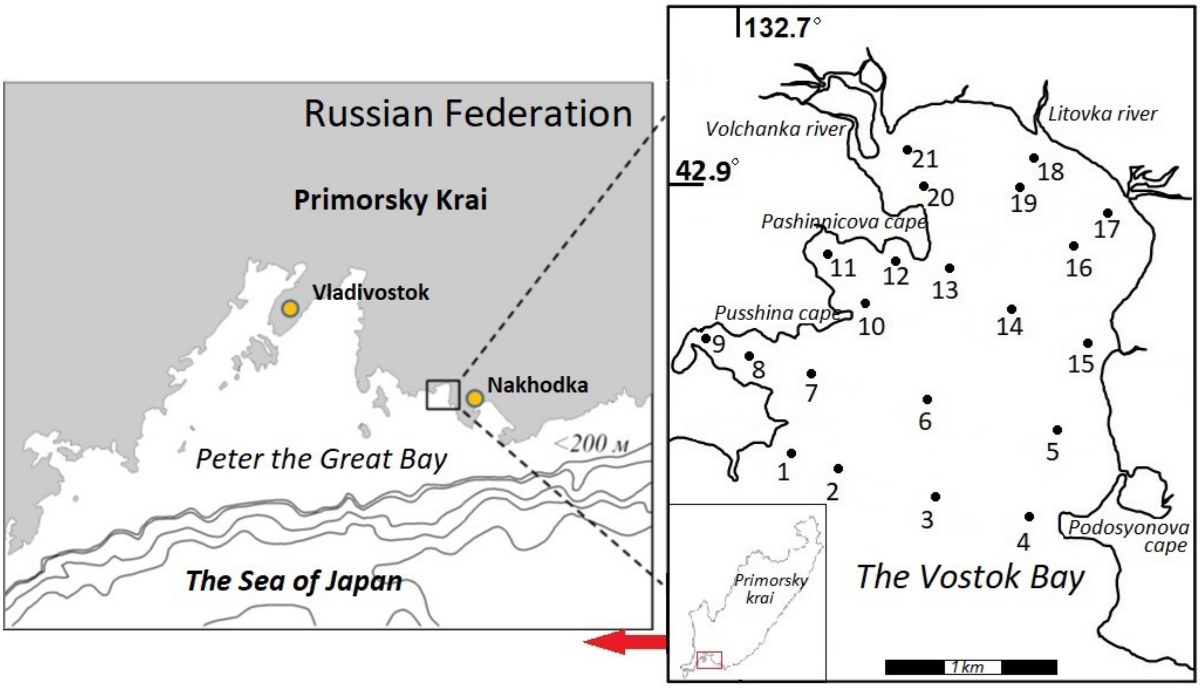

Fig. 1. Sampling sites in the Vostok Bay, the Sea of Japan.

Macrobenthos analysis

Quantitative samples of macrobenthos were collected in July 2020 and May 2021 in triplicates from each station by a scuba diver using a 1-m^2 hydrobiological sampling frame (for sampling epibenthos) and a 0.025-m^2 bottom grab (for sampling infauna). A total of 126 quantitative samples of macrobenthos were collected. Primary processing of the samples was performed the same day at the Vostok Marine Biological Station of the A.V. Zhirmunsky National Scientific Center of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences. Laboratory processing included the sample analysis for main taxonomic groups' identification, species identification, measuring and subsequent calculating of biomass (g/m^2) and population density (ind./m^2). These analyses were performed in the "Marine Ecology" Laboratory of the International UNESCO Department, Institute of the World Ocean, Far Eastern Federal University. The taxonomic analysis was carried out under Zeiss Stemi 2000C stereoscopic microscope; weighting, using laboratory scales DemCom DL-2002 (0.001-g accuracy). The systematic position of organisms is given according to the list of free-living invertebrates of the Far Eastern seas (Spisok..., 2013), as well as the worldwide electronic databases WORMS[8] and AlgaeBase[9].

Heavy metal content analysis and environmental risk assessment

Heavy metals were determined in two common species of bivalve mollusks (*Modiolus Kurilensis* F.R. Bernard, 1983 and *Crenomytilus grayanus* Dunker, 1853), collected in October 2020. Large, sexually mature mollusks of similar size were collected by scuba divers at each station, cleaned of sand, stones, and fouling algae, thoroughly washed in seawater with a stiff brush, and placed in plastic containers with regularly changed seawater for 48 hours to remove pseudofeces. After defecation was completed, the mollusks were dissected, the byssal threads were removed, and the soft tissues were then removed from the valves, transported to the university laboratory, and frozen for storage. Before chemical analysis, the mollusks were dried at 85 °C for 2–3 days to constant weight and then homogenized mechanically. Each individual was analyzed separately for tissue mineralization. Mineralization was performed in a MARS 6 microwave digestion system according to GOST R 26929-94[10].

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[8] Word Register of Marine Species. Web page. URL: https://www.marinespecies.org (accessed: 14.03.2024).

[9] AlgaeBase. Web page. URL: https://www.algaebase.org/browse/taxonomy (accessed: 14.03.2024).

[10] GOST R 26929-94. Food raw materials and products. Sample preparation. Mineralization for determining toxic element content.

Concentrations of Fe, Cu, Mn, Zn, Cd, Ni, and Pb were determined using atomic absorption spectrophotometry (AAS) on a Shimadzu AA-6800 instrument in a flame (Cu, Fe, Mn, Ni) and graphite furnace (Cd, Zn, Pb) in the Centre for Collective Use of the Centre for Landscape Diagnostics and GIS Technologies of the Pacific Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences. The accuracy of measurements was justified by standards with known trace element concentrations. A total of 50 mussel tissue samples were analyzed, 300 elemental determinations were performed.

Each station was characterized by the average concentration of elements based on soft tissue analysis of five individuals. To determine the geochemical anomaly coefficient for metal content in mollusks, a metal concentration coefficient was calculated:

$$K_c = C_i / C_{bi},$$

where C_i is the maximum actual concentration, and C_{bi} is the background concentration of the i-th metal, which upper value of the background range was previously published for the mollusks collected near Reineke Island (Shulkin, 2004).

To determine the magnitude of individual carcinogenic risk when exposed to non-threshold toxicants (Cd and Pb), a methodology developed by the United States Environmental Protection Agency was used, and the ILCR coefficient (Incremental Lifetime Cancer Risk) was calculated. This ratio estimates the increasing lifetime risk of developing cancer when consuming a product over a given period of time; it is widely used in Canada and the United States[11].

Results

Hydrological characteristics of surface waters

According to research conducted in 2020–2021 in the Vostok Bay, surface waters warm up faster than bottom waters in May, reaching an average temperature of 13 °C (Fig. 2). In July, the water temperature in the surface layer approaches 20 °C on average, while in the bottom layers it remains relatively cool, up to 14–16 °C in shallow water and up to 11–12 °C at the depths below 20 m. In October, the surface layer cools faster than the bottom layer; during the survey, the temperature of most of the bay's water mass was virtually uniform, averaging approximately 15 °C (Fig. 3**A**). Data on the hydrological, hydrochemical, and microbiological parameters of the bay were partially published earlier (Khristoforova et al. 2023). Spatially, the greatest temperature unevenness in the surface layer is observed in spring, when the difference between the inner part of the bay and its mouth is approximately 3 °C (Fig. 3**A**). In summer and autumn, the water temperature of the upper water layer is fairly the same in different parts of the bay.

The salinity of the surface layer is lower than that of the bottom layer in all seasons. The greatest difference between the layers is observed in spring, up to 3 psu (practical salinity units, equivalent to per thousand). The western part of the bay is characterized by lower salinity values in the surface water layer than the eastern part, which is especially pronounced in spring and summer (Fig. 3**B**). In autumn, salinity of the surface water layer is the same in the entire bay. As the depth increases, the water mass becomes more uniform in terms of salinity. The maximum salinity value (33.6 psu) has been recorded in the bottom layer at station 2 in autumn, and the minimum (25.7 psu), in the surface layer at st. 1 (bay outlet, Cape Tafuin) in May.

According to CTD-probe profiling, chlorophyll *a* concentration has a noticeable difference when comparing the surface and bottom water layers in all observation seasons; this parameter increases in both layers from spring to autumn (Fig. 3**C**). In all seasons, chlorophyll *a* concentration was higher in both surface and bottom waters in the western part of the bay. The maximum concentration (4.9 μg/dm^3) was recorded in October in the near-bottom water at st. 20.

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[11] Risk Assessment for Carcinogenic Effects. Web page. URL: https://www.epa.gov/fera/risk-assessment-carcinogenic-effects (accessed: 23.09.2025).

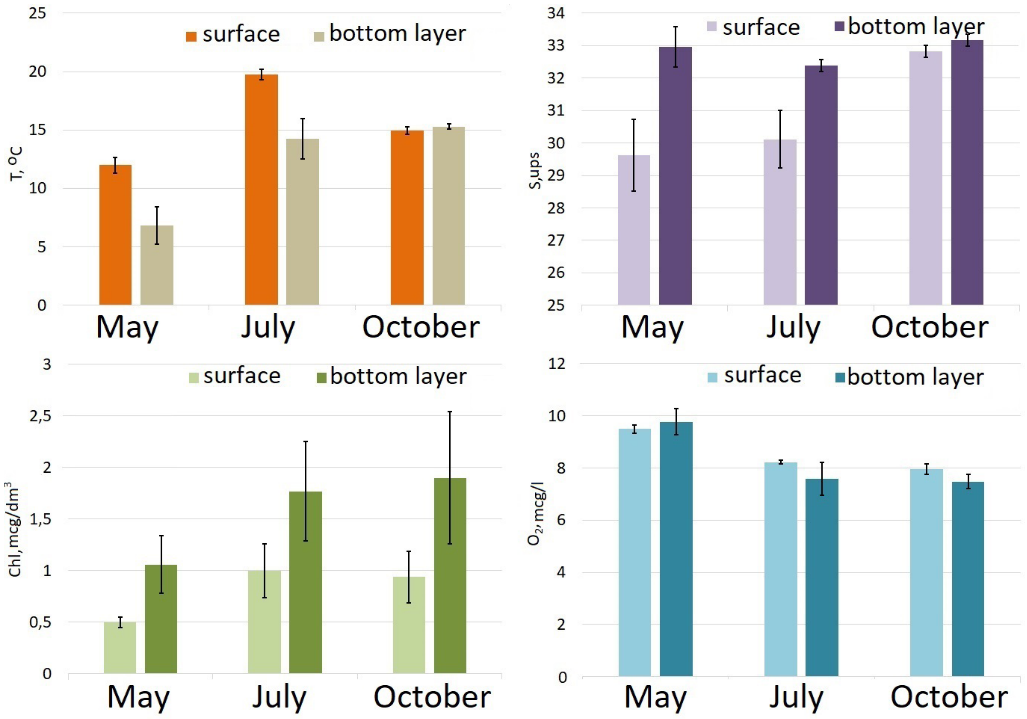

Fig. 2. Seasonal changes in hydrological parameters in the Vostok Bay based on data from July, October 2020 and May 2021. Data are presented as mean ± error of the mean.

The average dissolved oxygen concentration (DOC), measured by CTD in the Vostok Bay, shows a characteristic downward trend from spring to autumn (from 9.6–9.8 to 7.7–8.0 mg/L); these values fit the sanitary standard (Perechen'..., 1999). However, O_2 concentrations of less than 6 mg/L were still recorded in the near-bottom water layers in July and October (Fig. 3**D**). The presence of reduced O_2 background concentrations in the bottom layer indicates the preconditions for the emergence of localized zones of ecological risk (hypoxia) in various parts of the Vostok Bay. The absolute DOC maximum (10.65 mg/L) near the bottom has been recorded in spring near Cape Elizarov (st. 15), the minimum (~4.7 mg/L), in the summer near Cape Pashinnikov (st. 13) and in the autumn at the mouth of Gaydamak Inlet.

Microbiological assessment of surface waters

Microbiological assessment has been conducted only in the spring and summer. A general idea of water purity is provided by data on the content of heterotrophs, which consume dissolved organic matter. In the spring, quantitative HM indicators were low, indicating oligosaprobic water quality at the time of sampling.

The abundance of heterotrophs reaches the expected high values of $1.2 \cdot 10^4$ CFU/mL in the apex of the Gaydamak Inlet (st. 9), which is under the greatest anthropogenic impact. In the area of Cape Tafuin (st. 1), *Escherichia coli* (Migula 1895) has been recorded. Its appearance in the area of Cape Tafuin is quite logically explained by the removal of contaminated waters from the Gaydamak Inlet. In summer, HM abundance is quite high, generally $1 \cdot 10^3$–$1 \cdot 10^4$ CFU/mL, with a maximum recorded in the mouth of the Volchanka River, 10^5 CFU/mL (Table 1). Coliform bacteria (CB) stand out in the general pool of heterotrophs; they are found at all coastal stations in summer ($1 \cdot 10$–$1 \cdot 10^2$ CFU/mL), but are not detected in the central part of the bay and its mouth. *E. coli* is found in the summer in Gaydamak and Srednyaya inlets (up to $1 \cdot 10^2$ CFU/mL), which indicates stable fecal pollution of this area.

MRB have low concentrations during the spring season (Table 2). In summer, $1 \cdot 10^3$ Ni- resistant, as well as Cu- and Zn-resistant MOs, were detected in the northern corner of the bay (stations 18, 20, 21). the Gaydamak Inlet (stations 8 and 9) was characterized by a high abundance of Pb-resistant MOs in the summer.

Oil-resistant MO are detected in the surface waters of the Vostok Bay everywhere in both spring and summer, ranging $1 \cdot 10^2$–$1 \cdot 10^3$ CFU/mL (Table 3). Diesel-resistant MO are also found in both seasons at almost all stations, reaching $1 \cdot 10^4$ CFU/mL in July. A similar distribution pattern is observed for the

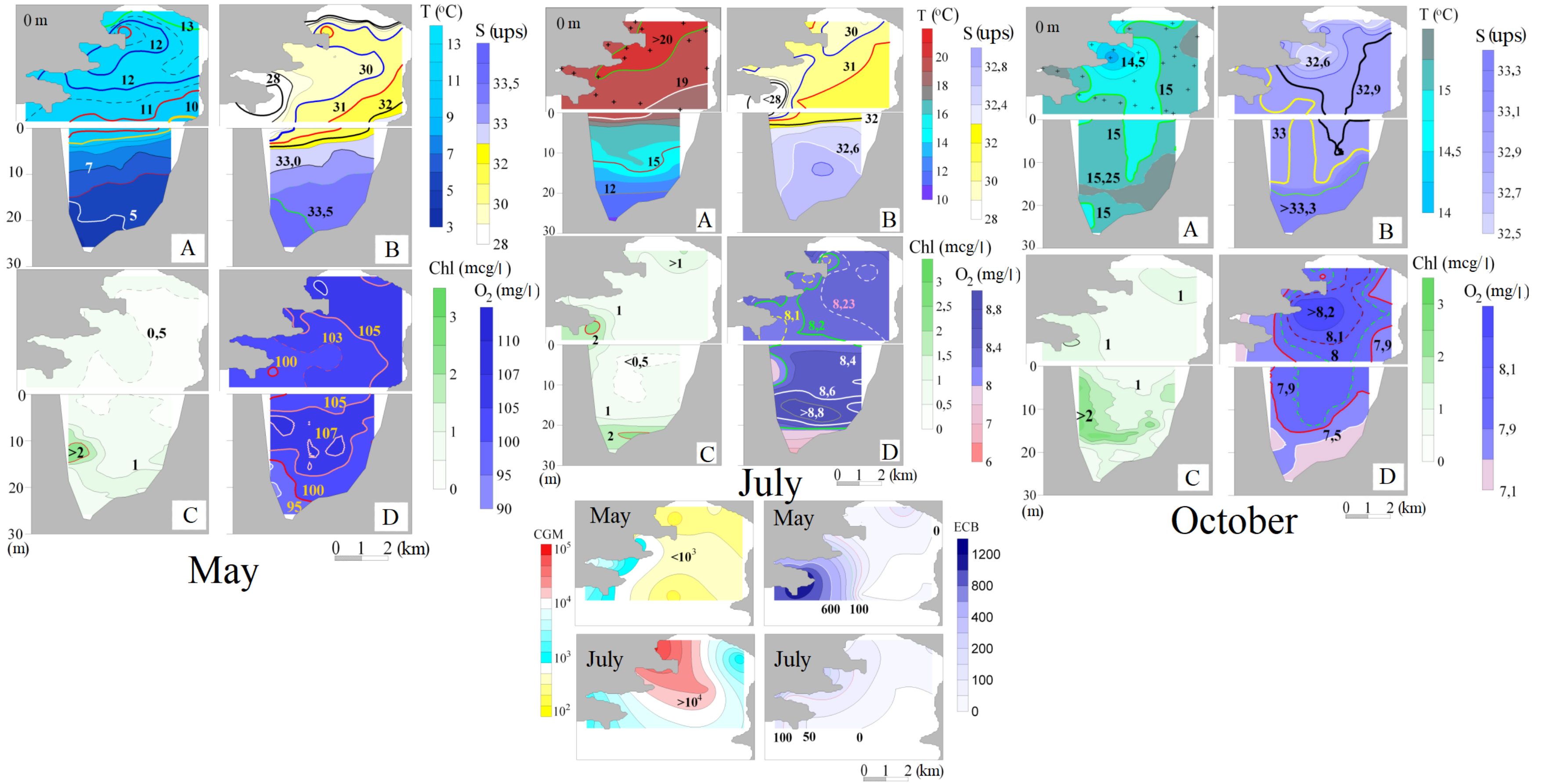

Fig. 3. Spatial distribution of temperature, T (**A**); salinity, S (**B**); chlorophyll *a* content, Chl (**C**); and dissolved oxygen, O_2 (**D**), at the water surface and near the bottom, and in the mouth of the Vostok Bay in 2020–2021 (the data was partly published in Khristoforova et al., 2023).

Table 1. HM and CB abundance in surface waters in the Vostok Bay in July 2020 and May 2021 (data published in the article by Khristoforova et al., 2023). *E. coli* abundance is shown in bold. Here and in Tables 2–9, data are presented as mean ± error of the mean; n.d. – no data. Values above the line are total CB abundance, below the line, *E. coli* abundance.

Station number	Area	HM, July 2020	CB, July 2020	HM, May 2021	CB, May 2021
1	Cape Tafuin	н/д	н/д	$(9.8 \pm 0.7)\times10^{2}$	$(1.3\pm0.6\times10^{3}$ **$(2.0\pm1.0)\times10^{2}$**
3	Exit from the Vostok Bay (central part)	$(8.5 \pm 0.4)\times10^{3}$	0	$(2.2 \pm 1.3)\times10^{2}$	0
4	Cape Podosenov	$(8.0 \pm 0.9)\times10^{3}$	0	$(3.7 \pm 1.1)\times10^{2}$	0
5	Antares Inlet	$(9.2 \pm 0.3)\times10^{3}$	0	$(6.2 \pm 0.6)\times10^{2}$	0
6	The center of the Vostok Bay	$(2.7 \pm 1.3)\times10^{4}$	0	$(5.4 \pm 0.7)\times10^{2}$	0
7	Exit from Gaydamak Inlet	n.d.	n.d.	$(5.2 \pm 0.7)\times10^{3}$	$(5.6 \pm 0.8)\times10^{2}$ **$(1.6 \pm 0.5)\times10^{2}$**
8	Cape Tchaikovsky	$(3.0 \pm 0.3)\times10^{3}$	$(4.0 \pm 1.0)\times10$	n.d.	n.d.
9	Gaydamak Inlet (the inner part)	$(6.7 \pm 0.1)\times10^{4}$	$(3.5 \pm 0.5)\times10^{2}$ **$(1.1 \pm 0.6)\times 10^{2}$**	$(1.2 \pm 0.5)\times10^{4}$	$(4.6 \pm 1.5)\times10^{2}$ **$2.1 \pm 0.3)\times10^{2}$**
10	Cape Pushchin	$(5.2 \pm 0.5)\times10^{4}$	0	n.d.	n.d.
11	Srednyaya Inlet (Podsobnaya)	$(4.2 \pm 1.1)\times10^{4}$	$(1.0 \pm 1.2)\times10^{2}$ **$(2.8 \pm 0.6)\times10$**	$(4.5 \pm 1.4)\times10^{2}$	0
12	Srednyaya Inlet (Pervaya Priboynaya Inlet)	$(2.3 \pm 0.7)\times10^{4}$	$(2.8 \pm 0.2)\times10^{2}$ **$(4.1 \pm 0.8)\times10$**	$(1.1 \pm 0.8)\times10^{2}$	$(2.0 \pm 1.0)\times10^{2}$ **$(1.5 \pm 0.3)\times10^{2}$**
13	Cape Pashinnikov	$(1.4 \pm 0.4)\times10^{3}$	0	$(4.5 \pm 1.4)\times10^{2}$	0
15	Cape Elizarov	$(1.0 \pm 0.2)\times10^{3}$	0	$(4.5 \pm 0.3)\times10^{2}$	$(1.6 \pm 1.1)\times10^{2}$
17	Litovka Inlet	$(1.0 \pm 0.7)\times10^{3}$	$(2.6 \pm 0.6)\times10$	n.d.	n.d.
18	The village of Volchanets (mouth of the Litovka River)	$(1.3 \pm 0.8)\times10^{4}$	$(1.2 \pm 0.1)\times10$	$(2.5 \pm 1.2)\times10^{2}$	$(1.0 \pm 0.1)\times10$
20	Marine biological station "Vostok"	$(2.2 \pm 0.7)\times10^{4}$	$(4.0 \pm 0.4)\times10$	$(1.9 \pm 0.7)\times10^{2}$	0
21	Mouth of the Volchanka River (Tikhaya zavod Inlet)	$(1.3 \pm 0.8)\times10^{5}$	$(2.1 \pm 0.2)\times10$	$(4.5 \pm 0.9)\times10^{2}$	0

Table 2. Abundance of metal-resistant MO at sampling stations in the Vostok Bay in July 2020 and in May 2021 (the data was partly published in Khristoforova et al., 2023). Maximum values are shown in bold. Here and in Tables 3–9, station no. numbers are given according to Table 1.

Statiom number	Metal-resistant groups of microorganisms (CFU/mL)									
	July 2020					May 2021				
	Cu	Ni	Zn	Pb	Cd	Cu	Ni	Zn	Pb	Cd
1	n.d.	n.d.	n.d.	n.d.	n.d.	$(2.0 \pm 0.1)\times10$	$(7.0 \pm 0.4)\times10$	$(3.0 \pm 0.3)\times10$	0	0
3	0	$(3.0 \pm 1.1)\times10^2$	0	0	0	0	0	0	0	0
4	0	$(2.1 \pm 0.3)\times10$	0	0	0	0	$(7.0 \pm 0.2)\times10$	0	0	0
5	$(2.1 \pm 0.2)\times10$	$(3.7 \pm 0.4)\times10$	0	0	0	$(1.0 \pm 0.2)\times10$	0	0	0	0
6	0	$(2.5 \pm 0.7)\times10^2$	0	$(4.5 \pm 0.1)\times 10$	0	$(2.5 \pm 0.5)\times10$	$(1.8 \pm 1.1)\times10^2$	0	$(1.5 \pm 0.5)\times10$	0
7	n.d.	n.d.	n.d.	n.d.	n.d.	$(2.5 \pm 0.7)\times10$	$(3.5 \pm 0.5) \times 10^2$	$(9.5 \pm 0.7)\times10$	0	0
8	$(2.4 \pm 0.2)\times10^2$	$(1.5 \pm 0.4)\times10^2$	$(1.5 \pm 0.4)\times10^3$	**$(1.3 \pm 0.4)\times10^2$**	0	n.d.	n.d.	n.d.	n.d.	n.d.
9	**$(8.8 \pm 0.3)\times10^3$**	$(2.3 \pm 0.5)\times10$	$(2.0 \pm 0.6)\times10^2$	**$(4.8 \pm 0.5)\times10^2$**	0	$(1.5 \pm 0.7)\times10^2$	$(1.5 \pm 0.4)\times10^2$	$(1.5 \pm 0.5)\times10^2$	0	0
10	0	$(9.2 \pm 0.8)\times10^2$	0	0	$(1.4 \pm 0.2)\times10$	n.d.	n.d.	n.d.	n.d.	n.d.
11	$(6.2 \pm 0.6)\times10^2$	$(7.1 \pm 0.8)\times10^2$	0	0	0	0	$(3.5 \pm 1.3)\times10^2$	$(2.0 \pm 0.6)\times10$	0	0
12	0	0	0	$(7.5 \pm 0.7)\times10$	0	0	$(3.3 \pm 0.7)\times10$	$(1.2 \pm 0.4)\times10^2$	$(1.0 \pm 0.2)\times10$	0
13	$(1.2 \pm 0.4)\times10$	$(4.3 \pm 0.4)\times10^2$	0	0	0	0	$(1.2 \pm 1.1)\times10^2$	$(2.5 \pm 1.1)\times10^2$	0	0
15	0	$(5.2 \pm 0.4)\times10^2$	0	0	0	0	$(1.5 \pm 0.7) \times 10^2$	$(2.0 \pm 0.7)\times10$	0	0
17	0	$(2.2 \pm 0.2)\times10$	0	$(4.0 \pm 0.5)\times10$	0	n.d.	n.d.	n.d.	n.d.	n.d.
18	**$(9.6 \pm 0.3)\times10^3$**	**$(1.7 \pm 0.5)\times10^3$**	**$(7.8 \pm 0.2)\times10^3$**	0	$(1.6 \pm 0.5)\times10$	0	$(4.6 \pm 1.2)\times10$	$(1.0 \pm 0.2)\times10$	0	0
20	$(1.2 \pm 0.4)\times10$	0	0	0	0	0	0	0	0	0
21	**$(5.9 \pm 0.6)\times10^3$**	**$(2.6 \pm 1.1)\times10^3$**	**$(5.3 \pm 0.4)\times10^3$**	0	$(1.3 \pm 0.5)\times10$	0	$(1.0 \pm 0.7)\times10^2$	0	0	0

phenol-degrading group of bacteria, reaching $1 \cdot 10^4$ CFU/mL in summer. For all the hydrocarbon-resistant MO analyzed, the overall abundance in May is an order of magnitude lower than in July. The maximum abundance of these bacteria groups is observed in the northern apex of the bay.

Macrobenthos

In total, 86 species of benthic invertebrates, algae, and seagrasses are found in the samples collected in 2020–2021. No new taxa were identified in the area. The average biomass of macrobenthos is ~1800 g/m^2. Only 15 species account for at least 1% of the total average biomass; they are designated as common species (Table 4). Some data obtained during survey in July 2020 are presented in the report by V.A. Chichenko (2022), supervised by Yu.A. Galysheva.

The eelgrass *Zostera asiatica* Miki has the highest average biomass in the bay, followed by Gray mussel *Crenomytilus grayanus* Dunker, 1853.

Stringy acid kelp *Desmarestia viridis* O.F. Müller (J.V. Lamouroux) is a dominant algae in the bay. Kuril horse mussel *Modiolus kurilensis* Linnaeus, 1758 and the Japanese scallop *Mizuhopecten yessoensis* (Jay, 1857) have approximately the same average biomass. Dominant species also include common eelgrass *Zostera marina* Linnaeus, sea urchin *Mesocentrotus nudus* (A. Agassiz, 1864), seersucker kelp *Costaria costata* (C. Agardh) De A. Saunders, brown algae *Saccharina cichorioides* (Miyabe) C.E. Lane, C. Mayes, Druehl & G.W. Saunders, bivalve mollusks *Mytilus coruscus* A. Gould, 1861 and *Swiftopecten swiftii* (Bernardi, 1858), sea urchins *Strongylocentrotus intermedius* (A. Agassiz, 1864) and *Scaphechinus mirabilis* A. Agassi , 1864, starfish *Patiria pectinifera* (Muller & Troschel, 1842) and *Asterias amurensis* Lutken, 1871.

The sampling stations in the Vostok Bay Nature Reserve comprise several ecotopes: foothills of capes with rocky platforms (stations 10, 13, 18), boulder scatterings (stations 15, 20), sandy plains (stations 11, 12, 17, 19), and muddy (silted) beds (stations 14, 16). The starfish *P. pectinifera* has the greatest distribution and frequency of occurrence at all four ecotope types. *Desmaretia viridis* is widespread on hard substrates. Mytilid bivalves (C. *grayanus*, *M. coruscus*, *M. kurilensis*) and spherical sea urchins (*M. nudus* and *S. intermedius*) prefer ecotopes with a predominance of rocky and bouldery grounds. The flat sea urchin *S. mirabilis* and eelgrasses of the genus *Zostera* are common on soft sandy substrates (Fig. 4). Therefore, the mass species of macrobenthos still coincide with the dominants identified in the composition of the bottom communities of the Vostok Bay earlier (Galysheva, 2004; Galysheva and Pustovalova, 2009; Galysheva and Yakovleva, 2007; Pogrebov and Kashenko, 1976; Tarasov, 1978).

Content of heavy metals in common aquatic species

The heavy metal concentrations in the Kuril horse mussel vary greatly: Fe (116.80–335.05), Zn (93.32–429.67), Cu (7.17–38.59), Ni (3.40–6.00), Pb (0.12–1.45), and Cd (2.17–3.60 μg/g dry weight) (Table 5). In the Gray mussel, these are Fe (66.3–336.63), Zn (77.50–359.23), Cu (3.96–16.97), Ni (2.03–4.01), Pb (0.12–1.29), and Cd (2.75–7.76 μg/g dry weight). The geochemical anomaly coefficients vary for the Kuril horse mussel as: Fe (0.49–1.11), Zn (0.13–0.62), Cu (0.15–0.76), Ni (0.95–1.54), Pb (0.03–0.08), Cd (0.18–0.31), for the Gray mussel, Fe (0.68–3.28), Zn (0.74–3.44), Cu (0.91–3.84), Ni (0.78–1.62), Pb (0.15–1.28), Cd (0.32–0.81). Thus, in the Kuril horse mussel only nickel and iron accumulate above the background level of values (for these elements $K_c > 1$), in the Gray mussel, all of the studied metals except cadmium.

In the tissues of *M. kurilensis*, three metals (Zn, Cu, Ni) have a wider range of content compared to *C. grayanus.* On the contrary, the variability of Fe and Cd content is greater for Gray mussel. In general, for most metals (except lead and cadmium), higher contents are characteristic of *M. kurilensis*. This is explained primarily by the fact that this species inhabits silty sediments, where the metals' content in the environment is increased due to the association with organic matter of detritus (Shulkin, 2004), and due to the adaptation of mollusks to such conditions, i.e., a decrease in biological control over their intake (Khristoforova et al., 1993).

Spatial variability in heavy metal accumulation by mollusks is examined based on the distribution of trace elements in Gray mussel. At station 5 (Lake Lebedinoye area), maximum concentrations of virtually all analyzed heavy metals (except cadmium) are found; the geochemical anomaly coefficients for Fe, Zn, Cu, Ni, and Pb are 3.28, 3.44, 3.84, 1.62, and 1.28, respectively.

Table 3. Abundance of MO resistant to oil, diesel fuel, and phenols in the surface waters of the Vostok Bay in July 2020 and May 2021 (the data was partly published in Khristoforova et al., 2023). Maximum values are shown in bold.

Station number	July 2020			May 2021		
	ORB	DRB	PRB	ORB	DRB	PRB
1	n.d.	n.d.	n.d.	(4.5 ± 0.4)×10^2	**(1.7 ± 1.4)×10^3**	**(1.3 ± 0.5)×10^3**
3	(5.3 ± 2.5)×10^2	(2.5 ± 2.1)×10^2	**(1.0 ± 0.7)×10^3**	(3.5 ± 1.3)×10^2	(2.3 ± 0.7)×10^2	(2.8 ± 0.2)×10^2
4	**(8.2 ± 0.5)×10^3**	**(2.9 ± 0.7)×10^3**	(1.3 ± 0.6)×10^2	(2.7 ± 0.7)×10^2	(3.9 ± 0.4)×10^2	(3.3 ± 0.8)×10^2
5	**(2.2 ± 0.3)×10^3**	(7.7 ± 0.6)×10^2	(9.1 ± 0.4)×10^2	(4.2 ± 1.2)×10^2	(2.5 ± 1.6)×10^2	(3.1 ± 0.9)×10^2
6	**(1.1 ± 0.1)×10^3**	**(2.8 ± 0.4)×10^3**	**(4.0 ± 1.2)×10^3**	(3.6 ± 0.7)×10^2	(6.7 ± 1.7)×10^2	**(4.0 ± 0.7)×10^4**
7	n.d.	n.d.	n.d.	(2.8 ± 2.4)× 10^2	(5.7 ± 1.1)×10^2	(9.0 ± 1.4)×10^2
8	**(1.2 ± 0.6)×10^3**	(5.1 ± 0.5)×10^2	(1.3 ± 0.7)×10	n.d.	n.d.	n.d.
9	(5.3 ± 1.5)×10^2	(5.6 ± 1.5)×10^2	**(4.3 ± 1.2)×10^3**	(6.7 ± 1.1)×10^2	(7.7 ± 4.2)×10^2	(3.1 ± 1.2)×10^2
10	(3.2 ± 0.2)×10^3	**(4.4 ± 0.9)×10^3**	(2.2 ± 0.8)×10^2	n.d.	n.d.	n.d.
11	(6.2 ± 0.6)×10^2	**(6.0 ± 0.8)×10^3**	(8.0 ± 1.2)×10^2	(2.4 ± 1.1)×10^2	(8.6 ± 0.6)×10^2	(5.7 ± 0.6)×10^2
12	(8.6 ± 1.1)×10^2	**(6.5 ± 0.6)×10^3**	**(9.5 ± 0.2)×10^3**	(4.4 ± 1.4)×10^2	(4.5 ± 0.8)×10^2	(4.6 ± 1.2)×10^2
13	**(1.1 ± 0.3)×10^3**	(6.3 ± 0.5)×10^2	(5.5 ± 1.1)×10^2	(3.4 ± 0.4)×10^2	(5.5 ± 1.5)×10^2	(5.5 ± 1.1)×10^2
15	(7.0 ± 0.7)×10^2	(5.2 ± 0.4)×10^2	**(7.3 ± 0.6)×10^4**	(3.4 ± 0.2)×10^2	(6.0 ± 0.1)×10	**(2.3 ± 1.2)×10^4**
17	(4.0 ± 0.5)×10^2	(1.3 ± 0.5)×10^2	**(1.7 ± 0.3)×10^3**	n.d.	n.d.	n.d.
18	(8.6 ± 1.5)×10^2	**(2.2 ± 0.9)×10^4**	**(2.2 ± 0.9)×10^4**	(2.8 ± 0.7)×10^2	(5.2 ± 1.2)×10^2	(3.2 ± 0.3)×10^2
20	(2.2 ± 0.7)×10^2	(4.0 ± 0.4)×10^2	(3.0 ± 0.4)×10	(8.6 ± 0.8)×10	(1.0 ± 0.1)×10	(2.5 ± 1.2)×10
21	**(3.6 ± 0.5)×10^3**	**(2.8 ± 0.9)×10^4**	**(2.1 ± 1.8)×10^4**	(1.5 ± 0.6)×10^2	(3.6 ± 1.2)×10^2	(1.1 ± 0.5)×10^2

Table 4. Abundance and biomass of dominant macrobenthic species in the Vostok Bay in 2020–2021.

Taxonomic group	Species	Average biomass ± standard deviation	Average settlement density ± standard deviation
Magnoliophyta	*Z. asiatica*	411.6 ± 694.6	–
Bivalvia	*C. grayanus*	218.9 ± 47.3	1.3 ± 2.3
Ochrophyta	*D. viridis*	134.9 ± 157.6	–
Bivalvia	*M. kurilensis*	95.9 ± 117.6	1.6 ± 1.7
Bivalvia	*M. yessoensis*	82.8 ± 140.2	0.2 ± 0.3
Magnoliophyta	*Z. marina*	76.5 ± 141.2	–
Echinoidea	*M. nudus*	62.0 ± 79.3	0.8 ± 1.0
Ochrophyta	*C. costata*	59.4 ± 100.4	–
Bivalvia	*M. coruscus*	55.7 ± 88.3	1.2 ± 1.9
Bivalvia	*S. swiftii*	50.2 ± 80.0	0.5 ± 0.8
Echinoidea	*S. intermedius*	49.7 ± 61.5	1.2 ± 1.5
Asteroidea	*P. pectinifera*	44.5 ± 36.6	3.3 ± 3.1
Asteroidea	*A. amurensis*	38.4 ± 59.1	0.2 ± 0.2
Ochrophyta	*S. cichorioides*	35.3 ± 54.3	–
Echinoidea	*S. mirabilis*	28.5 ± 52.6	0.8 ± 1.5

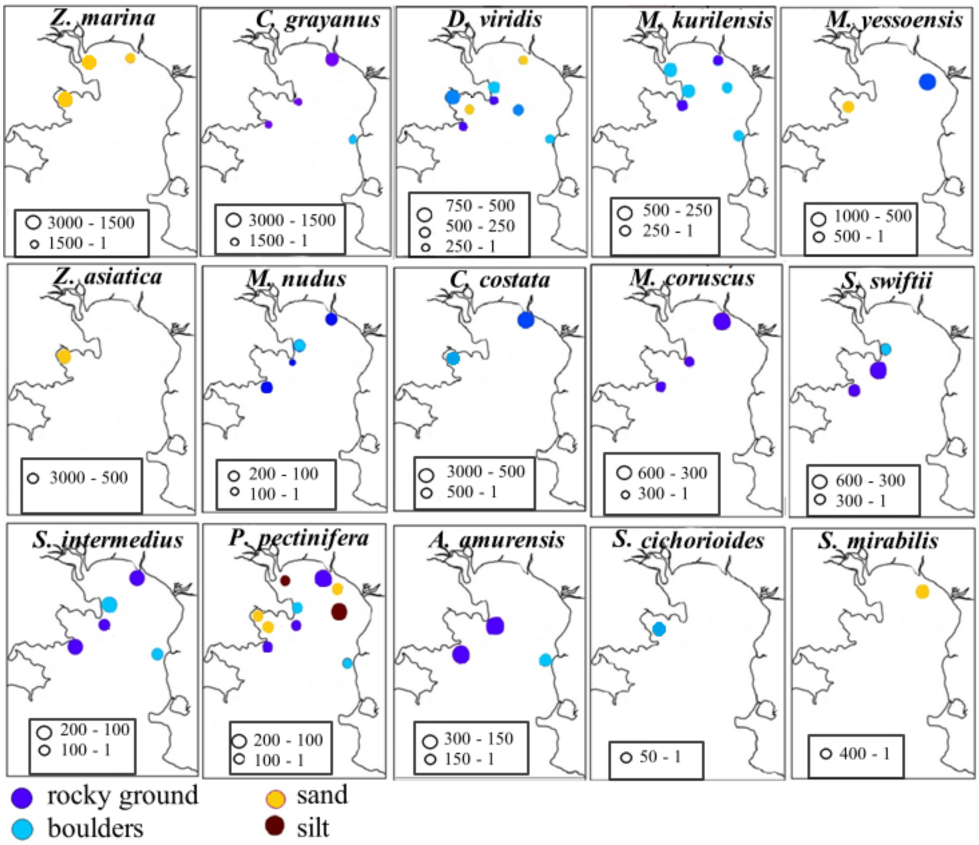

Fig. 4. Biomass of dominant macrobenthos species in the main areas within the Vostok Bay Nature Reserve in 2020–2021.

Table 5. Average concentrations of heavy metals (µg/g dry weight) in mussels (values above the line) and geochemical anomaly coefficient values (values below the line) in the Vostok Bay (October 2020). Data are presented as mean ± error of the mean; values in bold indicate that exceeding background levels.

St. no	Species	Fe	Zn	Cu	Ni	Pb	Cd
1	*C. grayanus*	92.58 ± 10.25 0.90	77.50 ± 13.16 0.74	6.36 ± 1.00 **1.51**	2.72 ± 0.65 **1.09**	0.12 ± 0.06 0.15	2.75 ± 0.76 0.32
4	*M. kurilensis*	304.83 ± 15.81 **1.11**	213.80 ± 42.48 0.30	38.59 ± 3.37 0.72	3.42 ± 0.98 0.95	0.41 ± 0.14 0.03	2.17 ± 0.96 0.20
5	*C. grayanus*	336.63 ± 36.78 **3.28**	359.23 ± 63.57 **3.44**	16.97 ± 1.82 **3.84**	4.01 ± 1.02 **1.62**	1.29 ± 0.24 **1.28**	5.21 ± 0.29 0.50
7	*M. kurilensis*	116.80 ± 26.10 0.49	93.32 ± 16.98 0.13	7.17 ± 1.56 0.15	3.40 ± 1.05 0.97	0.12 ± 0.06 0.01	3.60 ± 1.22 0.31
10	*C. grayanus*	126.90 ± 18.31 **1.27**	111.05 ± 22.06 **1.08**	5.02 ± 1.04 **1.24**	3.05 ± 1.32 **1.41**	0.16 ± 0.06 0.19	7.76 ± 1.01 0.81
13	*C. grayanus*	81.93 ± 13.61 0.84	95.78 ± 16.31 0.91	5.97 ± 1.42 **1.51**	2.03 ± 0.41 0.78	0.24 ± 0.06 0.25	3.46 ± 0.53 0.37
15	*C. grayanus*	66.43 ± 10.90 0.68	83.38 ± 13.14 0.78	3.96 ± 0.89 0.99	2.54 ± 0.84 **1.09**	0.20 ± 0.07 0.23	3.99 ± 0.97 0.46
18	*M. kurilensis*	275.75 ± 44.15 **1.10**	429.67 ± 97.27 0.62	23.65 ± 4.80 0.49	6.00 ± 1.09 **1.54**	1.45 ± 0.17 0.08	3.33 ± 0.65 0.26
20	*M. kurilensis*	335.05 ± 32.40 1.27	236.18 ± 36.85 0.32	36.36 ± 7.95 0.76	3.83 ± 0.73 0.99	0.61 ± 0.08 0.04	2.31 ± 0.43 0.18
	C. grayanus	101.48 ± 18.01 **1.05**	93.58 ± 4.35 0.80	4.08 ± 0.37 0.91	2.66 ± 0.97 **1.17**	0.15 ± 0.05 0.16	6.21 ± 1.44 0.70
	Background concentrations (Shulkin, 2004)						
	M. kurilensis	149–290	648–852	42–58	4.1–4.6	9.0–19.5	8.0–15.4
	C. grayanus	107–114	83–123	4.0–4.9	1.3–3.1	0.45–1.2	5.2–10.9

Mussels collected at st. 10 (Cape Pushchino) are characterized by high concentrations of some of the elements being determined (Fe, Zn, Cu, Ni), comparing to other stations and the background. The geochemical anomaly coefficients are 1.27 (Fe), 1.08 (Zn), 1.24 (Cu), and 1.41 (Ni). St. 13 (Cape Pashinnikova) and st. 15 (Cape Elizarova) are the least contaminated areas within the Vostok Bay, as found for *C. grayanus* tissues. No excess of background concentration values is recorded for almost any of the elements determined. Only for Ni (st. 15) and Cu (st. 13) the geochemical anomaly coefficients are 1.09 and 1.51, respectively. It is important to note that cadmium contamination is not detected for any of the samples (K_c values do not exceed 1). These differences have high statistical significance ($p \leq 0.01$) for almost all heavy metals, except nickel; but even for the latter the same tendency is observed ($p = 0.068$).

Discussion

Hydrological and hydrochemical assessment

Summarizing the results of seasonal surveys, we note the characteristic distribution of hydrological parameters in the Vostok Bay, corresponding to a cyclonic gyre, which is counterclockwise from the eastern coast to the center and west. The summer monsoon and the connection with the open waters of Peter the Great Bay have a decisive influence on the hydrological parameters of the water mass of the Vostok Bay. High concentrations of chlorophyll *a* are confirmed by the published data on high levels of phosphorus compounds and BOD_5 (biological oxygen demand) levels recorded in the Vostok Bay, accompanying the mass development of plant organisms (Grigoryeva et al., 2020; Khristoforova et al., 2023). Moreover, according to these publications, in the spring-summer period, the cyclonic gyre, identified by thermohaline characteristics, does not affect the distribution of BOD_5 values and thus reflects high level of easily oxidizable dissolved organic matter in the bay's waters. The natural background for this indicator is formed by the abundance of biota, which releases metabolic products and dead organic matter into the aquatic environment. Furthermore, anthropogenic sources associated with harbors, populated areas, and river estuaries play a significant role in the distribution of BOD_5 values in coastal waters. The peak concentrations of organic phosphorus compounds detected in the Vostok Bay correspond to the spring and autumn phytoplankton blooms and are confirmed by chlorophyll *a* concentrations.

The long-term dynamics of changes in the hydrological and hydrochemical parameters have been assessed in the Vostok Bay for the period of 2002–2021 (Fig. 5). Data on all parameters for 2002 come from: Galysheva and Khristoforova, 2007; for 2008 and 2009, from: Khristoforova et al., 2020; Zhuravel et al., 2012; data on BOD_5 and organic phosphorus for 2021, from: Khristoforova et al., 2023.

Over the 20-year study period, the seasonal temperature dynamics is generally consistent across years: spring water temperature ranges from 10.4 to 13.0 °C, warming to an average of 17.9–20.0 °C by July and cooling down to 5.6–15.0 °C by autumn. The seasonal dynamics shows an increase in average summer and autumn temperatures from 2002 to 2021. This trend is noticeably evident in the autumn periods of the last five years of observations. The slower cooling of coastal waters is apparently due to the weakening of the autumn-winter (northern) monsoon, which manifested itself in prolonged high atmospheric temperatures in southern Primorye in autumn. Furthermore, despite the fact that anomalous deviations from the baseline temperature norm defined by the World Meteorological Organization are characterized by the wave pattern, the overall linear trend in average annual temperatures, calculated for the coastal seawaters of Primorsky Krai, has been steadily increasing from the 1960s to the 2020s (Gaiko, 2017, 2023). Coastal warming will have ecological consequences for the characteristics of the marine environment and the processes occurring in marine ecosystems.

Over the 20-year period, the average dissolved oxygen content does not fall below the threshold of 6.0 mgO_2/L (Perechen'..., 1999), indicating the generally healthy condition of the waters of the Vostok Bay. The "mirror" pattern of long-term dynamics of surface water temperature and dissolved oxygen is pronounced the most in the spring and autumn periods. In long-term perspective, the average spring and autumn water temperature in the bay has increased from the early 2000s to the 2020s, while the dissolved oxygen content has decreased. This is associated with deteriorating oxygen solubility conditions in water with increasing temperature. However, this indicator remained within the normal range during our study period.

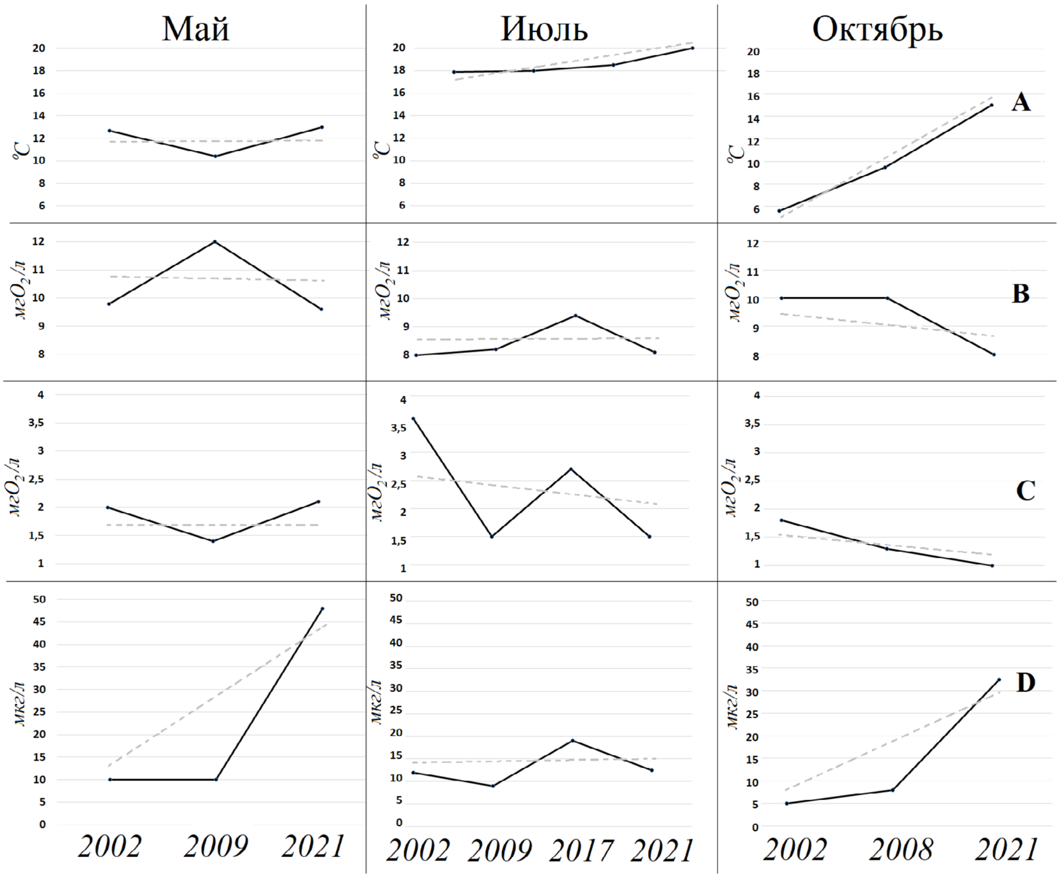

Fig. 5. Dynamics of average values and linear trend of hydrological and hydrochemical parameters in the Vostok Bay in 2002–2021. **A** – temperature, **B** – dissolved oxygen, **C** – BOD_5, **D** – organic phosphorus.

The long-term spring and summer dynamics of the average BOD_5 in the Vostok Bay is quite chaotic, while a downward trend is observed for the autumn period over the past 20 years. The highest BOD_5 values are registered in summer season. Even averaging the pooled data for 2002 and 2017 results in BOD_5 values that significantly exceed the sanitary standard of 2.1 mgO_2/L (Perechen'..., 1999). High values of this indicator in the summer season in different years are explained by two main factors: (1) the steadily increasing recreational load, which is constantly noted in research papers devoted to the ecological state of the bay (Barysheva et al., 2019; Galysheva and Khristoforova, 2007; Zhuravel et al., 2012), and (2) a spontaneous increase of the water flow of the rivers feeding the bay, associated with typhoons.

Both factors, along with the organisms inhabiting the bay, introduce easily oxidizable organic matter into the water column, ultimately forming suspended and dissolved organic matter (SOM and DOM) and serving as a nutrient resource for heterotrophs that consume oxygen to oxidize this organic matter. In the years, when recreational influence increases due to high river runoff (during typhoons in 2002 and 2017), the highest average BOD_5 has been recorded in the bay (Khristoforova et al., 2020).

Average organic phosphorus content gradually increases from the 2000s to the 2020s both in spring and autumn; in summer, no visible trend is noted (Fig. 5). High organic phosphorus content is likely related to the spring and autumn peaks of phytoplankton blooms, which are regularly observed in temperate marine waters. Furthermore, anthropogenic factors contribute to the long-term increase in this indicator; these are domestic wastewater from settlements, organic wastewater from industries, and agricultural runoff from the river valleys.

Microbiological indicators

Overall, in the Vostok Bay, the high levels of heterotrophic microorganisms (HM) are undoubtedly related to the spread of domestic wastewater from numerous sources located along its coast. The anthropogenic impact is particularly evident in the high values of this indicator. This is obvious even during the cool spring period in the Gaydamak Inlet, the most heavily impacted by human activity, against the background of generally low values of this indicator throughout the bay. The presence of the CB group and, specifically, *E. coli* demonstrates a constant source of fecal pollution.

By comparing microbiological data obtained in 2020–2021 with that of 2004, 2009, and 2017, the dynamics in the abundance of indicator groups of microorganisms have been assessed (Fig. 6). From 2004 to 2017, the HM abundance has increased, and the waters of the Vostok Bay have reached the mesosaprobic level, with some polysaprobic areas. By 2020–2021, the abundance of heterotrophic microorganisms in the bay decreased again to the level of 2004, so the waters were generally characterized as oligosaprobic in spring. However, despite the similar picture of long-term dynamics of HM indicators in spring and summer, their level increases by several orders of magnitude in summer, so the waters of the Vostok Bay belong to the mesosaprobic class.

A similar pattern is observed when analyzing CB group dynamics in summer. The number of sanitary indicator microorganisms has increased significantly in 2017 compared to that in 2004, but by 2020, they have decreased significantly. The CB abundance characterizes the bay's waters as sanitary unsafe and indicates biological, including fecal, pollution of the water area. From 2004 to 2021, the abundance of ORB and PRB has increased, while that of DRB remained at approximately the same level.

Therefore, the abundance of MO, characterizing water saprobity, fluctuates significantly over the study period. However, the sanitary indicator microorganisms consistently exceed permissible sanitary standards in the waters of the Vostok Bay in all years. A significant increase in the numbers of indicators of hydrocarbon pollution, associated with the steadily increasing recreational and anthropogenic load, has been detected. Overall, allochthonous microflora is recorded at most of the studied stations, which may soon lead to the complete displacement of indigenous microflora and, consequently, a slowdown in environmental self-purification processes and its degradation.

Macrobenthos

Long-term dynamics of abundance changes for eight species are assessed by comparing abundance of common macrobenthic species recorded in 2020–2021 with data from the 1970s and early 2000s (Table 6). The average biomass has been considered at the sites of species aggregations.

Over a 50-year observation period, the abundance of the Gray mussel *C. grayanus*, the sea urchin *M. nudus*, and the Kuril horse mussel *M. kurilensis* has decreased significantly, less decrease is observed for the biomass of the sand dollar *S.*mirabilis (Table 6). The average biomass of the Amur starfish *A. amurensis* and the sea urchin *S. intermedius* has increased in the same time period. Nor positive neither negative trend in biomass is found for the Japanese scallop *M. yessoensis* and blue bat star *P. pectinifera*, so these changes are likely natural fluctuations.

Over a 50-year period from the 1970s to the 2020s, significant changes in abundance have been found only for *C. grayanus* and *M. Kurilensis* (Student's t-test). For Gray mussel, a statistically significant decrease is observed for the first half of the study period (from the 1970s to the 2000s), for horse mussel, in the second half of the period, from the 2000s to the 2020s (Table 7). For the other species, the average biomass does not differ significantly for these two periods. Therefore, we assume that these fluctuations are natural.

Rapidly increasing recreational load on the Vostok Bay may be a possible factor influencing the decline in the abundance of the valuable commercial species, the Gray mussel and the Kuril horse mussel. The recreational load has increased significantly over the 50-year period as well as illegal fishing also. Maintaining high recreational load and its further increase, coupled with weak control of poaching in the Vostok Bay, jeopardizes the well-being of populations of other valuable benthic invertebrate species, primarily the Japanese scallop and sea urchins.

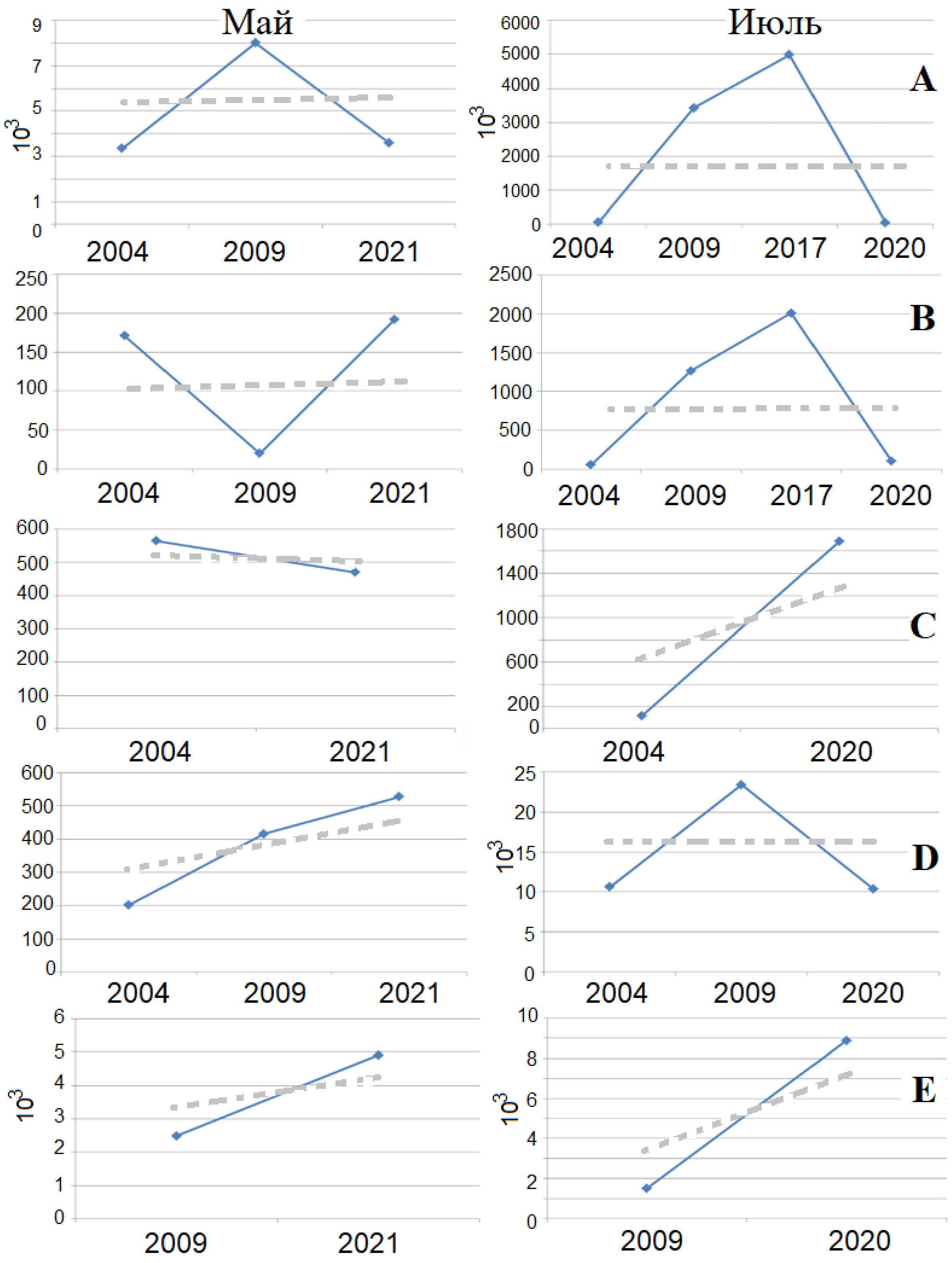

Fig. 6. Dynamics of average values and linear trend of abundance of ecotrophic groups of bacteria (CFU/mL) in the surface waters of the Vostok Bay in 2004–2021. **A** – HM, **B** – CB, **C** – indicators of oil pollution, **D** – indicators of environmental pollution by diesel fuel, **E** – indicators of phenolic pollution.

Table 6. Long-term changes in biomass (g/m^2) of common macrozoobenthos species at sublittoral of the Vostok Bay. Data are presented as mean ± error of the mean.

Species	Years of research and data authors		
	The 1970s (Pogrebov and Kashenko, 1976; Tarasov, 1978)	The 2000s (Galysheva, 2004; Galysheva and Yakovleva, 2007; Galysheva and Pustovalova, 2009)	2020s (our data)
C. grayanus	5846.6 ± 1831.1	1487.5 ± 74. 4	711.4 ± 642.3
M. kurilensis	1644.4 ± 513.7	1641.6 ± 516.6	207.9 ± 105.6
M. yessoensis	120.2 ± 80.5	286.7 ± 115.7	271.8 ± 240.2
M. nudus	336.5 ± 289.0	241.0 ± 71.3	161.2 ± 47.5
S. intermedius	77.3 ± 27.3	113.6 ± 65.2	129.2 ± 45.5
P. pectinifera	94.2 ± 39.5	35.8 ± 21.8	56.5 ± 38.6
A. amurensis	3.3 ± 3.3	46.3 ± 30.5	128.2 ± 91.1
S. mirabilis	–	352.7 ± 115.2	278.5 ± 52.6

Heavy metals in bivalve mollusks and the risk to human health

To identify the danger of pollution of the marine environment and its inhabitants with heavy metals, it is important to analyze the interannual variability in the accumulation of microelements by aquatic organisms.

It should be noted that the level of zinc and nickel in the tissues of horse mussel has increased significantly over the past 20 years, the concentrations of copper and cadmium have remained at a similar level, and the concentrations of iron and lead are below the 2002 level (Table 8). Pollution of the environment and aquatic organisms of the bay with heavy metals has been also noted in other publications (Chernova and Kozhenkova, 2020; Mazur et al., 2022).

Any species of harvested mussels is a valuable biological resource and a delicacy (Khristoforova et al., 1993). Mussel meat is widely used in cooking worldwide due to its nutritional value and medicinal and prophylactic properties. Under increasing anthropogenic pressure, mollusks accumulate toxic substances of anthropogenic and technogenic origin; in turn, this can pose a risk both to the ecosystem and to the human health. Therefore, determining the compliance of mussel meat quality with existing standards and assessing the health risk associated with its consumption is a crucial task. The Technical Regulation of the Customs Union "On the Food Safety" (TR CU 021/2011)[12] sets permissible levels of certain toxic heavy metals.

When comparing the Pb content in *C. grayanus* with the established permissible levels, none of the samples obtained in the Vostok Bay exceeded MPC (Table 9).

Cd exceeded the maximum permissible concentration at three of the six stations, where Gray mussels are found. The overall health risk from continuous consumption of mussels from the Vostok Bay during the summer season, estimated using the ILCR calculator, predicts a risk of cancer. The value of this coefficient, taking into account the actual concentrations of Cd and Pb in mussels, was $10.17 \cdot 10^{-5}$ (the permissible value, which is a safety criterion for seafood, is $1.0 \cdot 10^{-5}$). Cadmium is a recognized carcinogen (Fazlyeva et al., 2022). Therefore, consumption of mussels from the Vostok Bay is no longer safe and may contribute to an increase in the lifelong carcinogenic risk for humans.

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[12] Technical Regulations of the Customs Union TR CU 021/2011 "On the safety of food products".

Table 7. Values of Student's t-test and significance of differences in mean long-term biomass indices for dominant sublittoral species in the Vostok Bay. Statistically significant differences are highlighted in bold.

Species	1970–2000 (f = 399, $t_{critical}$ = 1.972, α = 0.05)	2000–2020 (f = 325, $t_{critical}$ = 1,972, α = 0.05)	1970–2020 (f = 186, $t_{critical}$ = 1.972, α = 0.05)
C. grayanus	**2.23**	0.83	**2.65**
M. kurilensis	0.00	**2.72**	**2.74**
M. yessoensis	1.19	0.06	0.60
M. nudus	0.32	0.94	0.55
S. intermedius	0.36	0.20	0.58
P. pectinifera	1.29	0.47	0.68
A. amurensis	1.40	0.85	1.37
S. mirabilis	–	0.59	–

Table 8. Average concentrations of heavy metals (µg/g dry weight) in horse mussels of the Vostok Bay in 2002 (Podgurskaya and Kavun, 2005) and 2020 (our data); data are presented as mean ± error of the mean.

Year of sampling	Fe	Zn	Cu	Ni	Pb	Cd
2002	691 ± 416	85 ± 22	30 ± 8	1.7 ± 0.99	4.59 ± 1.64	2.1 ± 0.7
2020	274 ± 111	243 ± 139	26 ± 15	4.1 ± 1.30	0.51 ± 0.32	2.7 ± 0.9

Table 9. Concentrations of Pb and Cd in *Crenomytilus grayanus* (mg/kg wet weight) in the Vostok Bay. Data are presented as mean ± error of the mean. Values in bold indicate values exceeding the MPC.

Station number	Pb	Cd
1	0.05 ± 0.02	1.21 ± 0.33
5	0.56 ± 0.06	**2.29 ± 0.13**
10	0.07 ± 0.03	**3.41 ± 0.45**
13	0.11 ± 0.03	1.52 ± 0.23
15	0.09 ± 0.03	1.75 ± 0.43
20	0.06 ± 0.02	**2.72 ± 0.63**
Acceptable level (AL)	10.00	2.00

Conclusions

The current state of the Vostok Bay environment has pronounced seasonal variations in key hydrochemical parameters and violations of sanitary standards (organic matter pollution) in summer. Long-term temperature dynamics reflects an increasing trend in spring and autumn, indicating an increase in the rate of seawater warming and a decrease in that of cooling for the last 50 years. This natural climate change is undoubtedly the cause of the deterioration of oxygen levels in the waters of the Vostok Bay, stimulating the restructuring of production and destruction processes, which affects the content of nutrient compounds and creates an environmental risk factor.

Microbial indicators confirm high levels of organic matter in the aquatic environment, reflected in HM abundance. Anthropogenic organic pollution is evidenced by high levels of CB and the presence of enterobacteria (including *E. coli*) in certain areas of the bay, as well as by high numbers of oil-, diesel-, and phenol-degrading bacteria. Based on analysis of metal-resistant microorganism abundance in the Vostok Bay, heavy metal levels are also characterized as high and are primarily associated with intensive economic activity in the Gaydamak Inlet.

Macrobenthos, as a component of the bay's ecosystem biota, currently shows signs of stability. However, for some valuable commercial species (Gray mussel and Kuril horse mussel), a significant multi-year decline has been detected in their biomass. This may be due to the increased recreational load and poaching of these valuable biological resources between the 1970s and 2020s.

At the same time, an assessment of the accumulation of heavy metals by mussels living in the bay reveals that cadmium exceeds permissible toxicological standards. Calculation of the human health risk based on the combined cadmium and lead content in mussels revealed a significant risk of cancer from continuous consumption of mussel soft tissues during the recreational season or longer.

In summary, we conclude that the current process of transformation of the Vostok Bay ecosystem is leading to a deterioration in the state of its environment and biota, which requires constant environmental monitoring and management decisions in nature management.

References

Barysheva, V.S., Chernova, E.N., Patrusheva, O.V., 2019. Zagriaznenie morskoi sredy zaliva Vostok Iaponskogo moria organicheskimi veshchestvami (2016–2018) [Pollution of the marine environment of the East Sea of Japan Bay by organic substances (2016-2018)]. *Vestnik DVO RAN [Bulletin of the Far Eastern Branch of the Russian Academy of Sciences]* **2**, 87-94. (In Russian).

Bezverbnaya, I.P., 2002. Otklik mikroorganizmov pribrezhnykh akvatorii Primor'ia na prisutstvie v srede tiazhelykh metallov [The response of microorganisms in the coastal waters of Primorye to the presence of heavy metals in the environment]. *PhD in Biology thesis.* Vladivostok, Russia, 177 p. (In Russian).

Chernova, E.N., Kozhenkova, S.I., 2020. Prostranstvennaia otsenka zagriazneniia zaliva Petra Velikogo (Iaponskoe more) metallami s pomoshch'iu buroi vodorosli Sargassum miyabei [Spatial assessment of pollution of Peter the Great Bay (Sea of Japan) by metals using brown algae Sargassum miyabei]. *Okeanologiia [Russian Journal of Oceanology]* **60** (1), 49–56. (In Russian).

Chichenko, V.A., 2022. Obilie i raspredelenie massovykh vidov makrobentosa zaliva Vostok po dannym s’emki iiulia 2020 g [Abundance and distribution of mass species of macrobenthos of the Vostok Bay according to July 2020 survey data]. *Materialy Regional'noi nauchno-prakticheskoi konferentsii studentov, aspirantov i molodykh uchenykh po estestvennym naukam [Materials of the Regional Scientific and Practical Conference of Students, postgraduates and Young Scientists in Natural Sciences].* Vladivostok, Russia, 519–522. (In Russian).

Fazlyeva, A.S., Daukaev, R.A., Karimov, D.O., 2022. Vliianie kadmiia na zdorov'e naseleniia i sposoby profilaktiki ego toksicheskikh effektov [The effect of cadmium on public health and ways to prevent its toxic effects]. *Meditsina truda i ekologiia cheloveka [Labor Medicine and Human Ecology]* **1** (29), 220–235. (In Russian).

Gaiko, L.A., 2017. Gidrometeorologicheskii rezhim zaliva Vostok (Iaponskoe more) [Hydrometeorological regime of Vostok Bay (Sea of Japan)]. Pacific Oceanological Institute of the Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, Russia, 229 p. (In Russian).

Gaiko, L.A., 2023. Osobennosti temperaturnogo rezhima pribrezhnoi zony primorskogo kraia na rubezhe vekov [Features of the temperature regime of the coastal zone of Primorsky Krai at the turn of the century]. In: Tsygankov, V.Yu., Yarusova, S.B. (red.), *Ekologicheskie issledovaniia na Dal'nem Vostoke Rossii: istoriia i sovremennost' [Environmental Research in the Russian Far East: history and Modernity]*. Vladivostok State University, Vladivostok, Russia, 73-82. (In Russian).

Galysheva, Yu.A., 2004. Soobshchestva makrobentosa sublitorali zaliva Vostok Iaponskogo moria v usloviiakh antropogennogo vozdeistviia [Macrobenthos communities of the sublittoral Bay of the East Sea of Japan under anthropogenic impact]. *Biologiia moria [Russian Journal of Marine Biology]* **30** (6), 423-431. (In Russian).

Galysheva, Yu.A., Boichenko, T.V., Chichenko, V.A., 2022. Vozdeistvie na zaliv Vostok Iaponskogo moria: obzor istorii i sovremennykh ekologicheskikh problem [Impact on the East Bay of the Sea of Japan: an overview of the history and current environmental issues]. IX Materialy Mezhdunarodnoi nauchno-prakticheskaoi konferentsii “Aktual'nye problemy nauki i obrazovaniia v usloviiakh sovremennykh vyzovov” *[Materials of the IX International Scientific and Practical Conference “Actual problems of science and education in the context of modern challenges”].* Moscow, Russia, 158-163. (In Russian).

Galysheva, Yu.A., Pustovalova N.P., 2009. Kolichestvennoe raspredelenie morskikh zvezd v nekotorykh akvatoriiakh Dal'nego Vostoka [Quantitative distribution of starfish in some waters of the Far East]. *Okeanologiia [Russian Journal of Oceanology]* **49** (6), 864-874. (In Russian).

Galysheva, Yu.A., Khristoforova, N.K., 2007. Sreda i makrobentos zaliva Vostok Iaponskogo moria v usloviiakh rekreatsionnogo vozdeistviia [Environment and macrobenthos of the East Sea of Japan Bay under recreational conditions]. *Izvestiia TINRO [News of the Pacific Fisheries Research Center]* **149**, 270-309. (In Russian).

Galysheva, Yu.A., Yakovleva, A.N., 2007. Otsenka kolichestvennykh pokazatelei nekotorykh promyslovykh bespozvonochnykh v osnovnykh mestakh lokalizatsii v zalivakh vostok i nakhodka [Assessment of quantitative indicators of some commercial invertebrates in the main localities in the bays of Vostok and Nakhodka]. *Izvestiia TINRO [News of the Pacific Fisheries Research Center]* **149**, 191-204. (In Russian).

Grigor'eva, N.I., Zhuravel', E.V., Mazur, A.A., 2020. Sezonnye izmeneniia kachestva vody v zalive Vostok (zaliv Petra Velikogo, Iaponskoe more) [Seasonal changes in water quality in Vostok Bay (Peter the Great Bay, Sea of Japan)]. *Vodnye resursy [Water Resources]* **47** (2), 162–169. (In Russian).

Dimitrieva, G.Iu., Bezverbnaya, I.P., 2002. Mikrobnaia indikatsiia – effektivnyi instrument dlia monitoringa zagriazneniia pribrezhnykh morskikh vod tiazhelymi metallami [Microbial indication is an effective tool for monitoring pollution of coastal marine waters by heavy metals]. *Okeanologiia [Russian Journal of Oceanology]* **42** (3), 408–415. (In Russian).

Il'inskii, V.V., Shadrina, N.A., Komarova, T.I., 2010. Geterotrofnye bakterii gorodskikh rodnikov: Moskovskii zapovednik «Krylatskie kholmy» [Heterotrophic bacteria of urbansprings: Moscow Krylatsky Hills Nature Reserve]. *Vodnye resursy [Water Resources]* **37** (4), 494–501. (In Russian).

Kashenko, V.P., 1976. Biologicheskaia stantsiia «Vostok» [The Vostok Biological Station]. In: Kas’yanov, V.L. (ed.), *Biologicheskie issledovaniia zaliva Vostok [Biological studies of the Vostok Bay].* Far Eastern Scientific Center of the Academy of Sciences, Vladivostok, USSR, 7–11. (In Russian).

Khristoforova, N.K., Boichenko, T.V., Kobzar', A.D., 2020. Gidrokhimicheskaia i mikrobiologicheskaia otsenka sovremennogo sostoianiia vod zaliva Vostok [Hydrochemical and microbiological assessment of the current state of the waters of the Vostok Bay]. *Vestnik DVO RAN [Bulletin of the Far Eastern Branch of the Russian Academy of Sciences]* **2**, 64–72. (In Russian).

Khristoforova, N.K., Shul'kin, V.M., Kavun, V.Ya., Chernova, E.N., 1993. Tiazhelye metally v promyslovykh i kul'tiviruemykh molliuskakh zaliva Petra Velikogo [Heavy metals in commercial and cultivated mollusks of Peter the Great Bay]. Dal'nauka, Vladivostok, Russia, 296 p. (In Russian).

Khristoforova. N.K., Lazaryuk, A.Yu., Zhuravel', E.V., Boichenko, T.V., Emel'yanov, A.A., 2023. Zaliv vostok: mezhsezonnye izmeneniia gidrologo-gidrokhimicheskikh i mikrobiologicheskikh pokazatelei [Vostok Bay: inter-seasonal changes in hydrological, hydrochemical and microbiological parameters]. *Izvestiia TINRO [News of the Pacific Fisheries Research Center]* **203** (1), 906–924. (In Russian).

Lazariuk, A.Yu., Kosheleva, A.V., 2014. Korrektsiia dannykh glubokovodnykh gidrologicheskikh nabliudenii CTD-zondov (CTD-data_Processing) [Correction of data from deep-sea hydrological observations of CTD probes (CTD-data_Processing)]. *Biulleten' Programmy dlia EVM [Bulletin of the Computer Program]* **96** (10). Svidetel'stvo № 2014619779 o gosudarstvennoi registratsii programmy dlia EVM [Certificate No. 2014619779 on state registration of the EVM program]. (In Russian).

Mazur, M.A., Zhuravel', E.V., Kovekovdova, L.T. et al., 2022. Monitoring zagriazneniia donnykh otlozhenii zaliva Vostok (zaliv Petra Velikogo, Iaponskoe more) i otsenka ikh potentsial'noi toksichnosti [Monitoring of bottom sediment pollution in Vostok Bay (Peter the Great Bay, Sea of Japan) and assessment of their potential toxicity]. *Tezisy dokladov II Mezhdunarodnoi nauchno-prakticheskoi konferentsii «Izuchenie vodnykh i nazemnykh ekosistem: istoriia i sovremennost'» [Abstracts of the II International Conference "Study of Aquatic and Terrestrial ecosystems: history and modernity"].* Sevastopol', Russia, 233–234. (In Russian).

Nalivaiko, N.G., 2006. Mikrobiologiia vody [Microbiology of water]. Publishing House of the Tomsk Polytechnic University, Tomsk, Russia, 139 p. (In Russian).

Perechen' rybokhoziaistvennykh normativov: predel'no dopustimykh kontsentratsii (PDK) i orientirovochno bezopasnykh urovnei vozdeistvii (OBUV) vrednykh veshchestv dlia vody, vodnykh ob"ektov, imeiushchikh rybokhoziaistvennoe znachenie [List of fisheries standards: maximum permissible concentrations (MPC) and approximately safe exposure levels of harmful substances for water, water bodies of fisheries importance], 1999. All-Russian Research Institute of Fisheries and Oceanography (VNIRO), Moscow, Russia, 304 p. (In Russian).

Pogrebov, V.B., Kashenko, V.P., 1976. [Communities of rocky soils of the Vostok Bay]. In: Kas'yanov, V.L. (ed.), *Biologicheskie issledovaniia zaliva Vostok [Biological research of the Vostok Bay].* Far Eastern Scientific Center of the Academy of Sciences, Vladivostok, USSR, 63–83. (In Russian).

Podgurskaia, O.V., Kavun, V.Ia., 2005. Sravnitel'nyi analiz subkletochnogo raspredeleniia tiazhelykh metallov v organakh dvustvorchatykh molliuskov *Crenomytilus grayanus* i *Modiolus modiolus* v usloviiakh khronicheskogo zagriazneniia [Comparative analysis of subcellular distribution of heavy metals in the organs of bivalve mollusks *Crenomytilus grayanus* and *Modiolus modiolus* under conditions of chronic pollution]. *Biologiia moria [Russian Journal of Marine Biology]* **31** (6), 435–442. (In Russian).

Rukovodstvo po metodam biologicheskogo analiza morskoi vody i donnykh otlozhenii [Guidelines on methods of biological analysis of seawater and bottom sediments]. Tsyban', A.V. (ed.). Gidrometeoizdat, Leningrad, USSR, 193 p. (In Russian).

Spisok vidov svobodnozhivushchikh bespozvonochnykh dal'nevostochnykh morei Rossii [List of free-living invertebrate species of the Russian Far Eastern seas]. In: Pugachev, O.N. (ed.), *Issledovaniia fauny morei. T. 75, vyp. 38 [Marine Fauna Research, Vol. 75, issue 38].* Zoological Institute oft he Russian Academy of Sciences, Saint-Petersburg, Russia, 256 p. (In Russian).

Shul'kin, V.M., 2004. Metally v ekosistemakh morskikh melkovodii [Metals in marine shallow water ecosystems]. Dal'nauka, Vladivostok, Russia, 279 p. (In Russian).

Tarasov, V.G., 1978. Raspredelenie i troficheskoe raionirovanie donnykh soobshchestv miagkikh gruntov zaliva Vostok Iaponskogo moria [Distribution and trophic zoning of benthic communities of soft soils of the East Bay of the Sea of Japan]. *Biologiia moria [Russian Journal of Marine Biology]* **1**, 16–22. (In Russian).

Tiurin, A.N., 1996. Morskoi zakaznik «Zaliv Vostok» [The Gulf of Vostok Marine Reserve]. *Biologiia moria [Russian Journal of Marine Biology]* **22** (1), 58–63. (In Russian).

Vyshkvartsev, D.I., 2010. O nedopustimosti stroitel'stva neftepererabatyvaiushchego zavoda v zalive Vostok (Iaponskoe more) [On the inadmissibility of the construction of an oil refinery in the Gulf of Vostok (Sea of Japan)]. *Vestnik DVO RAN [Bulletin of the Far Eastern Branch of the Russian Academy of Sciences]* **1**, 85-95. (In Russian).

Yoshimizu M., Kimura T., 1976. Study on the Intestinal Microflora of Salmonids. *Fishing Pathology* **10** (2), 243–259.

Zhuravel', E.V., Khristoforova, N.K., Drozdovskaya, O.A., Tokarchuk, T.N., 2012. Otsenka sostoianiia vod zaliva Vostok (zaliv Petra Velikogo, Iaponskoe more) po gidrokhimicheskim i mikrobiologicheskim pokazateliam [Assessment of the state of the waters of Vostok Bay (Peter the Great Bay, Sea of Japan) according to hydrochemical and microbiological indicators]. *Izvestiia Samarskogo nauchnogo tsentra Rossiiskoi akademii nauk [Proceedings of the Samara Scientific Center of the Russian Academy of Sciences]* **14** (9), 2325–2329. (In Russian).

Список литературы

Барышева, В.С., Чернова, Е.Н., Патрушева, О.В., 2019. Загрязнение морской среды залива Восток Японского моря органическими веществами (2016–2018 гг.). *Вестник ДВО РАН* **2**, 87–94.

Безвербная, И.П., 2002. Отклик микроорганизмов прибрежных акваторий Приморья на присутствие в среде тяжелых металлов. *Диссертация на соискание ученой степени кандидат биологических наук*. Владивосток, Россия, 177 с.

Вышкварцев, Д.И., 2010. О недопустимости строительства нефтеперерабатывающего завода в заливе Восток (Японское море). *Вестник ДВО РАН* **1**, 85–95.

Гайко, Л.А., 2017. Гидрометеорологический режим залива Восток (Японское море). ТОИ ДВО РАН, Владивосток, Россия, 229 с.

Гайко, Л.А., 2023. Особенности температурного режима прибрежной зоны приморского края на рубеже веков. В: Цыганков, В.Ю., Ярусова, С.Б. (ред.), *Экологические исследования на Дальнем Востоке России: история и современность*. Владивостокский государственный университет, Владивосток, Россия, 73–82.

Галышева, Ю.А., 2004. Сообщества макробентоса сублиторали залива Восток Японского моря в условиях антропогенного воздействия. *Биология моря* **30** (6), 423–431.

Галышева, Ю.А., Бойченко, Т.В., Чиченко, В.А., 2022. Воздействие на залив Восток Японского моря: обзор истории и современных экологических проблем. *Материалы IX Международной научно-практической конференции «Актуальные проблемы науки и образования в условиях современных вызовов»*. Москва, Россия, 158–163.

Галышева, Ю.А., Пустовалова, Н.П., 2009. Количественное распределение морских звезд в некоторых акваториях Дальнего Востока. *Океанология* **49** (6), 864–874.

Галышева, Ю.А., Христофорова, Н.К., 2007. Среда и макробентос залива Восток Японского моря в условиях рекреационного воздействия. *Известия ТИНРО* **149**, 270–309.

Галышева, Ю.А., Яковлева, А.Н., 2007. Оценка количественных показателей некоторых промысловых беспозвоночных в основных местах локализации в заливах восток и находка. *Известия ТИНРО* **149**, 191–204.

Григорьева, Н.И., Журавель, Е.В., Мазур А.А., 2020. Сезонные изменения качества воды в заливе Восток (залив Петра Великого, Японское море). *Водные ресурсы* **47** (2), 162–169.

Димитриева, Г.Ю., Безвербная, И.П., 2002. Микробная индикация – эффективный инструмент для мониторинга загрязнения прибрежных морских вод тяжелыми металлами. *Океанология* **42** (3), 408–415.

Журавель, Е.В., Христофорова, Н.К., Дроздовская, О.А., Токарчук, Т.Н., 2012. Оценка состояния вод залива Восток (залив Петра Великого, Японское море) по гидрохимическим и микробиологическим показателям. *Известия Самарского научного центра Российской академии наук* **14** (9), 2325–2329.

Ильинский, В.В., Шадрина, Н.А., Комарова, Т.И., 2010. Гетеротрофные бактерии городских родников: Московский заповедник «Крылатские холмы». *Водные ресурсы* **37** (4), 494–501.

Кашенко, В.П., 1976. Биологическая станция «Восток». В: Касьянов, В.Л. (ред.), *Биологические исследования залива Восток*. ДВНЦ АН, Владивосток, СССР, 7–11.

Лазарюк, А.Ю., Кошелева, А.В., 2014. Коррекция данных глубоководных гидрологических наблюдений CTD-зондов (CTD-data_Processing). *Бюллетень Программы для ЭВМ* **96** (10). Свидетельство № 2014619779 о государственной регистрации программы для ЭВМ.

Мазур, М.А., Журавель, Е.В., Ковековдова, Л.Т. и др., 2022. Мониторинг загрязнения донных отложений залива Восток (залив Петра Великого, Японское море) и оценка их потенциальной токсичности. *Тезисы докладов II Международной конференции «Изучение водных и наземных экосистем: история и современность»*. Севастополь, Россия, 233–234.

Наливайко, Н.Г., 2006. Микробиология воды. Издательство Томского политехнического университета, Томск, Россия, 139 с.

Перечень рыбохозяйственных нормативов: предельно допустимых концентраций (ПДК) и ориентировочно безопасных уровней воздействий (ОБУВ) вредных веществ для воды, водных объектов, имеющих рыбохозяйственное значение, 1999. ВНИРО, Москва, Россия, 304 с.

Погребов, В.Б., Кашенко, В.П., 1976. В: Касьянов, В.Л. (ред.), *Биологические исследования залива Восток*. ДВНЦ АН, Владивосток, СССР, 63–83.

Подгурская, О.В., Кавун, В.Я., 2005. Сравнительный анализ субклеточного распределения тяжелых металлов в органах двустворчатых моллюсков *Crenomytilus grayanus* и *Modiolus modiolus* в условиях хронического загрязнения. *Биология моря* **31** (6), 435–442.

Руководство по методам биологического анализа морской воды и донных отложений. Цыбань, А.В. (ред.). Гидрометеоиздат, Ленинград, СССР, 193 с.

Список видов свободноживущих беспозвоночных дальневосточных морей России. В: Пугачев, О.Н. (ред.), *Исследования фауны морей. Т. 75, вып. 83.* Зоологический институт РАН, Санкт-Петербург, Россия, 256 с.

Тарасов, В.Г., 1978. Распределение и трофическое районирование донных сообществ мягких грунтов залива Восток Японского моря. *Биология моря* **1**, 16–22.

Тюрин, А.Н., 1996. Морской заказник «Залив Восток». *Биология моря* **22** (1), 58–63.

Фазлыева, А.С., Даукаев, Р.А., Каримов, Д.О., 2022. Влияние кадмия на здоровье населения и способы профилактики его токсических эффектов. *Медицина труда и экология человека* **1** (29), 220–235.

Христофорова, Н.К., Бойченко, Т.В., Кобзарь, А.Д., 2020. Гидрохимическая и микробиологическая оценка современного состояния вод залива Восток. *Вестник ДВО РАН* **2**, 64–72.

Христофорова, Н.К., Шулькин, В.М., Кавун, В.Я., Чернова, Е.Н., 1993. Тяжелые металлы в промысловых и культивируемых моллюсках залива Петра Великого. Дальнаука, Владивосток, Россия, 296 с.

Христофорова, Н.К., Лазарюк, А.Ю., Журавель, Е.В., Бойченко, Т.В., Емельянов, А.А., 2023. Залив восток: межсезонные изменения гидролого-гидрохимических и микробиологических показателей. *Известия ТИНРО* **203** (1), 906–924.

Чернова, Е.Н., Коженкова, С.И., 2020. Пространственная оценка загрязнения залива Петра Великого (Японское море) металлами с помощью бурой водоросли *Sargassum miyabei*. *Океанология* **60** (1), 49–56.

Чиченко, В.А., 2022. Обилие и распределение массовых видов макробентоса залива Восток по данным съемки июля 2020 г. *Материалы региональной научно-практической конференции студентов, аспирантов и молодых учёных по естественным наукам*. Владивосток, Россия, 519–522.

Шулькин, В.М., 2004. Металлы в экосистемах морских мелководий. Дальнаука, Владивосток, Россия, 279 с.

Yoshimizu M., Kimura T., 1976. Study on the Intestinal Microflora of Salmonids. *Fishing Pathology* **10** (2), 243–259.