Analysis of Causes of Major Environmental Issues Occurring on Sea Coastlines of the Peter the Great Bay

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Abstract. The geoecological assessment of any territory or aquatic area is based on the evaluation of the natural resource potential, conditions and factors influencing its development as well as the analysis of major environmental issues that characterize the current regional state. The monitoring of water ecosystems under the conditions of anthropogenic impact on coastal areas is of significant importance within the study of the conservation and restoration of biodiversity, in the assessment of the dynamics of various environmental factors and their effects on ecosystems and on the bioresources management planning.

1. Introduction
The hydrochemical monitoring of the sea coastal waters is of great importance for assessing the state and analyzing the processes of ecosystems functioning. As a rule, the environmental studies are related to the analysis of environmental factors, establishment of biological regularities of the ecosystems functioning, and monitoring of human impact on these processes. For this purpose, we study such quantitative indicators as the dynamics of environmental factors, in particular the hydrochemical and hydrophysical factors, temperature, and impact thereof on the abundance, biomass, and production properties of the common species of hydrobionts, and the ecosystem as a whole. Typically, these data are obtained over time during the annual and seasonal observations using the traditional methods for hydro-biological research. As a rule, this involves time-consuming and lengthy procedures for collecting and processing the experimental data. A number of tasks in these studies can be automated using the modern methods for collecting and processing information, various underwater technical means, in particular, submersibles and computer modeling methods. In such studies, a hydrochemical analysis of the aqueous medium condition is a very important stage. This work demonstrates the results of the sample analysis for the 1973–2017 period (kindly provided by the leadership of the Department of Analysis of Water Resources, Soil Pollution and Toxic Wastes of the Center of Laboratory Analysis and Technical Measurements in the Primorsky Territory).

2. Methods
Typically, at the initial planning stage of hydro-biological research, a uniform grid of stations is placed over the map of the studied water body, and, after collecting the material, the data are processed as a single sample. With these preliminary results, it is already possible to plan the studies of seasonal dynamics of hydro-biological indicators on the areas (biotopes) typical of the said water body, which
are characterized by a specific coverage and conditions. In statistical studies, such approaches are characterized as a uniform data selection. The methods which are the most cost-effective for achieving the specified accuracy of studies may include the collection of hydro-biological data, when the entire area of a water body is divided into homogeneous segments, inside which the studied parameters are determined. This method allows reducing the number of collected samples, and decreasing the overall costs spent during the research conduction. The calculations are carried out for each selected biotope separately, and the average values for the entire water body are defined as weighted averages, wherein the weights for the average values of biotopes are their areas.

The sites of hydrochemical sampling are taken on the basis of the project documentation data of the industrial enterprises and the results of marine observations. The hydrochemical monitoring data are processed using a specially developed information system, which in addition to the database generation also allows analyzing and predicting phenomena and effects, including in the study of environmental safety and conservation of biodiversity. The statistical processing and analysis of the accumulated information allows us to develop and explore mathematical models for prognosing different situations and making appropriate decisions. For the material collected during the period under review, the statistical processing was carried out, according to the results of which the dynamics of the main indicators of the maximum, minimum, and threshold limit values was examined.

3. Results and discussion
The sources of pollution of the Amur Bay. Waste waters. Prior to the construction of waste treatment facilities by the Summit - 2012, Vladivostok discharged a huge amount of raw waste waters (in 1990 – 446,000 m³). In 1996, the DPL (degree of pollution limit) on the aquatic area of the Amur Bay in the downtown area ranged from 16–32, in the Vtoraia Rechka River district – from 8-32 and higher at the DPL rate of 8 [1,2]. As a result of the waste water discharges, the ecosystem of this aquatic area is degraded to the lowest levels, a change in the trophic structure of communities occurred, towards the domination of detritophagous animals, there is virtually a lack of benthic filter-feeding organisms, the process of reproduction of marine organisms is disrupted. The frequency of "red tides" increased that were caused by the intensive development of microorganisms and toxic phytoplankton [9]. In total, together with the waste waters (according to the data calculated by the normative method), 44,642.76 tons of pollutants of 28 types were discharged. The top-priority pollutants (according to the discharge mass fraction) are the organic substances in their full biological oxygen demand (BOD₉ₐ₉) – 14,954.03 tons (33.5%), suspended substances – 13,682.43 tons (30.6%), and biogenic substances – 5,232.31 tons (11.7% of the total discharge of pollutants). The largest amount of pollutants is discharged via the following outlets: "Pervorechenskii" – 16,059.89 tons/year (36%); "Vtoraia Rechka" – 12,184.64 tons/year (27.3%); The Razdol'naia River – 9,741.6 tons/year (22%), and "De-Friz" – 5,159.02 tons/year (11.7% of the total discharge of pollutants). A large proportion of the organic (by BOD₉ₐ₉) and suspended substances are discharged through such outlets as "Pervorechenskii" and "Vtoraia Rechka". However, the mass fraction of such pollutants as petroleum products, heavy metals (Zn, Cu, Ni, Pb, Cr, Cd, Mg) as well as boron and hydrogen sulfide is significantly higher in the effluents carried out by the Razdol'naia River [5]. Our studies have shown that in a semi-enclosed hypereutrophic water body within the city of Vladivostok (near the mouth of the Vtoraia Rechka River) in 2005-2006, the extremely high quantitative indicators of microalgae were universally observed, which reached hundreds of millions of cells per liter.

Heavy metals. Even in the Soviet times (1973), the amount of Cu discharged into the Amur Bay reached 11 maximum permissible concentration (MPC), and in 1996, the total content of zinc in the wastewaters discharged into the Bay increased 1.5 times, aluminum – 3 times, nickel – 45 times, as compared to 1995. According to the report of the Vladivostok Water Management in 1995, in 1996 the discharge of copper was 300 kg/year. According to the degree of water pollution, 50–60% of the Bay area is related to the dangerous and highly dangerous levels, and 40–50% – to the moderately dangerous and acceptable levels [2].
Oil pollution. Together with the wastewaters of settlements and enterprises, the petroleum hydrocarbons, suspended substances, chlorides, sulfates, nitrogen and phosphorous compounds, synthetic surfactants, fats, oils, phenols, aldehydes, and toxic metals are discharged in the Bay marine waters [3-5]. The total discharge of petroleum products (PP) in the commercial wastewaters in 1995 amounted to 77.83 tons/year [2]. In 1996, in the waters of the Amur Bay, the average annual content of petroleum hydrocarbons remained at the level of 1995, but the maximum values increased from 2 MPC to 11.4 MPC, wherein the exceedance of the maximum permissible concentration is observed both on the surface and at 10 m, in the bottom layer and especially in the sediments, i.e. throughout the entire water column. In 2002, the discharge of bilge waters from vessels was observed. The PP discharge at the end of the last century amounted to 131.6 tons/year [6].

Detergents. In 1996, the wastewaters discharged into the Amur Bay demonstrated the 18 times increase in the total content of synthetic surfactants (mainly due to discharges from the Razdolnenskiy Plant of Building Materials). The maximum concentration of phenols increased, which was especially observed in September in the northwestern part of the bay. The concentration of pesticides somewhat decreased, but they are present everywhere.

Dumping. Despite the fact that the discharge of soils was terminated in 1985, after 5 years the bottom sediments in the area of dumping contained 3–6 times higher concentrations of pollutants than on average in the Bay. The unauthorized dumps led to an increase in the concentrations of biogenes and to the growth of phosphates [7] from Ptot. – 26 µg/l (1985) to Pmin. – 83.5 µg/l (2003).

Bacteriological pollutions. According to the bacteriological indicators, 30% of water samples from the Amur Bay do not meet the standards. Every year, a culture of choleriform vibrio "El-TOR" is taken from its waters. In 1997 in Vladivostok, there was observed an outbreak of halophilic infection due to the consumption of shrimps [6]. The mass fish mortality and sewage discharges (more than 90% of the total inflow of pollutants into the Bay) occur annually. The consequence of the disastrous ecological state of the Amur Bay is the extinction of its flora and fauna [4].

The sources of pollution of the Zolotoy Rog Bay. The coastal territory of the Muravyov-Amursky Peninsula is the most polluted area of the Peter the Great Bay (especially the western and southern parts). Here is located a large city of Vladivostok with the developed industry (here are located the enterprises of the ship-repairing, fish processing, constructing, energy producing, food and light industries). The wastewaters from various enterprises are discharged into the coastal waters being insufficiently treated or completely untreated, so the significant exceedances of the MPC standards are observed according to many indicators.

The Zolotoy Rog Bay, located in the Peter the Great Bay, is the most intensely affected by the wastewaters of Vladivostok. The significant exceedances of the MPC standards were observed on the organic, biogenic elements, and the content of heavy metals. The negative impact on the water condition is made by the large urban ports, shipyards, small and large-capacity fleets as well as by the discharges of untreated industrial and municipal wastes. A significant contribution to the pollution of the bay is made by the Obiasnennia River, which is a receiver of wastewaters from a great number of objects and is subjected to the thermal treatment of cooling waters of the WTPP-2. The total volume of incoming wastewaters into the bay is 5 times higher than the volume of water in its aquatic area. At present, the Zolotoy Rog Bay has lost its fishery value becoming a lifeless transport artery.

The analysis took into account the data on several dozens of enterprises, the wastewaters of which are discharged directly into the river. The exceedance of the MPC standards was found out for chlorides – 43 MPC. This exceedance can be explained by the activity of the WTPP-2 having a direct discharge into the river [3].

Wastewaters. The Zolotoy Rog Bay is intensely affected by the urban wastewaters. Almost the entire coastline is a quay wall. The Zolotoy Rog Bay receives a significant amount of wastewaters from the urban combined-sewage system. In addition, the bay is also significantly affected by the large urban ports and ship-repairing plants. Large volumes of polluted waters come from the Obiasnennia River channel, which itself is a receiver of wastewaters from a large number of objects, and its high flow rate is provided by the cooling waters of the TPP-2. In view of the discharged waters of the
circulating cooling system of the TPP-2, of the private water flows of the Obiasneniiia River channel, the Buyakovka stream and the falling therein wastewater outlets of the incoming flows to the bay apex is about 500,000 thousand cubic meters per year. This is several times larger than the volume of bay waters. In 1996, according to A G Driakhlova [2], the wastewaters from 16 enterprises were discharged into the Zolotoy Rog Bay. The largest volume of the polluted wastewaters is discharged by the Vladivostok TPP-2 (7,220.6 thousand m$^3$/year) and the Dalzavod Ship Repair Center (2,340 thousand m$^3$/year), which accounts for 78.1% of all polluted wastewaters discharged into the Zolotoy Rog Bay. The total amount of wastewaters per year in 1995 and 1996, respectively amounted to 2,665,218.11 and 2,554,551.00 thousand m$^3$, out of which the polluted wastewaters are 4,709.9 and 12,230.8 thousand m$^3$, respectively. In 1998, the water quality of the Zolotoy Rog Bay deteriorated from "polluted" to "dirty", i.e. it returned to the level of 1992–1995.

Oil. Over the last fifty years, the oil-containing effluents of the industrial enterprises and ships were discharged into the Zolotoy Rog Bay, which is more than 50 tons/year of petroleum products [2]. In 1996, the oil pollution increased by 3 tons as compared to 1995. In 1998, it was noted that the surface of the Zolotoy Rog Bay was covered with a light oil fraction for 41–60%. As a result, the pollution of the bay by petroleum products (PP) in 2001 on average 1.4 times exceeded the MPC. In 2006, the percentage of the aquatic waters coverage reached to 41–100 [1].

Detergents. According to the Primorye Interregional Territorial Administration for Hydrometeorology and Environmental Monitoring of Roshydromet, the content of SS in the Zolotoy Rog Bay reaches 150–250 μg/l (at the MPC standard of 50–100 μg/l).

Heavy metals. In the Zolotoy Rog Bay in 1996, the increased concentrations of copper – 3.8 MPC, cadmium – 30 MPC, zinc – 1.4 MPC, and mercury – 2 MPC were documented.

The average concentrations of pesticides in the bay water are higher than in the water of the entire Amur Bay. The average content of phenols has decreased in the recent years from 3.3 to 2.0 MPC.

Bottom sediments pollution. V M Shulkin [8,9] studied the samples of silt taken from the bottom of the bay. In all samples, the hydrocarbon content was within the range of 0.3-0.33%. The dry residue was analyzed for the content of silicon, sulfur, and heavy metal ions. At the bottom of the bay, a sediment layer was formed, which, according to the definition of the Committee on Natural Resources of the Primorsky Territory Administration, is an "oil bituminous" layer that reaches a thickness of 0.7 to 1.5 meters and weight of more than 600,000 tons. If we make calculations based on the table data, with the bay bottom area equal to 6.7 million m$^2$, layer thickness of 0.8 m and a specific silt density of 1.5–16 tons/m$^3$, then the organic part of silt has a weight of approximately 640,000 tons.

Biological pollutions. The microbiological observations of the coastal marine area during the spring-autumn period of 2004 [1] show the following:

1. The total abundance of bacteria ion the aquatic area of the Zolotoy Rog Bay and the Eastern Bosphorus Strait averages to 0.90 x 106 cells/ml and varies from 0.45 x 106 to 2.91 x 106 cells/ml with an average biomass value of 564 mg/m$^3$.

2. The seasonal fluctuations of the total abundance and biomass of bacteria are: in the spring – 0.90 x 106 cells/ml (407 mg/m$^3$), in the summer – 1.45 x 106 cells/ml (657 mg/m$^3$), in the autumn – 1.24 x 106 cells/ml (615 mg/m$^3$). At the same time, the abundance of bacteria in the Zolotoy Rog Bay is 1.5-2 times higher than in the Eastern Bosphorus Strait.

3. The maximum values of the total abundance and biomass of bacteria are recorded in the area, where the Obiasneniiia River flows into the Bay and in the quayside area of the harbor station for coastline communications. The minimum values are found in the bottom horizons at the entrance to the Bay of Ulysses and at the outlet of the Eastern Bosphorus Strait.

4. The indicator bacteria are widespread throughout the entire study area. The most likely abundance of the heterotrophic saprophytic bacteria remains constant both in the bay and in the strait, and is more than 0.025 x 106 cells/ml.

5. The concentration of the oil oxidizing bacteria varies from 0 to 0.025 x 10$^6$ cells/ml. The maximum values of the oil oxidizing microorganisms are constantly found in the Zolotoy Rog Bay.
An analysis of the causes of the major environmental issues occurring on the sea coastlines of the Peter the Great Bay. The Peter the Great Bay is experiencing a strong anthropogenic influence. Its waters receive a large amount of domestic and industrial wastewaters from Vladivostok, Nakhodka, Ussuriysk, and other settlements. Moreover, the majority of the wastewaters fall into the bay without proper treatment. The runoffs of different enterprises contain volatile phenols, petroleum products, metals, including heavy metals, and wastes of the fish and agricultural products processing. The maritime transport vessels are also the sources of such pollutants as petroleum products, industrial oils, domestic sewage, and garbage.

To determine the water quality and the degree of pollution of the ecosystem of the Peter the Great Bay, it is necessary to conduct regular environmental monitoring on the basic hydrochemical indicators. To do this, it is advisable to use and develop information systems, which allow not only to generate databases, but also to analyze and forecast the phenomena with the assessment of the causes and consequences of the forecast. These technologies in recent decades have been widely used in different areas of human activity, including the study of the environmental safety of ecosystems and preservation of biodiversity.

The study of the current state of marine waters of the Peter the Great Bay from 2001 to 2008 showed that the concentrations of individual indicators of water pollution are quite significant [3].

The main environmental problems on the coastlines of the Peter the Great Bay are formed under the influence of the natural and anthropogenic factors, and the list thereof is extensive:
- The global factors (climate change, flooding of the sea coast, a need for the reintroduction and introduction of plants and acclimatization of those animals that better correspond to the modern climatic stage, etc.).
- The anthropogenic industrial factors (pollution of the waters of the World oceans, acid rains and related thereto drying of forests, atmospheric air pollution, problems of processing the wastes that are partly suitable for the production of feed additives, fertilizers, building materials, metal recovery, etc.).
- The anthropogenic domestic factors (wastewaters, drinking water quality, traffic noise and pollution, etc.).
- The environmental and economic factors (the need to conserve genetic resources and the most important natural resources for the future generations, the priorities of the food and environmental security, the need to create a reserve of energy and mineral resources, etc.).
- The geopolitical and international factors (protection of the territory and aquatic waters, preservation of bio-resources, creation of ecological corridors, protection from poaching, etc.).

The main regional transformation factors of the ecosystems of the Peter the Great Bay include depopulation; degradation of natural ecosystems; decrease in biodiversity and bio-productivity; reduction of natural resource potential; deterioration in the quality of the environment; poaching and overfishing. The results of the conducted analysis confirm the findings of many researchers about the critical state of the Peter the Great Bay. The collection of the environmental monitoring data on the marine coastlines of the area allows determining the ecological status of the coasts as an unsatisfactory one (sometimes critical, dangerous, and even extremely dangerous). The sharp increase in the emission volumes within the coastal zone has led to the fact that the extent of pollution has become very close to and often even overlaps the limits of the natural self-restoration. The consequence of the disastrous ecological state of the Bay is the extinction of its flora and fauna.

4. Conclusions
1. For the recent years, the environmental situation in the Amur Bay has been characterized as a sharply critical one. There is a trend to increase MPC on nitrites, phosphates, detergents, PD and BOD5 as compared to the background values. The level of water pollution periodically 20-30 times exceeds MPC. According to the bacteriological indicators, the waters do not comply with the standards, since almost annually the rotavirus, hepatitis A virus, choleraform Vibrio "El-TOR" are identified. At the bottom of the Bay, the cumulative concentrations of Zn, Cu, Ni, Pb, Cr, Cd, and Mg are 15-30 times higher than the background contents of the sedimentary rocks. According to the
pollution degree, the aquatic area is referred to the dangerous and highly dangerous levels by 5 elements (Zn, Cu, Pb, Cd, and Ag). The absorption capacity of the bay in relation to the allochthonous organics supplied by the urban agglomeration is almost exhausted.

2. In the in-seasonal dynamics of the hydro-pollutants in the Amur Bay, the following MPC exceedance is observed. In the spring: nitrites (1.22-1.44); phosphates (3.2-3.8); PD (47.7); BOD₅ (2.6); SS concentrations (7.4). In the autumn: SS (13.5-25); PD (3).

3. The aquatic areas of the Zolotoy Rog Bay. Refers to the α-β-mesosaprobic, eutrophic. The state of the bay waters is critical. The bay microflora cannot cope with the flow of domestic and industrial wastewaters.

4. The geoecological assessment of the Peter the Great Bay shows that, the western part of the Bay is largely dominated by the biogenic elements. The Aleut Bay and the Perevoznaya Bay demonstrate the exceedance of the MPC standards for a fishery water body on saline ammonium is 20 and 14.8 times, on phosphates is 27 and 8.9 times, respectively. A significant exceedance on the petroleum products is found out in the Slavyanka Bay – 11.5 times. The eastern part of the Bay is largely dominated by the organic substances. The content of volatile phenols in the Konyushkov Bay 47 times exceeded the MPC standards, in the Pyat Okhotnikov Bay – 8.1 times. The highest exceedance of the MPC standards on fats and anionic surfactants was observed in the Nazimov Bay – 58 times and 4.8 times, respectively. In the Konyushkov Bay and near the Cape Sysoev, the significant exceedances of the MPC standards for petroleum products were observed – 30 times and 13.4 times, respectively.

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