DOI: 10.22449/2413-5577-2022-2-19-37

Environmental Monitoring System in the Azov and Black Sea Basin

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Abstract
The paper presents the structure, tasks and features of environmental monitoring of the Black and Azov Seas as well as means and methods thereof adopted in the Russian Federation. The paper describes standards of analysis methods, layouts of offshore sampling stations, analyzed parameters, and specifics of the formation of the State Observation Network adopted by Roshydromet. Differences in the European and Russian systems of marine environmental monitoring and the systems' focus are shown. The features of satellite monitoring of the Azov and Black Sea basin were considered. The latest achievements of satellite monitoring of the Black Sea in the Russian Federation and the prospects for its development were analyzed. Additional opportunities to introduce satellite technologies in solving a number of environmental problems are listed. A new system of satellite monitoring of anthropogenic impacts on the Black Sea shelf of Russia, created by a team of scientists from the Aerocosmos Institute and institutes of the Russian Academy of Sciences, is considered. The possibilities of using mathematical modeling methods as an effective tool for predicting the consequences of anthropogenic impact on marine areas, including oil spills, were analyzed. The long-term changes in the water pollution index of the Black Sea marine areas were estimated in the area of responsibility of the Russian Federation. The implementation stages of the international project EMBLAS developed as part of the Bucharest Convention (1992) were analyzed. The purpose of the project was to develop a system of integrated monitoring of the Black Sea, to collect and manage the obtained data, and to improve the skill level of dedicated experts in the Black Sea states. The paper provides a map of ecological zoning of the eastern Black Sea with description of complex monitoring stations proposed for inclusion in the work program. The paper substantiates the necessity of ecological zoning and allocation of sites, the recreational use of which should be excluded or limited for the sake of people's health until the situation changes.

Keywords: environmental monitoring, water pollution index, station layout, Azov and Black Sea basin, satellite information, international projects

Acknowledgments: the work was performed under state assignment of MHI no. 0555-2021-0005 (code "Coastal studies").

For citation: Sovga, E.E., Korshenko, A.N., Mezentseva, I.V., Khmara, T.V. and Pogozheva, M.P., 2022. Environmental Monitoring System in the Azov and Black Sea Basin. *Ecological Safety of Coastal and Shelf Zones of Sea*, (2), pp. 19–37. doi:10.22449/2413-5577-2022-2-19-37

Система экологического мониторинга Азово-Черноморского бассейна

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Аннотация
Представлены структура, задачи и особенности экологического мониторинга Черного и Азовского морей, а также его средства и методы, принятые в Российской Федерации. Описаны используемые в Росгидромете стандарты на методики анализа, схемы расположения морских станций отбора проб, анализируемые параметры и особенности формирования государственной наблюдательной сети. Показаны различия в европейской и российской системах экологического мониторинга морской среды и направленность этих систем. Рассмотрены особенности спутникового мониторинга Азово-Черноморского бассейна. Анализируются последние достижения спутникового мониторинга Черного моря и перспективы его развития в РФ. Перечислены дополнительные возможности внедрения спутниковых технологий при решении ряда природоохранных задач. Рассмотрена новая система спутникового наблюдения за антропогенными воздействиями на шельфе Черноморского побережья России, созданная коллективом ученых института «Аэрокосмос» и институтов РАН. Проанализированы возможности использования математического моделирования как эффективного инструмента для прогнозирования последствий антропогенного воздействия на морские акватории, включая разливы нефти. Представлены оценки многолетних изменений индекса загрязненности вод Черного моря в зоне ответственности РФ. Проанализированы этапы реализации международного проекта *EMBLAS*, разработанного в рамках Бухарестской конвенции (1992 г.), цель которого состояла в развитии системы комплексного мониторинга Черного моря, сборе и управлении полученными данными, повышении уровня квалификации профильных специалистов в причерноморских государствах. Приведена схема экологического районирования восточной части Черного моря с описанием станций комплексного мониторинга, предлагаемых для включения в программу работ. Обоснована необходимость экологического районирования и выделения участков, рекреационное использование которых до изменения ситуации должно быть исключено или ограничено в целях сохранения здоровья людей.

Ключевые слова: экологический мониторинг, индекс загрязненности вод, схемы расположения станций, Азово-Черноморский бассейн, спутниковая информация, международные проекты

Благодарности: работа выполнена в рамках гос. задания ФГБУН ФИЦ МГИ № 0555-2021-0005 (шифр «Прибрежные исследования»).

Для цитирования: Система экологического мониторинга Азово-Черноморского бассейна / Е. Е. Совга [и др.] // Экологическая безопасность прибрежной и шельфовой зон моря. 2022. № 2. С. 19–37. doi:10.22449/2413-5577-2022-2-19-37

Introduction

The Azov and Black Sea basin is one of the most developed regions in terms of providing recreational-tourist, sanitary-resort and balneological services not only for Russia, but also for Europe as a whole. This is primarily due to the presence of sea beaches, as well as a network of mineral springs and sources of healing mud. Unique climatic and natural recreational conditions contribute to the development of a specific system of medical and resort complexes. At the same time, the catastrophic pollution of the Black and Azov seas is a generally recognized fact [1].

The main federal body of state power of the Russian Federation in the field of use and protection of the environment is the Ministry of Natural Resources and Ecology of the Russian Federation (Ministry of Natural Resources of Russia) (URL: www.mnr.gov.ru), whose competence includes monitoring environmental pollution. According to [2], monitoring is a systematic diagnosis of a situation with a certain specified frequency and using the same system of indicators. In relation to the monitoring of the hydrochemical state and the level of pollution of the marine environment, monitoring means regular observations in one place by the same or comparable methods. The Ministry of Natural Resources of the Russian Federation establishes requirements for conducting state monitoring of water bodies, including monitoring of the state of the environment and its pollution, collection, processing and storage of data, dissemination of information. The Ministry of Natural Resources of the Russian Federation coordinates and controls the activities of its subordinate the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), the Federal Service for Supervision of Natural Resources, the Federal Agency for Water Resources and the Federal Agency for Subsoil Use. In accordance with the Decree of the Government of the Russian Federation No. 477 dated 06.06.2013 "On the Implementation of State Monitoring of the State and Pollution of the Environment", Roshydromet was instructed to form and ensure the functioning of the State Observation Network (SON), its stationary and mobile points, as well as ship field research.

At present, the State Observation Network is formed on the basis of Regulations on SON (2003) and includes both regional Departments for Hydrometeorology and Environmental Monitoring (DHEM), and their branches – Centers for Hydrometeorology and Environmental Monitoring, which perform practical work on monitoring [1]. The results of observations of the marine network of Roshydromet

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[1] Rosgidromet. *The Structure of Rosgidromet.* 2022. [online] Available at: http://www.meteorf.ru/about/structure [Accessed: 06 June 2022].

are published in the Yearbooks of Marine Water Quality by Hydrochemical Characteristics [2)], which are regularly supplemented by the results of studies and observations of research institutes of Roshydromet and the Russian Academy of Sciences, individual field marine research of state and non-state organizations [2)], data obtained as part of the international exchange of information.

Contact methods of monitoring observations of the quality of marine waters are supplemented by remote (space) methods of obtaining information. According to the order of the Government of the Russian Federation No. MK-P9-01617 dated 10.02.2003 [3)], the State Institution *Scientific Research Center "Planet"* together with the Hydrometeorological Center of the Russian Federation, the Institute of Oceanology and the Space Research Institute of RAS in the Russian sector of the Black and Azov seas carry out satellite monitoring of the aquatic environment, the technology of which enables to receive processed satellite images of the visible, infrared and microwave ranges from *Meteor-3M*, *Monitor-E*, *Terra Aqua*, *NOAA*, *ERS-2*, *Envisat*, *IRS*, *QuikSCAT*, *Jason*, *TOPEX/Poseidon* and *Meteosat-9* satellites.

Twelve types of final satellite information include not only generalized schematic maps of the state of the aquatic environment, but also the maps of:

- oil pollution of the sea;
- water circulation, sea level changes;
- distribution of phytoplankton and algae, concentration of chlorophyll *a*;
- distribution of diffuse attenuation coefficient;
- sea surface temperature, surface wind;
- results of automated recognition of water bodies, etc.

The purpose of this work is to describe the structure and tasks of the state environmental monitoring of the Black and Azov seas, as well as to evaluate the means and methods for performing observations within the framework of international environmental projects.

Materials and methods

The problems of environmental monitoring of the Black and Azov seas are to be considered in the following order:

– structure and objectives of environmental monitoring. Features, structure and tasks of environmental monitoring in the Black Sea countries;

– means and methods of observations adopted in the Russian Federation, including contact and remote ones, as well as numerical modeling;

– proposals for improving the system of environmental monitoring of the Black Sea based on the results of implementation of international projects and programs.

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2) Korshenko, A.N., ed., 2020. *Marine Water Pollution. Annual Report 2019*. Moscow: Nauka, 232 p. (in Russian).

3) Roshydromet, 2001. [*On Introduction into Action of the Procedure of Preparation and Submission of General Information on the Environmental Pollution*]. Order by the Head of Roshydromet no. 156 as of 31 October 2000. Available at: https://docs.cntd.ru/document/901791258 [Accessed: 10 June 2022] (in Russian).

Results and discussion

Marine environmental monitoring (in this paper, monitoring in the Russian sector of the Black and Azov seas) is aimed at both assessing the current state of the marine environment and predicting the development of environmental risks based on a retrospective analysis of sources and factors of influence. According to this work [4)], the objects of marine environmental monitoring in the Black and Azov seas are: the marine environment within the exclusive maritime economic zone of the Black Sea states, hydrometeorological and climatic (seasonal) factors of influence, the main pollutants and their impact on the physicochemical parameters of the marine environment, coastal and marine sources of pollution, river and atmospheric runoff, exchange processes between the sea and the atmosphere, the sea and bottom sediments, the sea and living organisms, as well as bioproductivity.

It should be noted that the Russian system of ecological monitoring of the marine environment is significantly different from the European ones. Thus, the Russian system is based on the principle of chemical analysis of water and assessment of its pollution relative to the threshold limit value (TLV) of a particular chemical element in sea water.

The European monitoring system is based on the ecosystem approach, assessing the state of the marine environment using a set of indicators (descriptors) and focusing on assessing the direct impact of human activities on living organisms [5)]. One of the fundamental principles is the subsequent development of a system of measures to prevent or reduce further anthropogenic impact in the event of serious violations of the quality of the marine environment. This methodological approach enables not only to obtain an informative picture of the state of the main components of the marine environment, but also to influence its dynamics in the future. Such a system is currently used in all European seas, including most of the Black Sea [6)].

In 1992, in Bucharest, specialists from the Black Sea countries (Russia, Turkey, Ukraine, Romania, Bulgaria, and Georgia) signed the Convention for the Protection of the Black Sea from Pollution (Bucharest Convention). Within the framework of the Convention, these states assumed obligations to control and reduce pollution of the Black Sea, to monitor and protect the marine environment [7)]. Specific measures are determined by the three protocols of the Bucharest Convention [3]:

[4)] Monyushko, M.M., 2007. [Complex Ecological Monitoring of the Azov-Black Sea Basin (Current State)]. In: Publishing house Education and Science s.r.o., 2007. [*International Scientific and Applied Conference "Efficient Tools of Modern Sciences-2007" (3–5 May, 2007)*]. Praha: Publishing house Education and Science s.r.o., 2007.

[5)] European Parliament, 2008. Directive 2008/56/Ec of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union*, L 164, pp. 19–40. Available at: http://data.europa.eu/eli/dir/2008/56/oj [Accessed: 02 June 2022].

[6)] UNDP. *EU4EMBLAS*. 2022. [online] Available at: https://emblasproject.org/ [Accessed: 02 June 2022].

[7)] Black Sea Commission, 1992. *Convention on the Protection of the Black Sea Against Pollution (Bucharest, 21 April 1992)*. Available at: https://docs.cntd.ru/document/901892843 [Accessed: 02 June 2022] (in Russian).

– Protocol on the Protection of the Marine Environment of the Black Sea from Pollution from Coastal Sources;

– Protocol on Cooperation in Combating Pollution of the Marine Environment of the Black Sea with Oil and Other Harmful Substances in Emergency Situations;

– Protocol on the Protection of the Marine Environment of the Black Sea from Pollution from Discharges.

In 2002, the parties to the Convention signed the Protocol on the Conservation of Biodiversity and Landscapes of the Black Sea, and also compiled a List of Species Important to the Black Sea. The Black Sea Commission (Commission for the Protection of the Black Sea from Pollution) is entrusted with monitoring the implementation of the protocols of the Bucharest Convention, its Strategic Action Plan for the restoration and protection of the Black Sea. The established international advisory groups provide information and expert support to the Black Sea Commission and its permanent Secretariat. The work of the advisory groups is aimed at conducting environmental monitoring and assessing the level of pollution, controlling pollution from land-based sources and developing a unified methodology for the integrated management of the coastal zone, assessing the environmental aspects of regulating fisheries and extraction of other marine biological resources, preserving biodiversity and solving problems of environmental safety of navigation.

The Black Sea Commission manages the activities of the Black Sea regional centers organized on the basis of specialized national institutions [7)]. Support for the Black Sea national monitoring systems is included in the list of international projects carried out within the framework of the Strategic Action Plan for the restoration and protection of the Black Sea.

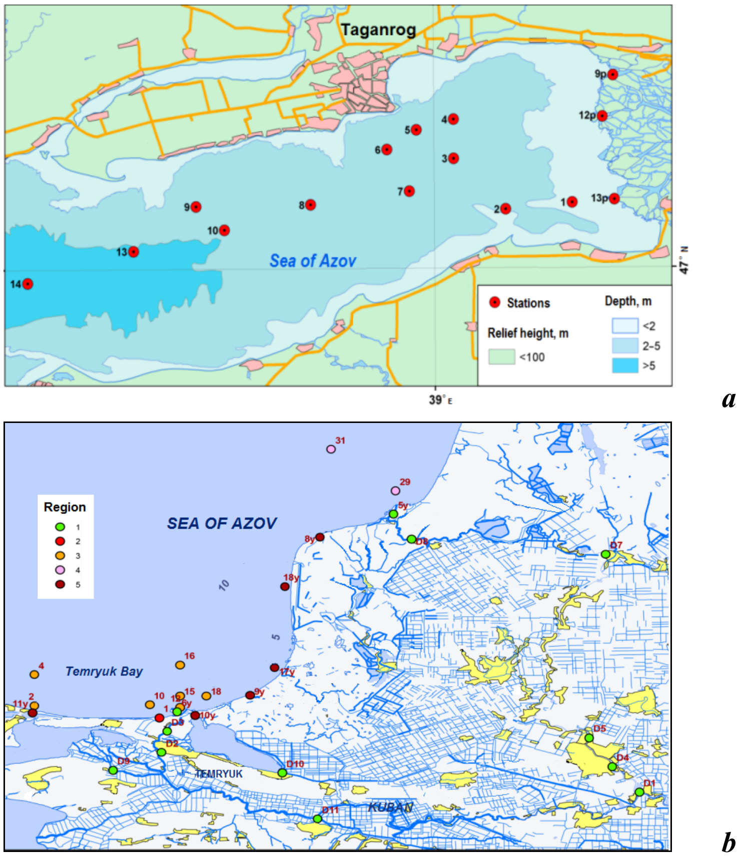
Monitoring stations of the Russian seas of Roshydromet

Stations of the State Service for Observation and Control of Pollution of Natural Environment Objects have a certain categorization depending on the composition and frequency of observations. Thus, single control stations of I category with constant monitoring are designed for operational monitoring of pollution level of the marine area. They are located in strategically important areas of the sea or in areas that are constantly subjected to intense pollution. According to the full program, observations of pollution and chemical composition of waters are carried out once a month, and according to the reduced program, monitoring is carried out two to four times a month. Single stations or complexes of stations (sections) of II category cover large areas of the sea, including estuarine sections of rivers, and serve to obtain systematic information, as well as to study the seasonal and interannual variability of controlled parameters. The monitoring is carried out once a month according to the full program (during the freezing period – once a quarter). The information about background levels of pollution, their seasonal and interannual variability is obtained at monitoring stations of III category, located in sea areas with a low level of anthropogenic load in relatively clean waters, where pollutants can get only as a result of their global transfer or regional migration processes. The stations of this category are also designed to determine the elements of the balance of chemicals. Observations under the full program are carried out once a season. The category and location of monitoring stations can be adjusted depending on the dynamics of the level of pollution of the marine environment or in relation to the emergence of new control objects [2)].

The monitoring programs carried out on the seas of the Russian Federation by the regional departments of Roshydromet are based on a permanent grid of stations of three categories. However, in reality, when implementing plans, it is often not possible to complete stations of the above categories due to constantly arising problems with a small scientific fleet adapted to perform outboard work for sampling water and bottom sediments. An additional complication is the need to analyze the content of chemical compounds and pollutants in seawater in very low concentrations, which requires modern chemical-analytical equipment and pure chemicals.

At present, the monitoring of the hydrochemical state and the level of pollution of the Sea of Azov is carried out in the eastern part of Taganrog Bay by the Don Estuary Hydrometeorological Station; in the delta of the Kuban River and on its estuarine coast in Temryuk Bay – by the Kuban Estuary Hydrometeorological Station (*Kubanskaya* EHS, the city of Temryuk), and at the stations of the section between the ports of Crimea and the Caucasus – by *Opasnoe* – the complex laboratory for monitoring environmental pollution (the city of Kerch). As an example, Fig. 1 shows the layout of stations for monitoring the pollution of the Sea of Azov waters.

In the water area of the Black Sea, the coastal waters of the Caucasian and Crimean coasts of Russia fall under state monitoring. In the coastal areas of the shelf in the area of the cities of Anapa, Novorossiysk, Gelendzhik and Tuapse, observations are carried out by *Kubanskaya* EHS (the city of Temryuk); in the coastal shallow zone in the area of the cities of Sochi and Adler from the mouth of the Sochi River to the mouth of the Mzymta River, the monitoring is carried out by a complex laboratory for monitoring environmental pollution of the Specialized Center for Hydrometeorology and Environmental Monitoring of the Black and Azov Seas (the city of Sochi). Off the Crimean coast of the Black Sea, the monitoring studies of the waters of Sevastopol Bay and the coastal zone of the South-Western Crimea are carried out by the Sevastopol Branch of the Federal State Budgetary Institution *N.N. Zubov State Oceanographic Institute* and the Department of Marine Biogeochemistry of the *Marine Hydrophysical Institute of the Russian Academy of Sciences*, and in the waters of the port of Yalta – a complex laboratory of monitoring of environmental pollution in the city of Yalta – Federal State Budgetary Institution *Crimean* EHS. The samples are taken from the surface and bottom layers, at deep water stations – from standard hydrological horizons of 0, 10, 25 and 50 m. The quality of sea water is controlled by characteristics, which include regime hydrological and hydrochemical characteristics (temperature, salinity, chlorine content, electrical conductivity, pH, total alkalinity and concentration of dissolved oxygen and suspended solids), concentration of biogenic elements (total phosphorus, phosphate phosphorus, ammonium nitrogen, nitrite, nitrate and total nitrogen, silicon) and pollutants such as petroleum hydrocarbons, anionic synthetic surfactants, phenols, organochlorine pesticides



F i g . 1 . Monitoring stations in the eastern part of Taganrog (*a*) and Temryuk (*b*) Bays of the Sea of Azov

of the DDT and HCCH groups, heptachlor, aldrin and polychlorinated biphenyls, as well as heavy metals. All chemical analyzes during work on the marine environment monitoring network are carried out in accordance with the methods of regulatory documents (RD) – guidelines for the chemical analysis of sea water.

Satellite monitoring of the Black and Azov seas in the Russian Federation and prospects for its development

Remote monitoring of the Russian waters of the Azov-Black Sea basin, which are subject to anthropogenic impact, is possible using modern satellite technologies. To do this, the monitoring system uses satellites, measuring equipment on ships and buoys, as well as a centre for receiving and processing information. When arranging satellite monitoring, both the world experience in carrying out such work, as well as the features of the sources of pollutant inflow and the dynamics of the water masses of the Black and Azov seas are taken into account.

For example, according to [4], in 2006, in the course of satellite monitoring of the state of the natural environment in the Russian sector of the Azov and Black seas, more than 1100 satellite images were obtained, processed and analysed from nine specialized Earth remote sensing satellites. Based on the analysis of ground-based observational data from the meteorological stations of Sochi, Tuapse, Novorossiysk, Anapa, Rostov-on-Don and Kerch, as well as previous satellite data, 12 types of operational satellite information and generalized schematic maps of the state and pollution of the marine environment were produced [4].

Modern satellite technologies can provide imaging of marine areas in the visible, infrared and microwave ranges of electromagnetic radiation. Sounding in the infrared and microwave ranges is used to determine the temperature of the sea surface, to study the thermodynamics of sea ice and to determine the salinity of water. Satellite imagery in the visible range makes it possible to monitor the state of the coastal zone and the dynamics of sea coasts, to determine the content of suspended particles, as well as the composition and productivity of phyto- and zooplankton. Spectral imaging can provide qualitative and quantitative analysis of suspensions, determination of chlorophyll in phytoplankton (and indirect water pollution) and detection of oil films on the sea surface.

In 2009, within the framework of the Bucharest Convention, a Strategic Action Plan was adopted to reduce oil pollution of the sea. Its *MONINFO* project is based on the use of satellite technologies for the detection of surface oil pollution in the sea. However, in 2008, even before the implementation of the EU initiative, the first comprehensive project Monitoring of Black Sea Oil Pollution and Environmental Safety of Navigation in Areas of Intensive Navigation in the Kerch Strait, the Water Area of the Port of Novorossiysk and on the Approach Routes to It was successfully implemented in the Russian Federation (with participation of the operator of the satellite data provision service *ScanEx RDC*, which has access to the operating system for positioning vessels (*Automatic Identification System, AIS*), developed by the Federal State Budgetary Institution *Administration of the Black Sea Ports*) [5]. The implementation of the project made it possible to monitor areas of intensive shipping, identify ships involved in unauthorized discharges of oily waters, and provide technical support in planning and conducting search and rescue operations in relation to ships in distress, including ships that do not transmit radio signals.

Space monitoring data from *Sentinel-1B* satellite, received on January 21, 2020, made it possible to detect an oil spill 146 km from Feodosia (Fig. 2). This was reported on January 23, 2020 by the Federal State Budgetary Institution *Scientific Research Centre 'Planeta'*, which identified the object as a film of oil pollution from ships [8)]. The area of pollution was 86.1 km^2, the length was 55.1 km. Pollution of coastal waters with oil products is one of the main environmental problems of the Black Sea region.

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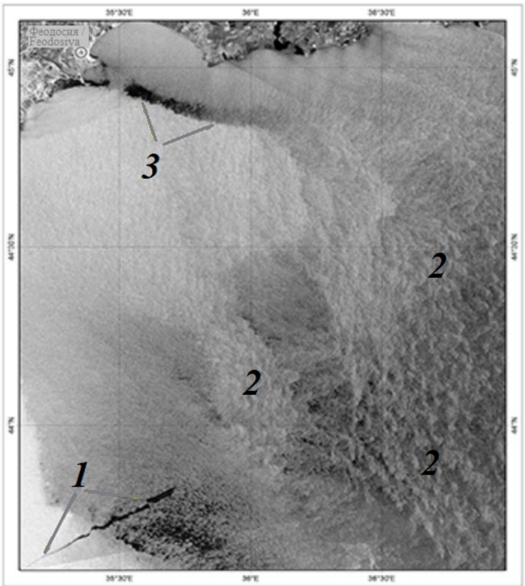
8) Chizhevskiy, A., 2020. [*Space Monitoring Data Showed a Major Oil Spill off the Coast of Crimea*]. Available at: https://neftegaz.ru/news/incidental/520743-dannye-kosmicheskogo-monitoringa-pokazali-krupnyy-razliv-nefti-u-beregov-kryma/ [Accessed: 10 June 2022] (in Russian).



F i g . 2 . Radar image of the Black Sea off the Crimean coast: *1* – films of oil pollution from ships; *2* – manifestation of the impact of atmospheric convection on the rough sea surface; *3* – manifestation of the impact of the atmospheric front on the rough sea surface

Another area of environmental monitoring in the Russian sector of the Black Sea was a timely detection and diagnosis of sea water blooming by measuring the concentration of chlorophyll according to satellite observations. Thus, in March 2008, in the northeastern part of the Black Sea, thanks to the timely acquisition of satellite images, the so-called red tide caused by the development of a species of dinophyte algae was recorded for the first time [6, 7]. Optical *MODIS* images taken at that time over the coastal areas of the Black Sea made it possible to trace the spatial and temporal distribution of polluted (blooming) waters. Chlorophyll maps obtained using *Aqua/MODIS* sensors confirmed the results of field observations.

Operational sounding of the optical properties of the Black Sea surface carried out at MHI NASU and regular studies of phytoplankton in its north-eastern part carried out by the staff of the SSC RAS made it possible in May–July 2012 to record an anomalous (over the past 15 years) in intensity and duration blooming of water. According to [8], it was caused by the massive development of the nanoplanktonic species of coccolithophorids.

Currently, a team of scientists from the *Research Institute of Aerospace Monitoring 'Aerokosmos'* with the participation of specialists from the MHI RAS (Sevastopol) and the IO RAS is working on the creation of a system for the integrated monitoring of anthropogenic impacts on the offshore areas of the Black Sea coast of Russia. This system will collect, process and analyze information important for assessing the state of marine areas and the response of coastal ecosystems to human activity, and in the event of a threat, it will be used to develop measures to prevent pollution of the marine environment.

This system for data collection provides for the use of ground-based sources of information, including instruments located on the coast and installed on ships, buoys and fixed platforms, as well as satellite systems that can transmit information on various characteristics of coastal waters in the operational mode. Such a complex will make it possible to record the direction and speed of the wind, the direction and height of the waves, the speed of the currents, to register vertical distributions of temperature and salinity of the waters, to determine transparency of the waters to identify suspensions, to detect pollution of marine areas, including the presence of oil pollution, surfactant films and plumes of different nature.

To work out the interaction of information flows, test areas were selected that were subject to intense pollution. These were the coast near Sevastopol, the southern coast of Crimea (the village of Katsiveli, where there is an oceanographic platform) and the Krasnodar Territory (the coast near Gelendzhik). The first preliminary results of the integrated system of regional monitoring of coastal waters for the indicated test areas are presented in [9].

It is worth recalling that modern satellite technologies are not limited to studying the surface of the sea. For example, remote sensing makes it possible to register underwater plumes, including those formed as a result of sewage discharges. A plume is a mesoscale formation with anomalous waters of anthropogenic or terrigenous origin [10].

According to [9], starting from 2015, space monitoring of the coast near Sevastopol was carried out based on a detailed analysis of optical multispectral images of high and medium resolution (from 1 to 30 m on the ground) from *Resurs-P No. 1*, *GeoEye*, *WorldView-2*, *WorldView-3*, *Landsat-7*, *Landsat-8*, *Sentinel-2A* satellites. The monitoring revealed the existence of a plume (Fig. 3), which was formed as a result of an emergency rupture of the sewer main of the *Yuzhnye* urban wastewater treatment plant [11]. On satellite images, the plume was distinguished by an anomalous reflectivity spectrum, which differed significantly from the corresponding spectrum for the background areas of the observed water area.

The project was supported by the Federal Target Program "Research and Development in Priority Areas of Development of the Scientific and Technical Complex of Russia for 2014–2020" [12]. The Ministry of Natural Resources and

F i g . 3 . Coastal area near the Sevastopol city on a fragment of an optical multispectral image from WorldView-2 satellite (September 17, 2015). The dotted line outlines the characteristic optical anomaly, the solid line shows the position of the underwater sewer line [11]

Ecology of the Russian Federation, the Federal Service for Hydrometeorology and Environmental Monitoring, the Ministry of Emergency Situations of Russia, and others are already interested in its results. These developments are of particular interest to shipbuilding, transport, oil and gas companies, educational and scientific institutions.

Mathematical modeling as a tool for assessing the state of the environment

The use of mathematical modeling makes it possible not only to fill in the gaps at the points of lack of field data, but also to carry out a model assessment of the ecosystem state in the conditions of variability of its components depending on external factors. Modeling enables us to evaluate interactions that occur in real systems, which cannot be or difficult to directly measure.

In addition, the use of the model enables to obtain a forecast of the ecosystem evolution under the mutual influence of natural and anthropogenic factors, to take into account the trends in the state of the ecosystem and the likely consequences of a particular economic program in order to search for a scientifically based set of environmental protection measures. Based on the simulation results, the environmental monitoring program can be optimized.

Complex multi-purpose mathematical models of marine water quality consist of the following blocks: hydrodynamic, impurity transfer, pollutant self-purification, eutrophication and oxygen regime blocks [13].

At present, many mathematical models have been created to predict the spread of an oil slick after a spill. The MHI RAS also developed an operational system for forecasting the spread of oil spills in the Black Sea (*Black Sea Track Web, BSTW*), which is based on the synthesis of the modules of the Baltic oil spill forecast system and the MHI Black Sea circulation model adapted to the physical and geographical conditions of the Black Sea [14, 15].

To assess the quality of waters and compare different marine areas, the calculated values of the water pollution index (WPI) are used, which make it possible to attribute the waters of the study area to a certain purity class. The rules for calculating WPI are determined by methodological recommendations [2)]. The WPI calculation method includes:

– selection of the level of data averaging over space and time;

– calculation of priority pollutant concentrations for the considered water area in a given period of time (in TLV);

– assessment of the water quality class according to the obtained WPI value according to the table "Water quality classes and WPI values".

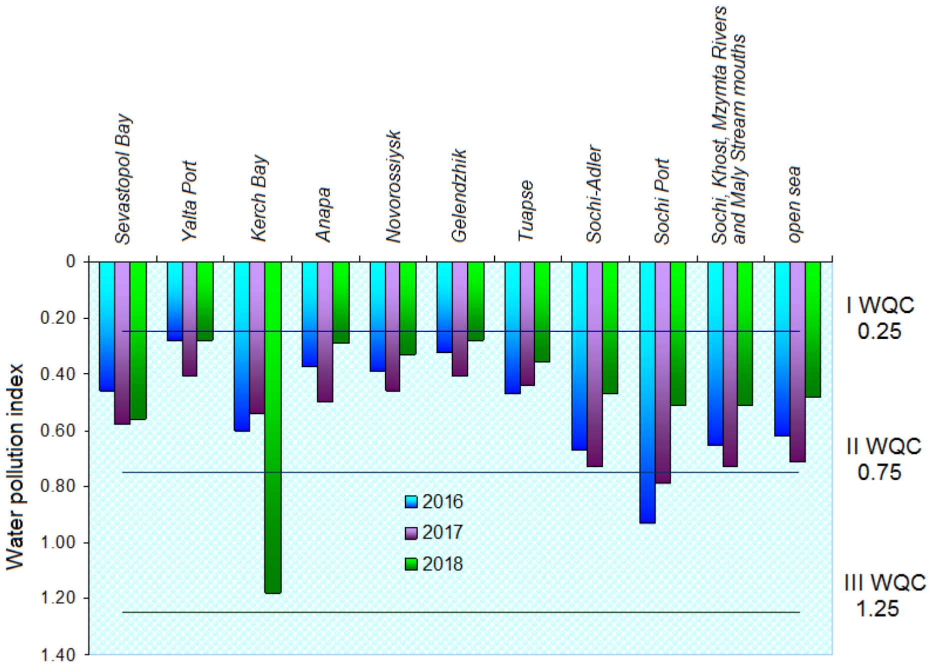
For sea waters, when calculating WPI, at least three parameters of pollutants are used and the content of dissolved oxygen is mandatory (TLV = 6 mgO_2/dm^3). The WPI calculation formula:

$$\mathrm{WPI} = \sum_{i=1}^{4} \frac{C_i}{\mathrm{TLV}_i} \div 4,$$

where C_i – concentration of the three most significant pollutants, the average content of which in the water of the study area to the greatest extent exceeded the corresponding TLVs. Water quality classes depending on WPI values are presented in the Table. Fig. 4 shows the long-term change in the WPI of the Black Sea water areas.

Water quality classes and WPI values [2)]

Water quality class	WPI value range
I. Very clean	≤ 0.25
II. Clean	0.25 … ≤ 0.75
III. Moderately contaminated	0.75 … ≤ 1.25
IV. Contaminated	1.25 … ≤ 1.75
V. Polluted	1.75 … ≤ 3.00
VI. Very polluted	3.00 … ≤ 5.00
VII. Extremely polluted	> 5.00



F i g . 4 . Long-term change in the WPI value of the Black Sea areas in the area of responsibility of the Russian Federation. WQC – water quality class

Proposals for the improvement of the Black Sea environmental monitoring system within the framework of international projects and programs

On March 15, 2010, the Black Sea Synergy environmental partnership initiative was launched in Brussels to support the efforts of the EU and its partners to find common approaches to the challenges facing the Black Sea region [9)].

In 2013–2020 a number of Black Sea projects (*EMBLAS-I, EMBLAS-II, EMBLAS-Plus*) were aimed at improving the methods of marine monitoring and supporting the implementation of the Bucharest Convention in order to develop a monitoring system, collect and systematize the data obtained, and improve the skills of specialized specialists near the Black Sea states. Thus, within the framework of these projects, the FSBI *N.N. Zubov State Oceanographic Institute* conducted, using generally accepted world methods, complex coastal expeditions to assess the ecological state of the marine environment along the Caucasian coast of the Russian Federation, in the Kerch Strait and in more detail in the area of the cities of Sochi and Adler. The purpose of these studies was to improve the quality of monitoring data on the chemical and biological state of the Black Sea by optimizing observation systems, taking into account the practical proposals of the EU Directives *WFD-2000, MSFD-2008* and *Black Sea Strategic Action Plan* (2009), as well as expanding the capabilities of the project partner countries for the implementation of marine monitoring, taking into account both the practical recommendations of the EU in the *WFD* and *MSFD* Directives, and the results of the study set out in the *Black Sea Diagnostic Reports I* and *II*.

During the *EMBLAS* project implementation, the following activities were carried out:

1) analysis of national monitoring systems and opportunities for access to the data obtained;

2) support for the Black Sea states in the implementation of the Bucharest and other international conventions;

3) methodological and technological assistance to countries in the course of marine monitoring, including:

– assistance in the development and implementation of cost-effective and unified biological and chemical monitoring of the marine environment in accordance with the requirements of international agreements, as well as *WFD* and *MSFD* [5)];

– development and implementation of a training program on monitoring methods in order to ensure the quality of the results obtained in accordance with *ISO* 17025;

– preparation and implementation of the methodology of sea voyages (*Joint Black Sea Surveys*) to assess the state of the open part of the Black Sea;

4) development and creation of the Black Sea Water Quality Database (web-based), including hydrological and hydrochemical blocks and most of the biological characteristics of the sea ecosystem (*Black Sea Water Quality Database*);

[9)] The Commission on the Protection of the Black Sea Against Pollution, 1996. *Strategic Action Plan for the Rehabilitation and Protection of the Black Sea*. [online] Available at: http://blacksea-commission.org/_bssap1996.asp [Accessed: 06 June 2022].

5) preparation of proposals for improving the Black Sea marine environment monitoring program in the territorial waters and exclusive economic zones of the Black Sea states.

The FSBI *N.N. Zubov State Oceanographic Institute* and other Russian organizations and laboratories took part in international expeditions, trainings and intercalibrations together with scientists from other Black Sea countries under the guidance of leading world experts. In the course of work, the participants improved their skills and knowledge and at the same time contributed to the acquisition and dissemination of up-to-date knowledge about the ecological state of the Black Sea. Based on the data obtained during coastal expeditions in the spring-summer-autumn periods of 2016, 2017 and 2019, proposals were formed to change the location of stations, unify the measured parameters depending on the depth and frequency of sampling to solve the following tasks:

1) assessment of the current state of hydrochemical and biological parameters of the marine environment;

2) assessment of long-term interannual variability of nutrient concentrations and eutrophication levels in the north-eastern part of the Black Sea with special attention to several local areas (Gelendzhik Bay, Golubaya Bay, Anapa district, Sochi-Adler area);

3) obtaining the necessary data to assess the level of anthropogenic pollution of the marine environment and sources of toxic pollution in the coastal waters of the Caucasus;

4) assessment of the level of pollution by marine macro debris, as well as research into the sources of its entry into the sea;

5) assessment of the structural characteristics of marine communities: concentration of chlorophyll and other photosynthetic pigments, species composition, abundance and biomass of phyto-, meso-, macrozooplankton, zoo- and phytobenthos;

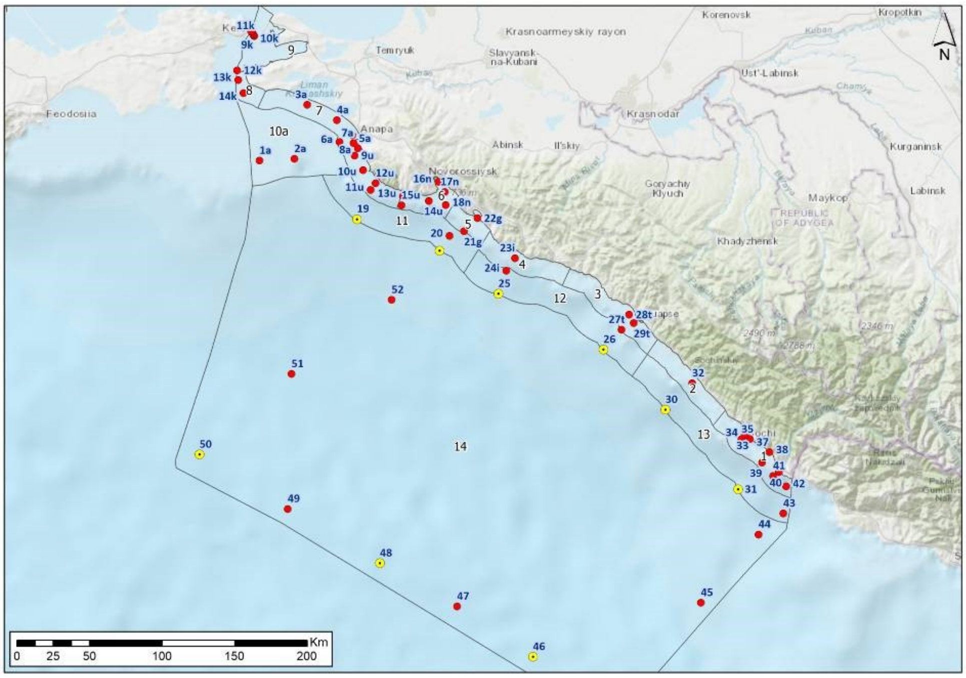
6) assessment of the presence of invasive species (invading species);

7) assessment of the biological consequences of water pollution in coastal waters, the open sea and marine specially protected natural areas.

New stations were proposed covering all ecological regions of the coastal waters of the Caucasus and the central zone of the eastern part of the Black Sea. Particular attention was paid to the Kerch Strait as a narrow channel with intensive navigation and a large source of highly eutrophicated Azov waters. An additional serious source of pollution in the north-eastern part of the sea is anchor transshipment stations (sites) on the shelf south of the Kerch Strait. A narrow strip of heavily polluted waters along the coast from Anapa in the north to Adler in the south is significantly affected by urban sewer discharges, and is also subject to significant pollution due to intensive resort and tourist exploitation. Several stations in the open sea can be considered as background for the calculation of permitted discharges in accordance with Russian legislation. Five stations along the southern maritime border with Abkhazia are needed to control the transboundary transport of pollutants. For the coastal regions of the Caucasus and the open sea, a new ecological zoning scheme and the optimal spatial arrangement of 51 monitoring stations along the coast and in the open sea, as well as 9 stations in the Kerch Strait were proposed to obtain comprehensive information on hydrological, hydrochemical and biological processes in different parts of the region (Fig. 5).

Based on the data obtained during coastal expeditions of the *EMBLAS* project series in the spring-summer-autumn periods of 2016, 2017 and 2019, some proposals were developed to improve the system of state environmental monitoring of the Black and Azov seas, as well as to form an observation program in the eastern part of the Black Sea, taking into account the principles of ecological zoning. Proposals to expand the capabilities of the national authorities of the Black Sea countries in the implementation of integrated environmental monitoring were based on modern hydrological, hydrochemical and biological data obtained in the course of field research.

Thus, the information obtained using complex methods of modern environmental monitoring will make it possible to identify areas of coastal waters that require priority environmental measures.



F i g . 5 . Scheme of ecological zoning of the eastern Black Sea and integrated monitoring stations proposed for inclusion in the work program. Red dots mark regular stations, yellow ones – background stations

Conclusions

1. The paper describes the objects and tasks of marine environmental monitoring. Differences in the European and Russian systems of monitoring the marine environment, the orientation of these systems are shown. The Bucharest Convention (1992) is considered, as well as the tasks of the Commission for the Protection of the Black Sea from Pollution and its advisory groups.

2. An analysis of the features, structure and tasks of environmental monitoring of the Black and Azov seas, its means and methods adopted in the Russian Federation is presented. The standards adopted by Roshydromet for the methods of analysis and the layout of offshore sampling stations are described.

3. The directions and possibilities of satellite monitoring of the Azov-Black Sea basin are considered. The latest achievements in the field of remote sensing of the Black Sea in the Russian Federation and the prospects for their development are analyzed. On specific examples for various areas of the Black Sea, the availability of space information systems is shown.

4. The creation of a new system of integrated monitoring of anthropogenic impact on the offshore areas of the shelf regions of the Black Sea coast of Russia and the prospects for its use are considered.

5. It is shown that mathematical models as a modern tool for environmental monitoring make it possible to assess the impact of various types of anthropogenic effect on an ecosystem and obtain a forecast of its evolution.

6. The use of WPI of waters for a comprehensive assessment of the quality of waters in certain areas of the Black Sea is considered. The possibility of comparing the quality of waters in marine areas with different levels of pollution in a retrospective for any selected period is shown.

7. The implementation stages of the international project *EMBLAS* aimed at developing a system of integrated environmental monitoring of the Black Sea in order to fulfil the Bucharest Convention are analysed. A scheme of ecological zoning of the eastern part of the Black Sea with a description of integrated monitoring stations proposed for inclusion in the work program is given.

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Submitted 10.02.2022; accepted after review 1.03.2022;
revised 27.04.2022; published 25.06.2022

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Irina V. Mezentseva – calculation of WPI for the Black Sea water area, discussion of results

Tatiyana V. Khmara – preparation of information of mathematical modelling methods as a tool of ecological monitoring, discussion of results, article editing

Maria P. Pogozheva – preparation of illustrations, information of tasks of monitoring as part of EMBLAS project implementation

All the authors have read and approved the final manuscript.