https://doi.org/
UDC 574.5(262.5:477):504.054:678.7]-047.37(045) **10.15407/ugz2023.04.027**

Iemelianov, V. O., ORCID: https://orcid.org/0000-0002-8972-0754,
Nasiedkin, Ye. I., ORCID: https://orcid.org/0000-0003-2633-9291,
Kukovska, T. S., ORCID: https://orcid.org/0000-0001-7532-8885,
Mytrofanova, O. A., ORCID: https://orcid.org/0000-0001-5971-9122,
Dovbysh, S. M., ORCID: https://orcid.org/0000-0002-3542-7472.

The State Scientific Institution "The Center for Problems of Marine Geology, Geoecology and Sedimentary Ore Formation of the National Academy of Sciences of Ukraine"

Research of Plastics and Microplastics in the Black Sea Geoecosystem as a Component of Its Pollution Assessment

This publication presents a series of relevant aspects of the problem of pollution of the Black Sea geoecosystem and its geological and aquatic subsystems with plastics and microplastics. The condition of research on this issue, terms and prospects for creation of an effective system for field observations of plastic waste distribution with a microplastic component within the Ukrainian part of the Black Sea geoecosystem are discussed. Emphasis is placed on the modern, European standard adapted component in organizing research on the pollution of the Black Sea geoecosystem by synthetic polymers. The feasibility of a comprehensive study in the pathways and sources of these pollutants' entry into its aquatic and geological subsystems is determined, taking into account natural characteristics of the ecological subsystem of the North-Western shelf of the Black Sea, while developing an optimum network of relevant monitoring observations. The research is based on data obtained from comprehensive field observations and subsequent analytical studies of the composition, sources of entry, and distribution of plastics and microplastics in modern sandy beach sediments and suspended in sea waters within the coastal region of Odessa in Ukraine. The results of analysis and generalization of materials on applied research of artificial polymers within the coast and waters of the Black Sea obtained by the authors from archival and published literary sources were also employed. Methodological approaches to organizing research on plastics and microplastics in the Black Sea geoecosystem and its main environmental subsystems are proposed as a necessary component of their pollution assessment.

Keywords: *plastics, microplastics, geoecosystem, the Black Sea, beach, research arrangement*

УДК 574.5(262.5:477):504.054:678.7]-047.37(045)

Ємельянов В. О., ORCID: https://orcid.org/0000-0002-8972-0754,
Насєдкін Є. І., ORCID: https://orcid.org/0000-0003-2633-9291,
Куковська Т. С., ORCID: https://orcid.org/0000-0001-7532-8885,
Митрофанова О. А., ORCID: https://orcid.org/0000-0001-5971-9122,
Довбиш С. М., ORCID: https://orcid.org/0000-0002-3542-7472.

Державна наукова установа «Центр проблем морської геології, геоекології та осадового рудоутворення НАН України»

Дослідження пластику та мікропластику в геоекосистемі Чорного моря як складової оцінки її забруднення

У публікації викладено низку актуальних аспектів проблеми забруднення чорноморської геоекосистеми, її геологічної та аквальної субсистем пластиком і мікропластиком. Розглянуто умови і перспективи створення ефективної системи натурних спостережень розподілу пластикового сміття з мікропластиковою складовою в межах української частини геоекосистеми Чорного моря. Увага акцентується на сучасній, адаптованій до європейських стандартів, складовій організації досліджень забруднення геоекосистеми Чорного моря синтетичними полімерами. Запропоновано методологічні підходи до організації досліджень пластику і мікропластику в геоекосистемі Чорного моря та в її основних середовищних субсистемах як необхідної складової оцінки їх забруднення.

Ключові слова: *пластик, мікропластик, геоекосистема, Чорне море, пляж, організація досліджень*

Relevance of the Research

Over the past decade, the issue of rapid growth in the volume of waste from the polymer industry and plastic pollution has been gaining increasing significance. Additionally, the harmful impact of the degradation of synthetic materials (microplastics) on functioning of the marine bioecological subsystem and on human health, which is an integral part of this unique bio-physico-chemico-ecological system, has been extensively discussed and studied. While the technological sector of plastic waste management has shown noticeable progress today, the handling of microplastics remains at the early stages of innovative exploration and discovery, particularly concerning its risk assessment and identification of potential solutions to this problem.

The primary objective of this study is to develop the scientific and organizational aspects of a methodology for investigating plastics and microplastics as essential components of the pollution assessment process within the Black Sea (BS) geoecosystem (GES) and its geological and aquatic subsystems.

Materials and Methods of Research

The study is based on data obtained from comprehensive field observations and subsequent analytical investigations regarding the composition, sources, and distribution of plastics and microplastics in modern sandy beach deposits and in the air of marine waters adjoining specific beach areas located in Odesa region of Ukraine's coastal zone. Additionally, results from the analysis and synthesis of materials from applied studies on plastics and microplastics within the coastal zone and waters of the Black Sea, acquired from archival and published literary sources, were utilized.

Throughout the past decade, there has been an active discussion and investigation into the issue of rapid increase in the volume of waste from the polymer industry, same as the negative impact of degradation of synthetic materials (microplastics) on condition and functioning of higher-level global geoecosystems (GES) on our planet. This issue is particularly relevant to the ocean as its global subsystem, complex bio-physico-chemico-ecological systems of animal and plant life, and also the unique bio-physico-chemico-ecological system that includes human based on anthropocentric perspective. While the technological sector of plastic waste management demonstrates significant progress today, the issue of microplastics management remains at the stage of initial research and innovative discoveries, especially concerning its risk assessment for condition and functioning of living systems, as well as identifying possible approaches to resolving this problem.

State of the Problem, Research Review

The coastal zone of the Black Sea basin, serving as the boundary between the terrestrial geoecosystem (GES) and the marine environment, as well as the upper layer of sediment deposits within this basin, demarcating the boundary between the geologic-ecological and aqua-ecological subsystems of the Black Sea GES, functions as a unique "reservoir" in the system of plastic and microplastic waste distribution across the territory of modern Ukraine. It serves as the final stage of migration and burial for persistent waste, particularly durable synthetic polymers. Unlike other "traditional" pollutants, plastic waste of various sizes, especially micro-sized, remains the least explored component in the comprehensive list of pollutants entering, spreading, and accumulating in the southwestern part of the Black Sea waters. Today, for the majority of Ukrainian scientists, the issues related to the influx and dispersion of synthetic polymers and their fragments in the marine environment represent a relatively new research domain. The establishment and development of their theoretical and methodological aspects, including scientific-organizational considerations, are at their initial stage.

Regarding the immediate research within the Ukrainian GES sector of the BS (CEZ), the distribution of microplastics and plastic waste in its main environmental (geological and aquatic) subsystems should be noted. These studies do not have a long-term or systematic nature and are carried out by separate scientific institutions of the National Academy of Sciences of Ukraine (NASU), the Ministry of Education and Science of Ukraine (MESU), and the Ministry for Environmental Protection and Natural Resources (MEPNR) of Ukraine.

The main organizational and financial platform for implementing such research in state scientific insti-

tutions is formed through international projects and grants, which significantly complicates the implementation of a comprehensive approach to the issues, objective task allocation, and concentration of attention on the most important for our country directions. Another significant challenge in the practical aspect of conducting research on this matter is the necessity of establishing an optimal network of field observations for the most crucial ecosystems and their sufficiently representative component-subsystems.

The analysis of available literary sources on the directions and scope of such work in Ukraine has revealed a limited number of publications (including reports on fieldwork results) regarding the applied aspects of plastics and microplastics research in ecosystems developed and functioning within the coast and waters of the Black Sea. Typically, these studies are focused on addressing scientific tasks of various orientations. In particular, experts from the State Institution "Institute of Marine Biology of the National Academy of Sciences of Ukraine" (SI IMB NASU) are engaged in studying the fauna and flora inhabiting plastic debris in BS waters. Based on extensive field and experimental laboratory research into the patterns of biological overgrowth on different types of plastic substrates, scientists have identified the key indicator species of corresponding biological communities. They have conducted an inventory of the distribution and types of marine debris on the seabed of the Odesa Bay ***[1–5]***.

Floating litter monitoring within the framework of a number of EMBLAS projects has been carried out by the Ukrainian Scientific Center for Marine Ecology of the Ministry of Ecology and Natural Resources of Ukraine (UkrSCME) and the SSI IMB since 2016 using profiles in the open sea by observing from the ship using the EU Joint Research Center's Floating litter program. The application of the program, according to the information report by the executors, allowed to transfer the results to the database of the EU Joint Research Center RIMMEL, as well as to monitor floating litter in some mouths of the Danube and Dniester rivers with the transfer of information to the river litter observation network of the said center ***[6]***.

The study of seabed contamination was also carried out by UkrSCEM as part of the pilot studies within the EMBLAS project (2017). The total number of samples collected and subjected to laboratory analysis was 12 (samples of the seabed surface layer) ***[7]***. The same institution studied the distribution of beach litter in certain areas of the coast of Odesa region as part of the "Litter Survey" subprogram of the expeditionary research program.

All of these studies of microplastics and plastic debris conducted by Ukrainian scientists in the Black Sea were not well coordinated and were of a non-systematic nature. They concerned only small localized areas of the seabed, water surface and coast. Nevertheless, they allowed to gain some practical experience, identify a certain range of field research methods, and get a preliminary idea of the degree of pollution and the qualitative composition of plastic formations in certain components of coastal ecosystems.

Studies of the distribution of beach litter within certain coastal areas of the Odesa region, in particular on the beach of Yuzhne, conducted by MorGeoEcoCenter on the basis of international grant support, have a distinct systematic nature (seasonal observations in 2020–2021). Field and subsequent analytical studies of active recreation areas within the Ukrainian coastline allowed us to identify a number of features of microplastic distribution in modern sandy sediments and marine suspended matter ***[8]***.

The Issue of Establishing a Methodological Component

The data presented in the framework of international projects related to the monitoring of floating and beach litter is extremely insufficient to conduct an in-depth analysis of its prevalence, quantity, composition, sources of origin, and impact on the marine environment within the Ukrainian sector of BS. This, in turn, does not allow developing a set of measures to prevent litter from entering marine ecosystems, as well as to reduce the amount of litter already in marine environment.

Taking into account the problem of increasing the amount of plastics produced by industry and used by the population, increasing the risks of pollution of marine environment by a group of synthetic materials, the issue of developing and implementing comprehensive marine monitoring projects, including plastic and microplastic waste, in order to form clear, consistent, reliable scientific databases that will help assess its impact on the condition and functioning of marine ecological subsystems, marine life, and biophysics and biochemistry of the biophysico-chemical-ecological subsystem and and human as a unique global bio-eco-physicochemical subsystem of our planet's GES. The implementation of a set of

measures aimed at preventing the pollution of marine ecosystems by plastics and microplastics of various origins, minimizing the effects of such synthetic materials entering the marine environment, should be preceded by the creation of modern systems for determining and modeling the formation, distribution and impact of these synthetic materials on various environmental objects, including humans, based on international best practices.

Obtaining reliable information on the extent and patterns of plastics and microplastics distribution in the space of BS GES should be determined by the implementation of in situ monitoring (preferably based on interagency cooperation) with sufficient spatial coverage and a unified methodology for sampling and processing based on international standards. If this research area is developed without proper interagency cooperation, the inconsistency of the methodological component and methodological developments by different research teams ***[9]*** may become a major obstacle for the reliability of obtaining and processing, as well as the possibility of further unification of data available to specialists from different scientific institutions. Priority measures to address the tasks of standardizing methodologies for sampling, identification and quantification of microplastics of different composition and origin in the aquatic environment and geological environment of the relevant ecosystems should be formed by agreeing on standard procedures for field sampling, laboratory methods for sample preparation and analysis, and the creation and maintenance of databases.

Particular attention should be paid to field methods of microplastic sampling for different spatial components of the aquatic marine environment (certain layers of the aquatic ecosystem, beach sediments within different types of coastline, certain substance-genetic types of geological and ecological subsystem (bottom sediments), etc.) This area of research should also cover the issues of coordination of vertical sampling intervals, scopes and volumes of environmental samples, selection of primary systems for separating microplastics from natural matter, including the sequence of various operations: gravity separation, chemical purification, visual separation, etc. ***[10]***.

Identification of the main trends in production and import, types and volumes of utilization of this type of pollutants, distribution and degree of consumption within the territory of Ukraine, qualitative and quantitative properties of plastics should precede the development of appropriate methodological frameworks for the creation of observation, assessment and forecasting systems. In addition to taking into account the national specifics of plastic waste generation and management, the geo-environmental conditions of the country's territory that affect the transit of plastic pollutants to marine areas should be considered.

Today, the sectors of economic activity in which plastics are used are roughly divided into services, construction, transportation, textiles and household appliances. The main man-made polymers produced today are polypropylene (PP), high and low density polyethylene (HDPE and LDPE), polyethylene terephthalate (PET), polystyrene (PS), polyamide (PA), and polyvinyl chloride (PVC). PP and PE are used in all applications, but mainly in packaging, PVC is mainly used in the construction sector. Polyesters (PET) and polyamides (in particular, nylon) are the main polymers used in textiles ***[11]***, etc.

According to recent statistics, no more than 10% of plastics are recycled ***[12]***, and they are mostly mechanically recycled, with twelve percent of plastics in waste being incinerated ***[12]***. The majority of plastics produced in the world are disposed off in landfills, from where they can end up in the environment ***[13]***, which according to some estimates is 2% of their total production ***[14]***. The latter plays a significant role for our country—Ukraine generates 9 million tons of household waste, which is disposed off at 6,000 official landfills and other landfills with a total area of 9,000 hectares. Taking into account that there are several times more unofficial landfills, and the total amount of household waste contains from 6% to 19% of the polymer component (depending on the economic status of the territory, the welfare of the population, climate, season, etc.), these sources of pollution will have the greatest capacity to supply plastic material and the intensity of its dispersion in spaces of the relevant environmental ecosystems and their living biological components.

The study of the main pathways of plastic inputs into marine ecological sub-systems of BS GES within Ukraine indicates the expediency of dividing them into three main, but not equivalent categories:

1. Direct introduction into water area within the boundaries of social and industrial facilities bordering the water area (settlements, recreational areas, industrial and port centers, marine and road transport, dumping areas, etc.).

2. Transit through rivers, which generally come from the sources identified above, but undergo certain physical, chemical and mechanical transformations during the transfer process, which is also influ-

enced by the characteristics of watercourses and the length of the waterway transfer path.

3. Transit by air flows.

In numerous publications, foreign experts consider rivers and other watercourses to be the main source of microplastic emissions into marine ecosystems, and at the same time the most intense way of transporting plastics to the seas ***[15–18]***. A detailed assessment of the river transit of plastics is extremely important. According to foreign experts ***[14]***, 80% of the plastic found in marine environment comes from inland sources and is released into the seas and oceans by rivers. Coastal cities are considered to be important sources of synthetic polymers, and the number of inhabitants, building density and their industrial development, intensity of shipping routes and wastewater discharge cycles correlate with an increase in the microplastic load on natural waters ***[19–23]***. These statistics are based on the transfer of plastic and microplastic particles from land-based facilities with discharge, return and wastewater from treatment plants, agricultural runoff, air transport and precipitation ***[24–25]***, and the demolition of synthetic polymer fragments from road surfaces ***[26–28]***. According to some estimates, the transfer through wastewater treatment plants alone accounts for up to 520,000 tons of microplastics that enter European rivers and streams ***[26, 29]***.

An important aspect of the overall assessment of plastic material transport is to take into account the hydrological and hydromorphological characteristics of surface watercourses ***[30–31, 22]***, as well as a number of other natural factors (hydro- and aerodynamics, geomorphological characteristics of watercourse channels and coastal areas, seasonal and weather events ***[32–33]***). In the environments of river hydropower plants, certain transformation of plastic material occurs due to hydrological, geological, physical, mechanical, and hydrobiological factors (level and dynamics, in particular seasonal, of the water environment, deposition or remobilization of plastics in coastal areas when water level changes, directions of its movement, etc. At the same time, the processes of mechanical, chemical and biological degradation (destruction) of plastic waste and the formation of a secondary flow of microplastics occur in the water column and at the bottom of surface watercourses.

Based on the geomorphological and hydrological features of the territory of Ukraine, the catchment areas of both the main watercourses—the Danube, Dniester, Southern Bug and Dnipro—and medium and small rivers should be considered separately and in detail to determine the sources of plastic waste and microplastics pollution, as well as the conditions of their transportation to large and small waterways. This should address a wide range of issues, including the presence of natural objects with restoration of water flow quality, bioplatforms, hydrodynamic natural sediment traps, etc.; the degree of industrial and social load on water bodies, the impact of hydraulic structures and other infrastructure facilities (hydroelectric power plants, reservoirs, dams and dams, the state of drainage systems; the state of different levels of natural, anthropogenic and mixed ecosystems located within river catchments (categories of water resources, condition and number of household/industrial waste dumps, amount and nature of discharges, ecological capacity of different river ecosystems for self-purification, including with the active participation of hydro- and geobionts.

When exploring potential sources of pollution within marine areas, special attention should be paid, in particular, to Odesa coastal region, a significant part of which is occupied by the largest urban agglomeration in BS, and its industrial and transport capacities include the three largest port centers of Ukraine (Odesa, Chornomorsk, Yuzhny), where transport routes converge, and where active construction and transshipment of various cargoes is underway. Not surprisingly, according to the relevant state monitoring, GESs of the Odesa Bay of the Black Sea are characterized by a consistently high level of pollution, and the water environment of its aquatic subsystem has been classified as "dirty" over the years, with few exceptions. In addition to GES of Odesa bay, the most polluted subsystems of the Black Sea GES within Ukraine include the aquatic and geological-ecological subsystems of Sevastopol bays and the Danube coastline.

The flow of plastics caused by human economic activity in coastal areas and on the shelf has its own specifics. Firstly, these are recreation areas, developed infrastructure of the service sector, which have powerful sources of household plastics in marine environment, commercial fishing and mariculture facilities, exploration and exploitation of oil and gas fields within the shelf, dredging and soil dumping, which generates large-scale pollution and corresponding consequences. For example, according to literature ***[34]***, dumping of waste from various industrial activities contributes to about 10% of all pollutants entering the World Ocean. Soil dumping to underwater marine landfills is carried out mainly during construction, reconstruction, and repair dredging in waters of ports and their approach chan-

nels, with soil extraction taking place within the most contaminated areas and storage within conditionally clean open parts of water area. According to ***[34]***, up to 5 million tons of soil are transported and stored annually in the northwestern part of the BS.

The particular geo-environmental conditions of the Ukrainian part of BS GES as a research site for studying the distribution of plastic and microplastic waste in its space, as well as the peculiarities of its economic development and exploitation of its resources, determine a number of important emphases in the formation of the observation network.

Firstly, the distribution of plastic debris and microplastics, which comes from both river waters and coastal sources, is significantly related to currents, including river hydrofronts. As is well known, the flow of the Dnipro, Southern Bug, Dniester and Danube rivers determines 80% of the total river flow to the Black Sea GES, and hydrological fronts formed along the coast between freshwater and marine water masses extend within a radius of 20 km to 30 km for the Danube, Dniester and Dnipro. In the hydrofront zone, an increase in the sedimentation rate associated with the coagulation of suspensions in the river estuarine plumes is noted ***[35–36]***. Thus, when determining the features and patterns of redistribution in the water column and transportation of plastics, taking into account their density and weight, it is necessary to use data on the distribution of current directions and velocities, as well as salinity indicators.

The geological and ecological subsystem of GES of the sea basins, including BS, is the main and final accumulating medium for most pollutants, and in particular, a sink for plastic and microplastic waste. At the same time, polymeric waste accumulating in the geological environment of the mentioned BS GES subsystem, especially in the southwestern part of its space, is the least studied segment of the entire spectrum of pollutants that accumulate in it and affect it.

The patterns of distribution of plastic debris and microplastics, as well as traditional pollutants, are influenced by hydrological, hydrochemical, hydrobiological, sedimentological and geological conditions and properties of the relevant environmental subsystems of the seas and oceans. It has been established that plastics, due to their density and shape, can move vertically from the aquatic environment to the geological environment and return to the aquatic environment, even migrating to its surface—the border with the air environment of the marine aeroecosystem. This possibility also depends largely on a number of natural conditions and processes, such as turbulence that can be created as a result of, for example, storms, changes in the density of water environment and current directions, etc. Such mobility is a powerful environmental factor that leads to vertical mixing of plastic particles with the environment, their resedimentation and planar transport ***[37–38]***.

Plastic waste in the seas is subject to degradation. Macroplastics are fragmented to meso-, micro-, and even nanoparticles, increasing the number of plastic elements smaller than 1 micron. The mechanisms of fragmentation of various plastics are not fully understood. However, it is already known that they include a mechanical component, which is realized through physical contact with denser components of the environment, as well as thermophysical and thermochemical components, which are activated, among other things, by ultraviolet radiation (photodegradation) ***[39]***. These factors are particularly active on beaches and the shores of seas and rivers, where plastics are exposed to high temperatures and significant temperature fluctuations, as well as high-level ultraviolet radiation. Such impacts accelerate the degradation of polymers compared to the degradation of plastic components that are stable in aquatic or geological environment of the relevant environmental subsystems of marine GES.

All of these impact agents determine the expediency of taking into account the natural, inherent dynamic hydrophysical, geological, hydrochemical and hydrobiological factors in BS GES, in particular, in its shelf zone, when forming the relevant data set and developing a logical model of plastics distribution and accumulation. Among them, the following should be noted: currents (speed, direction, vertical stratification, etc.); properties of the water environment.

A significant role in the migration, accumulation, destruction of plastics and formation of its impacts on the natural environment of BS GES, their hydrobiont components, and human as a unique living biophysical and chemical ecosystem—the main consumer of resources of these GES and subsystems, peculiarities of sedimentation and resedimentation conditions and circumstances, the substance-genetic type, physical-mechanical and physical-chemical properties of the marine geological environment, taking into account the regional geomorphological features of the border between ecological aquatic and geological sub-systems of BS GES.

It is the synergy of interaction between all these factors and complex functioning systems and subsystems that determines the presence of natural and artificial sediment traps, intensity of

sedimentation, plastic accumulation or plastic decomposition, including through the functioning of naturally distributed aquatic organisms that accumulate, destroy or precipitate plastics and/or microplastics—plankton, benthos, bacteria, algae, plants, etc.

Conclusions

Summarizing the above, it should be emphasized that the organization of research on plastics and microplastics in the Black Sea GES and its ecological sub-systems according to the methodology described above, based on a qualitative theoretical and practical basis, is an innovative component in assessing their pollution. The reliability of data acquisition and processing, as well as further harmonization, in particular, within the framework of implementation of a system of integrated monitoring of plastic wastes and microplastics, will depend on quality of the theoretical and methodological component and methodological developments. This indicates the need to use relevant provisions of the theory of complex systems adapted to the object of our research, and to prioritize the task of standardizing methods and techniques for the selection, identification, and quantification of microplastics in water and geological environments of the relevant environmental subsystems of the BS GES. The northwestern part of the said marine GES deserves priority attention in terms of these studies due to the proactive development and implementation of standard operating procedures (field methods and sampling techniques—laboratory methods of sample separation and separation of plastic particles—hardware complex for identifying various quality and size components of plastic), etc.

The list of key issues in the area of field and laboratory research should include:

- direct terminological definition of the research object, characteristics that identify its chemical composition, species distribution, size, etc.;
- field methods of microplastic sampling for different components of water (marine) and geological environment (certain layers of the water column of aquatic subsystem of GES, beach sediments within different types of coastline, substance-genetic types of the geological environment of the geological and ecological subsystem of GES, etc.);
- primary technical systems for separating microplastics from natural matter, including the sequence of various operations—gravity separation, chemical purification, visual separation, etc.;
- unifying the use of high-tech equipment and hardware systems for determining the types of plastics and microplastics, their chemical composition, peculiarities of their transformation in water and geological environments and on their borders, etc.

To create a general picture of the distribution, dynamics and accumulation of these pollutants, it is desirable to conduct regular, planned thematic systemic studies (cyclic observations with sampling in different seasons, etc.), including: sampling of plastics from coastal sediments and beaches; sampling of plastics from different layers of the water column of the relevant GES subsystem; sampling of plastics from the surface and different layers of the vertical section of the geological environment of relevant marine GES subsystem.

At the same time, for the sake of comprehensiveness of research, it is necessary to determine the possible impact of plastic pollutants on the parts of the geological and ecological subsystem of marine GES that are valuable in bioproductive, recreational and other respects: areas of recreation areas, spawning/feeding grounds for the development of aquatic life (for example, for the northwestern part of BS GES—the ecological subsystem of marine botanical reserve "The Zernov Phyllophora Field").

When constructing the profiles for sampling from the surface and different layers of the vertical section of geological environment of the geological and ecological subsystem of sea GES, it is also desirable to provide for testing of sites represented by different substance-genetic types of the geological environment, taking into account a comparative analysis of the relationship between the results obtained and the classical scheme of sedimentation. The selection of plastic pollutants from the aquatic environment should be carried out according to the general scheme: river mouths—areas of active economic activity at sea and on the coast—test background areas within the open sea space of the aquatic ecological subsystem of the studied GES.

It should be emphasized that the success of solving problems related to the study of the intake and distribution of synthetic polymers in marine GES and their environmental sub-systems for the scientific community of Ukraine will be determined by a systematic approach to the problem at the level of interagency cooperation. Concentration on the most important research areas, unification of methods and methodologies based on international expe-

rience, identification of the most representative sites for systematic observations and development of the relevant national databases are possible only within the framework of coordinated actions of all interested scientific institutions of the National Academy of Sciences of Ukraine, the Ministry of Ecology and the Ministry of Education and Science of Ukraine.

The organizational component of such approaches should be based on the relevant legal and regulatory framework, which would include the fixation of new environmental tasks in basic legislative documents or bylaws. In particular, in the context of the state's lack of financial capacity and the moratorium on new program initiatives, it is advisable to review and amend a number of legislative and legal regulations regarding the need to launch systematic research related to various aspects of the distribution of microplastics in the environmental components-subsystems of marine GES. Amendments and additions to such documents, in accordance with modern environmental challenges, in particular, the danger of microplastics accumulation in the components of the main natural environments of GES, will contribute to the completion of the first stage of the innovative cycle of plastic and microplastic waste management, namely, research on the degree of its hazard and identification of possible solutions to the problem of its presence and functioning as a component of ecological inanimate and living systems of different scales and levels, including in order to minimize its impact on living organisms, including humans.

Scientific Innovativeness

The scientific and organizational aspects of the methodology of plastics and microplastics research as an important component of the assessment of the relevant pollution of Black Sea geo-ecosystem and its geological and aquatic subsystems have been developed.

Acknowledgments

The research in this area and the corresponding publication were made possible by the authors' participation in the international project DOORS. DOORS (https://www.doorsblacksea.eu/) has received funding from the European Union's Horizon 2020 Framework Program for Research and Innovation under a grant agreement No. 101000518.

References [Література]

1. Snigirova, A. A., Uzun, E. Ye., Portyanko, V. V. (2020). *Colonizing of sea floor litter by benthic organisms in the northwestern Black Sea (Gulf of Odessa).* Marine Litter in the Black Sea, 247–267.

2. Snigirova, A. A., Kapshina, I. A. (2019). *Experimental studies of phytoperyphyton formation on the plastic surface.* International scientific conference, dedicated to 95th Anniversary of Academician of the NAS of Ukraine Yuvenaly Zaitsev "Achievements in studies of marginal effect in water ecosystems and their practical significance": Book of abstracts, p. 50.

3. Uzun, E. Ye. (2019). *First revision on ostracods (Crustacea, Ostracoda) of plastic substrate in Odessa marine region.* International scientific conference, dedicated to 95th Anniversary of Academician of the NAS of Ukraine Yuvenaly Zaitsev "Achievements in studies of marginal effect in water ecosystems and their practical significance": Book of abstracts, p. 65.

4. Snigirova, A. A., Kurakin, A. P. (2019). *Microalgae on the plastic substrates in the coastal area of the Gulf of Odessa (the Black Sea).* Advances in Modern Phycology, 103–105.

5. Snigirova, A. O., Portianko, V. V. (2018). *Some data on the impact of plastic materials on the bottom maritime groups of the Black Sea.* Collection of materials of the V Scientific and Practical Conference of Young Scientists "Modern Hydroecology: place of scientific research in solving current problems," 52–54. [In Ukrainian].

[Снігірьова А. О., Портянко В. В. *Деякі дані до вивчення впливу пластикових матеріалів на донні морські угруповання Чорного моря.* Збірник матеріалів V Науково-практичної конференції молодих вчених «Сучасна гідроекологія: місце наукових досліджень у вирішенні актуальних проблем». 2018. С. 52–54].

6. The EMBLAS project. (2017). *Revealing the Secrets of the Black Sea.* UNDP Regional Bureau for Europe and the CIS. URL: https://emblasproject.org/wp-content/uploads/2017/04/Joint-Black-Sea-Surveys-2016_16.pdf. [In Ukrainian].

[*Розкриваючи таємниці Чорного моря.* Регіональне бюро ПРООН для Європи та СНД. Проект EMBLAS. 2017. URL: https://emblasproject.org/wp-content/uploads/2017/04/Joint-Black-Sea-Surveys-2016_16.pdf].

7. The EMBLAS project. (2018). *National Pilot Monitoring Studies and Cooperative High Seas Research in Georgia, the Russian Federation, and Ukraine, 2017: Final Scientific report.* Seredniak T. K. https://emblasproject.org/wp-content/uploads/2022/03/EMBLAS-II_NPMS_JOSS_2017_ScReport_ISBN-978-617-7953-62-2.pdf. [In Ukrainian].

[Проект EMBLAS. *Національні пілотні моніторингові дослідження та спільне дослідження відкритого моря в Грузії, Російській Федерації та Україні, 2017*: *Заключний науковий звіт.* Середняк Т. К. 2018. URL: https://emblasproject.org/wp-content/uploads/2022/03/EMBLAS-II_NPMS_JOSS_2017_ScReport_ISBN-978-617-7953-62-2.pdf].

8. Iemelianov, V. O., Nasiedkin, Ye. I., Kukovska, T. S., & Mytrofanova, O. A. (2021). *Regarding the distribution of plastic waste within the surf zone of Yuzhne city beach.* Geology and minerals of the World Ocean, 3, 34-41. DOI: https://doi.org/10.15407/gpimo2021.03.041. [In Ukrainian].

[Ємельянов В. О., Насєдкін Є. І., Куковська Т. С., Митрофанова О. А. *Щодо розподілу пластикового сміття в межах хвилеприбійної зони пляжу міста Южне.* Геологія і корисні копалини Світового океану. 2021. № 3. С. 34–41. DOI: https://doi.org/10.15407/gpimo2021.03.041].

9. Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). *Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification.* Environmental Science & Technology, 46(6). DOI: https://doi.org/10.1021/es2031505.

10. Löder, M. G. J., & ZGerdts, G. (2015). *Methodology Used for the Detection and Identification of Microplastics—A Critical Appraisal.* Marine Anthropogenic Litter, 16, 201–227. https://doi.org/10.1007/978-3-319-16510-3.

11. PlasticsEurope, (2018). *Plastics—the Facts 2018*, P. 60. URL: https://plasticseurope.org/wp-content/uploads/2021/10/2018-Plastics-the-facts.pdf.

12. Geyer, R., Jambeck, J. R., Law, K. L. (2017). *Production, use, and fate of all plastics ever made.* Science Advances, 3(7). DOI: https://doi.org/10.1126/sciadv.1700782.

13. Hoornweg, D., & Bhada-Tata, P. (2012). *What a waste: a global review of solid waste management.* Urban Development Series, 15, p. 116.

14. Jambeck, J. R., Geyer, R., Wilcox, Ch., Siegler, Th. R., Perryman, M., Andrady A., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347, 768–770. DOI: https://doi.org/10.1126/science.1260.

15. Duis, K., & Coors, A. (2016). *Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects.* Environmental Sciences Europe, 28. DOI: https://doi.org/10.1186/s12302-015-0069-y.

16. Lebreton, L. C. M., van der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2017). *River plastic emissions to the world's ocean.* Nature communications, 8. DOI: https://doi.org/10.1038/ncomms15611.

17. Faure, F., Demars, C., Wieser, O., Kunz, M., & de Alencastro, L. F. (2015). *Plastic pollution in Swiss surface waters: Nature and concentrations, interaction with pollutants.* Environ. Chem., 12, 582–591. DOI: https://doi.org/10.1071/EN14218.

18. Schmidt, L. K., Bochow, M., Imhof, H. K., & Oswald, S. E. (2018). *Multi-temporal surveys for microplastic particles enabled by a novel and fast application of SWIR imaging spectroscopy—Study of an urban watercourse traversing the city of Berlin, Germany.* Environ. Pollute, 239, 579–589.

19. Gallitelli, L., Cesarin, G., Cera, A., Sighicelli, M., Lecce, F., & Scalici, M. (2020). *Transport and deposition of microplastics and mesoplastics along the river Course: A case study of a small river in Central Italy.* Hydrology, 7. DOI: https://doi.org/10.3390/hydrology7040090.

20. Murphy, F., Ewins, C., Carbonnier, F., & Quinn, B. (2016). *Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment.* Environ. Sci. Technol., 50, 5800–5808. DOI: https://doi.org/10.1021/acs.est.5b05416.

21. McCormick, A. R., Hoellein, T. J., Mason, S. A., Schluep, J., & Kelly, J. J. (2014). *Microplastic is an abundant and distinct microbial habitat in an urban river.* Environ. Sci. Technol., 48, 11863–11871. DOI: https://doi.org/10.1021/es503610r.

22. Napper, I. E., Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Mar. Pollut. Bull., 112, 39–45. https://doi.org/10.1016/j.marpolbul.2016.09.025.

23. Mani, Th., Hauk, A., Walter, U., & Burkhardt-Holm, P. (2016). *Microplastics profile along the Rhine River.* Scientific Reports, 5. DOI: https://doi.org/10.1038/srep17988.

24. Dris, R., Imhof, H., Sanchez, W., Gasperi, J., Galgani, F., & Laforsch, Ch. (2015). *Beyond the ocean: contamination of freshwater ecosystems with (micro-) plastic particles.* Environmental Chemistry, 12, 539–550. DOI: https://doi.org/10.1071/EN14172.

25. Dehghani, S., Moore, F., & Akhbarizadeh, R. (2017). *Microplastic pollution in deposited urban dust, Tehran metropolis, Iran.* Environmental science and pollution research, 24, 20360-20371. DOI: https://doi.org/10.1007/s11356-017-9674-1.

26. Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). *Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities.* Science of the Total Environment, 586, 127–141. DOI: https://doi.org/10.1016/j.scitotenv.2017.01.190.

27. Ziajahromi, S., Neale, P. A., & Leusch, F. D. L. (2016). *Wastewater treatment plant effluent as a source of microplastics: review of the fate, chemical interactions and potential risks to aquatic organisms.* Water science and technology, 74, 2253–2269. DOI: https://doi.org/10.2166/wst.2016.414.

28. Estahbanati, S., & Fahrenfeld, N. L. (2016). *Influence of wastewater treatment plant discharges on microplastic concentrations in surface water.* Chemosphere, 162, 277–284. DOI: https://doi.org/10.1016/j.chemosphere.2016.07.083.

29. Frei, S., Piehl, S., Gilfedder, B. S., Loder, M. G. J, Krutzke, J., Wilhelm, L., & Laforsch, C. (2019). *Occurence of microplastics in the hyporheic zone of rivers.* Scientific Reports, 9(1). DOI: https://doi.org/10.1038/s41598-019-51741-5.

30. Constant, M., Ludwig, W., Kerherve, P., Sola, J., Charriere, B., Sanchez-Vidal, A., & Heussner, S. (2020). *Microplastic fluxes in a large and a small Mediterranean river catchment: The Tet and the Rhone, Northwestern Mediterranean Sea.* Sci. Total Environ., 716. DOI: https://doi.org/10.1016/j.scitotenv.2020.136984.

31. Besseling, E., Quik, J. T. K., Sun, M., & Koelmans, A. A. (2017). *Fate of nano- and microplastics in freshwater systems: A modeling study.* Environ. Pollute, 220, 540–548. DOI: https://doi.org/10.1016/j.envpol.2016.10.001.

32. Corcoran, P. L., Belontz, S. L., Ryan, K., & Walzac, M. J. (2020). *Factors controlling the distribution of miroplastic particles in benthic sediment of the Thames River, Canada.* Environ. Sci. Technol., 54, 818–825. DOI: https://doi.org/10.1021/acs.est.9b04896.

33. Falahudin, D., Cordova, M. R., Sun, X., Yogaswara, D., Wulandari, I., Hindarti, D., & Arifin, Z. (2020). *The first occurrence, spatial distribution and characteristics of microplastic particles in sediments from Banten Bay, Indonesia.* Sci. Total Environ., 705. DOI: https://doi.org/10.1016/j.scitotenv.2019.135304.

34. Zaitsev, Yu. P. (1992). *Ecological condition of the shelf zone of the Black Sea off the coast of Ukraine.* Hydrobiological Journal, 4, 3–18. http://www.hydrobiolog.com.ua. [In Russian].

[Зайцев Ю. П. *Экологическое состояние шельфовой зоны Черного моря у побережья Украины.* Гидробиологический журнал, 1992. № 4. С. 3–18. http://www.hydrobiolog.com.ua].

35. Aybulatov, N. A., & Artyukhin, Yu.V. (1993). *Geoecology of the shelf and coasts of the world ocean.* Saint Petersburg: Gidrometeoizdat, 304 p. [In Russian].

[Айбулатов Н. А., Артихин Ю. В. *Геоэкология шельфа и берегов Мирового океана.* Санкт-Петербург: Гидрометеоиздат, 1993. 304 с.]

36. Larchenkov, E. P., & Cherednichenko, A. P. (1996). *Influence of geological processes on the ecological condition of the North-Western shelf of the Black Sea.* Geoecology of recreational zones of Ukraine, 2, 71–78. [In Russian].

[Ларченков Е. П., Чередниченко О. П. *Влияние геологических процессов на экологическое состояние Северо-Западного шельфа Черного моря.* Геоэкология рекреационных зон Украины. 1996. № 2. С. 71–78].

37. Kukulka, T., Proskurowski, G., Morét-Ferguson, S., Meyer, D. W., & Law, K. L. (2012). *The effect of wind mixing on the vertical distribution of buoyant plastic debris.* Geophysical Research Letters, 39. DOI: https://doi.org/10.1029/2012GL051116.

38. Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., & Reisser, J. (2018). *Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic.* Scientific Reports, 8. DOI: https://doi.org/10.1038/s41598-018-22939-w.

39. Andrady, A. L. (2015). *Persistence of Plastic Litter in the Oceans.* Marine Anthropogenic Litter, 57–72. DOI: https://doi.org/10.1007/978-3-319-16510-3.

The manuscript received on September 6, 2023.

References [Для цитування]

Iemelianov, V. O., Nasiedkin, Ye. I., Kukovska, T. S., Mytrofanova, O. A., & Dovbysh, S. M. (2023). *Research of Plastics and Microplastics in the Black Sea Geoecosystem as a Component of Its Pollution Assessment.* Ukr. Geogr. Ž. No. 4. 27–36. [In English]. DOI: https://doi.org/10.15407/ugz2023.04.027

Ємельянов В. О., Насєдкін Є. І., Куковська Т. С., Митрофанова О. А., Довбиш С. М. *Дослідження пластику та мікропластику в геоекосистемі Чорного моря як складової оцінки її забруднення.* Укр. геогр. журн. 2023. № 4. С. 27–36. [Англійською мовою]. DOI: https://doi.org/10.15407/ugz2023.04.027