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Assessment of Microplastic Pollution Sources in the Coastal Recreational Zones

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ABSTRACT

The authors propose a methodology for assessing the sources of microplastic pollution (particles 0.5-5 mm in size), which makes it possible to differentiate coastal recreational areas according to the degree of vulnerability to microplastic accumulation. The methodology takes into account the sources of microplastics coming to the beach directly from vacationers - factors of recreational activities, as well as the influence of factors of the adjacent territory: the type of adjacent territory, saturation with transport infrastructure, etc. An analysis of the results of monitoring the microplastic concentration in beach and bottom sediments of seven beaches of the Sevastopol region with varying degrees of anthropogenic load during 2018–2020, as well as an assessment of the sources of microplastic pollution on these beaches using the proposed methodology, made it possible to differentiate these coastal recreational areas according to the degree of vulnerability to accumulation of microplastic pollution. The most vulnerable are the beaches that are actively visited by tourists and located in close proximity to large blocks of apartment buildings and extensive transport infrastructure (Pesochniy and Omega). The beaches Konstantinovsky and Goryachka (placed close tothe thermal power station), located in the zone of active navigation of ships of various tonnage, are confined to areas of low and moderate pollution. The main stream of vacationers on them are local residents with a high turnover rate. The least vulnerable are the beaches with park areas: Uchkuevka, Solnechny and Zolotoy. The source of microplastic pollution on these beaches is mainly vacationers.

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INTRODUCTION

Recycling of plastic material accounts for a small percentage of its output (Bergmann et al., 2015; Plastics Europe, 2020), which leads to the appearance of plastic waste everywhere in terrestrial and marine ecosystems. This is facilitated by unauthorized landfills, the intensive use of plastic materials in everyday life and construction, as well as natural phenomena that lead to the fragmentation of plastic waste and their transfer. On shore, plastic waste is subject to degradation processes under the influence of heat, photo-oxidation by ultraviolet rays and mechanical action of water or soil. Usually, mega- and macroplastic debris, larger than 20 mm, is regularly removed during cleaning in coastal recreation zones (CRZ). Smaller mesoplastic particles can remain in the soil &, over time, are crushed to microplastics (MP) (particles 0.5-5 mm in size) (Barnes et al., 2009; Andredy, 2011).

In many regions of the world, the growth of microplastic pollution on the body of the beach and in the bottom soil is being monitored, and MP particles have been detected almost everywhere in the coastal zones. A large number of articles have been published on microplastic

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pollution of the pelagial, benthal and the land-sea contact zone of the World Ocean. In the bottom sediments, MP was found in high concentrations in the Mediterranean Sea off the southeastern coast of Tunisia (Chouchenea et al., 2019), in the Adaman Sea and the northwestern region of the Black Sea an order of magnitude lower (Jiwarungrueangkul et al., 2021; Cincinelliet al., 2021), the least polluted area is the southeastern coast of Vietnam (Hien et al., 2020). In beach sediments, the beaches of Japan and the Rügen Islands in the Baltic Sea are the most susceptible to microplastic pollution (Hidalgo-Ruz et al., 2012; Hengstmann et al., 2018), and an order of magnitude less was found on the beaches of the Aegean Sea (Kaberi et al., 2013; Karkanorachaki et al., 2018).

In the selected area, studies of microplastic pollution have been carried out by the authors since 2018 (Sibirtsova et al., 2021; Sibirtsova et al., 2022). However, the works devoted to the study of sources and assessment of the MP influx into the coastal zone have not been carried out earlier.

The main goal of most recent works studying microplastic pollution in beach and bottom sediments is the assessment of MP concentrations (Kim et al., 2015; Hengstmann et al., 2018; Chouchenea et al., 2019; Hien et al., 2020; Glushko and Bespalova, 2021, Manbohi et al., 2021, etc.) without analyzing potential sources of its entry. Only a few publications indicate the alleged sources of MP: wastewater treatment plants (Dodsona et al., 2020; Keerthika et al., 2022), tourism load (Graca et al., 2017; Urban-Malinga et al., 2020; Hien et al., 2020; Veiga et al., 2022; Gül, 2023), land-based sources (Martinez-Ribes et al., 2007; Graca et al., 2017), removal of fishing gear to land (Graca et al., 2017; Napper et al., 2022), river flow (Turrell, 2020; Meijer et al., 2021; Veiga et al., 2022) and marine sources (van Sebille et al., 2018; van Duinen et al., 2022; Vogt-Vincent et al., 2023). Therefore, a study that analyzes in detail the potential range of MP sources in coastal areas and the degree of intensity of each of the considered sources is extremely of current interest. Our article is one of the first works on the assessment of the complex of various sources of MP in beach and bottom sediments in the CRZ.

This paper proposes a methodology developed by the authors for assessing the sources of entering microplastics particles into coastal recreational areas.

MATERIAL and METHODS

The assessment of the sources of MP inflow into the CRZ was carried out taking into account the analysis of anthropogenic load factors and local characteristics of the area. The values of each factor were set in the range from 0 to 1, where 0 - the factor is absent, 0.1-0.3 – weak or irregularly present, 0.4-0.6 – average regular influence, 0.7-0.9 – high regular influence of the factor, 1 – the maximum possible negative impact of the factor on the cumulation of MP in the CRZ. In this work, the significance of each factor is assessed separately and its presence in the studied CRZ. Comparison of the influence of factors among themselves was not carried out.

The one-time allowable recreational load (En) on a beach area of one linear meter was determined by the formula:

$$En = k_{1.} k_{2.} n; \quad (1)$$

where $k_{1.}$ is the socio-ecological coefficient, its value (0.5-0.8) depends on the degree of negative human intervention in natural complexes, on the flow of possible impacts associated with economic activity; $k_{2.}$ is the coefficient of recreational attractiveness. Its value (0.4-0.8) depends on the improvement of the territory, the possibility of currently using it for recreation, the popularity of the recreation area; n – the standard for the maximum allowable recreational load corresponds to the number of vacationers during the day, who accounted for 1 linear meter of the beach strip along the seashore. According to the method (Sibirtsova et al., 2022), for pebble beaches it corresponds to 4, for sandy beaches – 3.5; for sand and pebble – 3.75 person-days./m

The actual average value of En, also in terms of a length of 1 m, was recorded directly in the field (En_{fact}., person/m).

Daily attendance was determined by the formula:

$$Vn = k_3 \cdot En, \quad (2)$$

where k_3 is the turnover coefficient of the contingent of vacationers on the beach during the day.

The value of k_3 was established by questioning vacationers about the time period of their rest during the day on a particular beach. For the summer season, the time of daily recreation on the beach was taken equal to 10 hours:

$$K_3 = 10/t, \quad (3)$$

To study the actual recreational loads (Vn_{fact}), a selective moment method was used: at the time of accounting, the number of vacationers present on the beach and adjacent water area was recorded. On each studied beach, the observations were carried out for seven days on working and non-working days, in the summer season and in good weather, when the number of vacationers is maximal.

Approbation of the methodology was carried out on seven beaches of the Sevastopol region (Fig. 1).

The material for the work was the data of our own research, obtained as a result of comprehensive monitoring of the MP concentration in the summer-autumn period of 2018-2020 in beach and bottom sediments of seven CRZs with different anthropogenic load (see Fig. 1) (Sibirtsova et al., 2021; Sibirtsova et al., 2022).

RESULTS AND DISCUSSION

The factors were divided into two categories. The first category included those that are the source of MP pollution directly on the body of the beach, conventionally designated as "factors

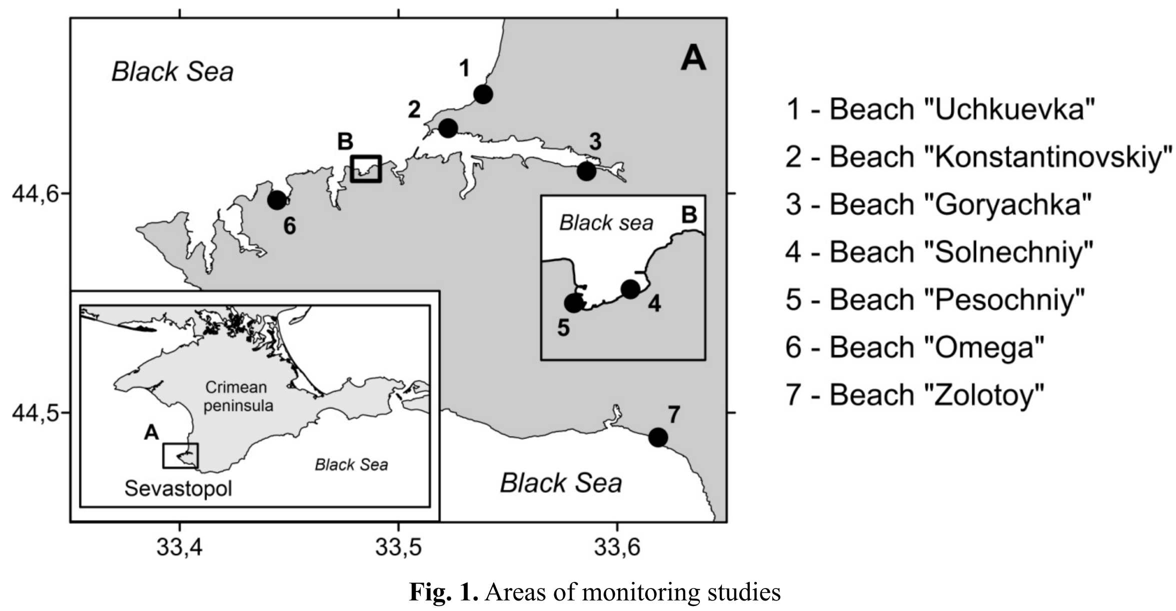

Fig. 1. Areas of monitoring studies

of recreational activity". They are associated both with the abundance of plastic equipment on the beach itself (chaise lounges, umbrellas, awnings, plastic lining of retail outlets, showers and toilets, etc.), and with the number and type of vacationers (Table 1).

Factors characterizing the territory adjacent to the CRZ, including the presence/absence of water runoff of various types and features of sea and land transport infrastructure, were assigned to the second category of anthropogenic sources of MP. This category was designated as "factors of the adjacent territory" (Table 2).

The maximum value of the factor "specifics of the adjacent territory" was assigned to a residential area with multi-apartment buildings. This is due to the presence of garbage cans and unauthorized dumps of household and construction waste in residential areas. Lower values are assigned to the industrial zone and the private sector zone. The minimum value of 0.1 corresponds to natural areas.

With emergency flows, which are of a non-permanent nature, MP particles from municipal solid waste get into the CRZ, this factor is assigned a value of 0.3. Untreated effluents are permanent and carry more pollution than others, so the coefficient is set at 0.5. If all types of runoff are present near the CRZ, then the value of this factor is assumed to be equal to the maximum - 1.

Modern small boats, in addition to unauthorized dumping of garbage directly into the sea, have a large number of plastic elements, including coatings made of polymer paints and varnishes, which, during the operation of the vessel, undergo corrosion processes, peel off, grind and also fall directly into the sea. Private fishermen who go out to fish and set up nets, as a rule, change fishing areas when fish schools are detected by an echo sounder. Thus, the influence of this parameter on each of the CRZ has a seasonal character. Since fragments of polyamide and silicone networks can also become a source of MP particles, the value of this parameter is in the range of 0.3-0.6. The berths of small boats pose the greatest danger, so this parameter is assigned the maximum value. The active movement of ships, including passenger boats, in the immediate vicinity of the CRZ can also be a source of MP.

Thanks to detailed registration and analysis of all constituent components characterizing the beaches, the socio-ecological coefficient and coefficient of recreational attractiveness of seven

Table 1. Recreational activity factors

Factor number	Factor	Explanation	Parameter	Value
1	One-time load	En_{fact}/En, The ratio of the actual one-time allowable recreational load to the calculated according to the standards	Insignificant (< 0,8)	0,25
			Normal (0,8-1,2)	0,5
			High (> 1,2)	1
2	Dailyattendance	Vn_{fact}/Vn, The ratio of actual daily attendance to calculated according to the standards	Insignificant (< 0,8)	0,25
			Normal (0,8-1,2)	0,5
			High (> 1,2)	1
3	Typeofvacationers	The factor value corresponds to the sum of the parameter values	Tour groups	0,1
			Local citizens	0,2
			Vacationers with children	0,2
			Foreign vacationers	0,2
			Camping tourists	0,3
4	Plasticequipment	The abundance of plastic equipment on the beach, including land and water beach attractions	Absent	0
			Not many	0,25
			Reasonable amount	0,5
			A lot	1

Table 2. Factors of the adjacent territory

Factor number	Factor	Parameter		Value
5	Adjacent area specifics	Natural zone		0,1
		Park area		0,2
		Industrial zone		0,5-0,7
		Living zone	Private sector	0,3-0,5
			Multiple family dwelling	0,7-1,0
6	Water runoff	Natural runoff (rain, storm water)		0,1
		Alarm		0,3
		Raw wastewaters		0,5
		All types		1
7	Sea transport	Small boats (excursion and fishing)		0,3-0,6
		Intensive passage of vessels of different tonnage		0,5
		Berths of small boats		1
8	Municipal transport infrastructure	Absent		0
		Distantly		0,2
		In close proximity		0,4
		Private transport		0,1-0,3
		Public transport		0,2
		Heavy traffic		0,1

Table 3. One-time allowable recreational load (En) and daily attendance (Vn) of the investigated CRZ

	Uchkuevka	Konstantinovsky	Goryachka	Solnechny	Pesochniy	Omega	Zolotoy
En, person/m	1,68	1,05	0,9	1,44	1,35	1,47	1,8
Vn, person/m	6,2	5,25	9	6,6	5,4	6,3	5,6
En_{fact},person/m.	2,4	0,8	0,6	2,3	3,57	3,8	0,88
Vn_{fact}	8,9	4	6	13,8	12,7	16,3	2,7
En_{fact}/En	1,43	0,76	0,67	1,6	2,64	2,59	0,49
Vn_{fact}/Vn	1,44	0,76	0,67	2,09	2,35	2,6	0,49

beaches of the Sevastopol region were determined, which made it possible to establish a one-time allowable recreational load (En) and daily attendance (Vn) of each beach (Table 3) .

For each region of the study, petal diagrams were constructed, the petal number corresponds to the number of the factor on which the obtained factor value is plotted. All diagrams are made on the same scale (Fig. 2).

It was noted that on the beaches of Pesochniy and especially Omega (see Fig. 2e, f) there are high values of both factors of recreational activity (factors 2, 3, 4) and factors of the adjacent territory (factors 5, 8).

Uchkuevka and Zolotoy beaches (see Fig. 2a, 2g) have high rates of recreational load and attractiveness for different categories of vacationers, but in practice it turned out that the actual Vn is below the established norms. The values of other factors for Zolotoy beach are minimal among all considered beaches.

The main negative factors for the Goryachka (thermal power station) beach (see Fig. 2c) are wastewater and traffic load of both marine and land structures. The second beach of the semi-closed Sevastopol Bay - Konstantinovsky has a similar characteristic (see Fig. 2b).

The values of recreational activity factors, as well as several factors of the adjacent territory on Solnechny Beach are similar to those on Pesochniy Beach (see Fig. 2d, 2e). The difference is noted only in the factors of transport infrastructure. This is most likely due to the location of these beaches on different sides of the same bay.

The highest values of most of the considered parameters at Omega Beach suggest that the concentration of MP will increase faster than at other beaches. At the same time, rather low analogous values near Konstantinovskiy and Zolotoy beaches make it possible to predict the maintenance of the minimum concentration of MP on them for a long time, provided that the current parameters of the factors described above remain unchanged.

Application of the results of the assessment of sources of MP

An analysis of the concentrations of MP in beach sediments over a three-year period made it possible to identify a trend towards cumulation of MP in almost all studied CRZs (Sibirtsova et al., 2022). The concentration of trace minerals increased on the beaches of the Sevastopol Bay - Goryachka and Konstantinovsky by 5.5 and 3.5 times, respectively. A significant increase in the concentration of trace minerals in the beach soil was found on the beaches of Pesochniy, Omega and Zolotoy.

Based on the results of monitoring the concentration of mineral oils in beach sediments, as well as on the analysis of the characteristics of the territories adjacent to the CRZ, the authors differentiated all the studied PZR into 3 groups according to the degree of vulnerability to accumulation of MP.

The most vulnerable are the beaches belonging to group I, the least vulnerable - to group III (Fig. 3). The beaches of the first and third groups are a place of active visits not only for residents of the city, but also for tourists.

Group I includes the Pesochniy and Omega beaches with the maximum concentrations of

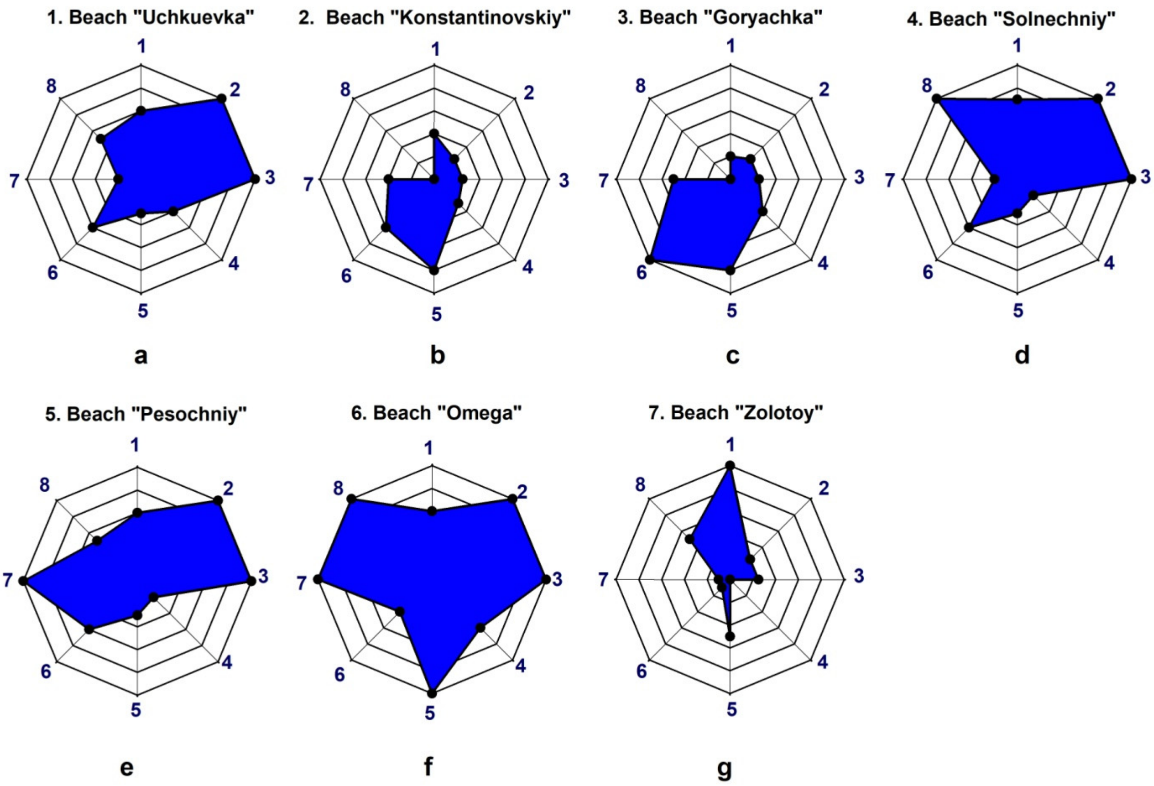

Fig. 2. Distribution of estimated values of anthropogenic factors

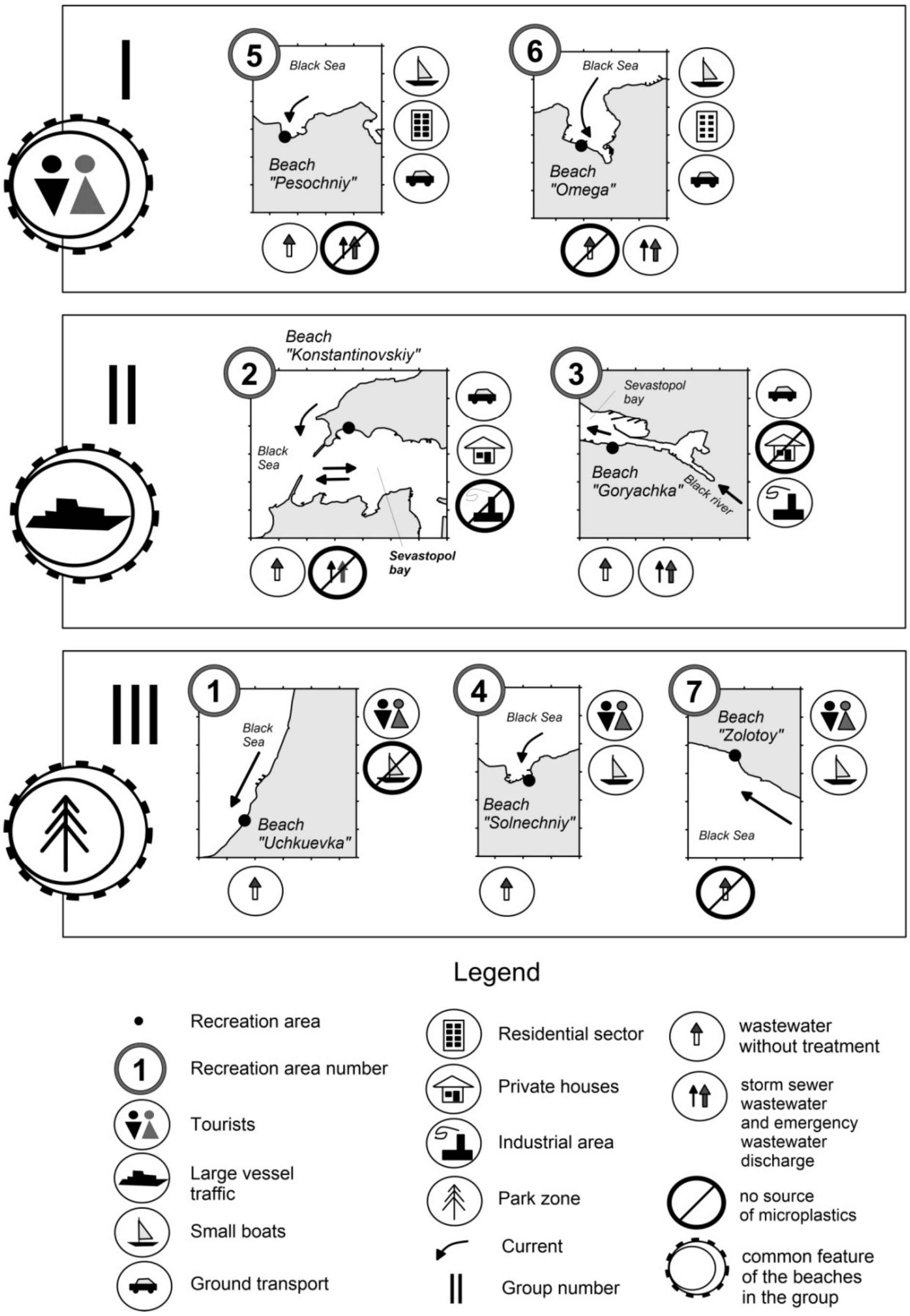

Fig. 3. Sources of MP in the CRZs of the Sevastopol region and differentiation of beaches into groups according to the degree of vulnerability to accumulation of MP

trace minerals. The source of MP for them is the presence in the immediate vicinity of large blocks of apartment buildings and an extensive transport infrastructure.

The influx of MP from the sea can be associated with the activity of small-sized watercraft (skiffs, PVC boats, etc.) here. The traverse of these bays is a popular destination for private fishermen. Wastewater is discharged to Pesochnaya Bay without treatment, and in Omega there is a wastewater outlet and a storm sewer drain for the entire microdistrict (Ovsyany et al., 2001; Gruzinov et al., 2019). Another important source of MP is the plastic waste left by vacationers in the CRZ, and the abundance of plastic equipment on the beaches (chaise lounges, umbrellas, etc.). On the beaches of Pesochniy and Omega, a significant excess of the actual values of En was registered – 2.6-2.8 times relative to the normative ones. These values are the highest among all the studied beaches.

Group II includes the beaches of the Sevastopol Bay - Konstantinovsky and the thermal power station, located in the zone of active navigation of ships of different tonnage. The CRZ data are confined to areas of low and moderate pollution (Sovga et al., 2014). The concentration of MP in the beach and bottom soil is almost an order of magnitude less than in the first group of CRZs. Studies of the beach soil revealed a three-fold increase in the concentration of MP over three years. Perhaps this is the result of the action of runoff water in the vicinity of these beaches and the industrial area around the Goryachka beach. The main stream of vacationers on them are local residents. The turnover of the contingent on the beach is high (k_3 = 10). For a short stay on the beach, vacationers leave less plastic trash than on Group I beaches.

Group III included beaches with park areas: Uchkuevka, Solnechny and Zolotoy. The concentration of MP in the soil is low here. The source of MP on these beaches is mainly vacationers with a low turnover of the contingent (k_3 in the range of 3.1-4.6) and a high level of recreational load.

CONCLUSIONS

The methodology presented in this paper for assessing the sources of MP entering the CRZs was tested on seven beaches of the Sevastopol region with varying degrees of anthropogenic load and an individual set of local conditions. Due to a diverse set of factors that determine the uniqueness of the study areas, and a wide range of values for each factor, it was possible to compare the degree of saturation of the anthropogenic load in different CRZs.

The studied beaches were also differentiated into three groups according to the degree of vulnerability to the accumulation of mineral pollutants. The most vulnerable are the beaches that are actively visited by tourists and located in close proximity to large blocks of apartment buildings and extensive transport infrastructure (Pesochniy and Omega). The beaches of the Sevastopol Bay - Konstantinovsky and the thermal power station, located in the zone of active navigation of ships of various tonnage, are confined to areas of low and moderate pollution. The main stream of vacationers on them are local residents with a high turnover rate. The least vulnerable are the beaches with park areas: Uchkuevka, Solnechny and Zolotoy. The source of MP on these beaches is mainly vacationers.

The authors propose the following as universal preventive measures for the accumulation of MP:

1. Minimize the use of plastic materials as CRZ equipment (chaise lounges, umbrellas, etc.), switch to natural materials.
2. Carry out a set of measures for regular cleaning of the beach area and provide the optimal number of containers for separate waste collection.
3. Ensure quality control of the services of the operator for the disposal of solid waste from the territory of the CRZ and the territory adjacent to it. Ensure monitoring of the territory adjacent to the CRZ for the fact of the appearance of unauthorized dumps.
4. Regularly clean the near-surface layer of water in water areas from plastic debris.

The described technique can be used in ecology, hydrobiology, health resorts, recreational geography and allows us to formulate recommendations for minimizing the MP in the CRZ, which is undoubtedly relevant for municipal and environmental organizations.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of thismanuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication &/ or falsification, double publication &/or submission, andredundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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