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Contamination of Sandy Beaches with Marine Litter Microparticles (the Eastern Part of the Gulf of Finland of the Baltic Sea)

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Abstract

This article discusses the features of the distribution of marine microlitter (particles less than 5 mm) in 2019–2020 on 13 beaches of St. Petersburg and the Leningrad Region located on the coast of the Russian part of the Gulf of Finland (the Baltic Sea). Microlitter was found on all beaches, however, its composition and amount varied significantly depending on the beach exposure and other factors. The concentration of microlitter ranged from 0.1 to 55.5 particles/m^2. The largest amount of microlitter in the wrack zone was found on the beach in the center of St. Petersburg, the least – in Alexandria Park on the south coast; the predominant type of microlitter on most beaches is plastic. Using a cluster analysis, the beaches were classified according to the degree of their contamination: the most contaminated beaches are located within the city on the coasts of the Neva Bay, the least contaminated beaches are either outside the Neva Bay or at a considerable distance from the center of St. Petersburg. In the Neva Bay and on the northern coast of the open part of the Gulf of Finland, the concentrations of microlitter are higher, which may be due to the peculiarities of currents and winds determining the removal of particles coming with the Neva River runoff and their transport to the north. Comparison of the obtained data with the results of other studies in this region showed that, as compared with the beaches of other parts of the Baltic Sea, the Eastern Gulf of Finland has the highest values of the number of microparticles on the beaches.

Keywords: marine litter, microlitter, Neva Bay, Gulf of Finland, beaches, microplastics, contamination, marine ecosystems

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Загрязнение микрочастицами морского мусора песчаных побережий восточной части Финского залива Балтийского моря

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Аннотация
Рассмотрены особенности распределения морского микромусора (частиц размером менее 5 мм) в 2019–2020 гг. на 13 пляжах Санкт-Петербурга и Ленинградской области, расположенных на побережье российской части Финского залива Балтийского моря. Микромусор обнаружен на всех пляжах, однако его состав и количество значительно варьируют в зависимости от экспозиции пляжа и других факторов. Концентрация микромусора составила от 0.1 до 55.5 частиц/м^2. Самое большое количество микромусора в зоне заплеска обнаружено на пляже в центре Санкт-Петербурга, меньше всего – в парке Александрия на южном побережье. Преобладающим типом микромусора на большинстве пляжей является пластик. С помощью кластерного анализа пляжи охарактеризованы по степени их загрязненности: наиболее загрязненные пляжи расположены в черте города на побережьях Невской губы, наименее загрязненные пляжи – либо за пределами Невской губы, либо на значительном отдалении от центра Санкт-Петербурга. В Невской губе и на северном побережье открытой части Финского залива концентрации микромусора выше, чем на южном побережье, что может быть связано с особенностями течений и ветров, обусловливающих вынос и перенос к северу частиц, поступающих со стоком реки Невы. Сравнение полученных данных с результатами других исследований в данном регионе показало, что, по сравнению с побережьями других частей Балтийского моря, в восточной части Финского залива наблюдаются более высокие значения количества микрочастиц на пляжах.

Ключевые слова: морской мусор, микромусор, Невская губа, Финский залив, пляж, микропластик, загрязнение, морские экосистемы

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Introduction

For a long time, waste was considered a problem for areas near industrial sites and densely populated urban areas, but not for marine ecosystems. However, after the discovery of the Great Pacific Garbage Patch, the problem of marine litter became known to a wide audience [1]. Currently, marine litter is having a negative impact on the economy and well-being of people living near the sea, as well as on marine ecosystems [2]. Every year, up to 20 million tons of plastic waste enter the World Ocean [3]. Marine litter easily crosses borders between countries; it can be found near its place of origin or it can be carried by currents and winds. This makes it difficult to assess the distribution of marine litter and to find its sources.

Microlitter is particles of both natural and synthetic materials with the largest dimension of up to 5 mm. Microplastics can be primary (pre-production pellets are small polymer particles used in the manufacture of various products) and secondary (fragments resulting from the destruction of larger plastic products) [4]. Microplastics have been found in filter feeders and other benthic organisms [5]. Laboratory studies have shown that many marine invertebrates such as bivalves, echinoderms, amphipods, and zooplankton can ingest microplastics [6, 7]. Plastic often contains hazardous additives, can adsorb hydrophobic persistent organic pollutants and transfer these substances into marine food chains [8].

Monitoring studies of marine and, in particular, beach litter are important for identifying the sources of its entry into the marine environment. In the Baltic region, the studies of beach litter have been carried out for several years (see report [1)] and works [9–11]). The first large-scale studies of beach litter were carried out in 2011–2013 within the framework of the *MARLIN* project, during which from 75 to 236 fragments of macrolitter per 100 m of beach [1)] were found on the coasts of Sweden, Finland, Estonia and Latvia. It was discovered that the main sources of marine litter in the Baltic Sea were maritime transport, fishing, domestic sewage, as well as recreational activities on the coast [9].

Large scale research on microplastics in 2014–2016 on German beaches showed that the upper layer of sand on the beaches of the Baltic coast of Germany contained an average of 2–11 microplastic particles per kilogram of dry mass [12], and on the beaches of the Kiel Fjord – from 2 to 30 particles per kilogram of dry mass [13]. At the same time, on the beaches of the German island of Rügen, the amount of microplastics was already 80–100 particles per kilogram of dry mass in the sand layer [14]. The beaches in Poland were also contaminated with microplastics, their concentrations on the sand surface ranged from 25 to 43 particles per kilogram of dry weight in 2014 [15].

Beaches can be contaminated with microlitter of various sizes: from tens of microns to 5 mm. In 2014–2016, on the beaches of Germany and Lithuania, monitoring studies [10] of contamination with visually distinguishable microlitter (2–5 mm) were carried out using the methods that were later used in this work. The following results were obtained: the occurrence of microlitter particles ranged from 0.02 to 3.9 particles/m^2. Studies by various authors show that microlitter is found on all beaches. However, it is very difficult to compare contamination assessment results due to differences in the methodologies used. In addition, the authors can describe contamination by all types of microlitter, as well as focus only on microplastics.

On the Russian coast of the Baltic Sea, studies of microplastics in beach sands have been conducted since 2016. It was established that on the beaches of the Kaliningrad region, microplastics were present both on the surface of the sand

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[1)] European Commission, 2013. *Final Report of Baltic Marine Litter Project MARLIN – Litter Monitoring and Raising Awareness 2011–2013*. Available at: https://www.pidasaaristosiistina.fi/files/1994/Marlin_Final_Report_2014.pdf [Accessed: 06 March 2022].

and at a depth of more than 1 m, and the concentrations varied from 2 to 572 particles per kilogram of dry mass [16]. On the coasts of the eastern part of the Gulf of Finland, the study of marine litter was started by the Russian State Hydrometeorological University (RSHU) in 2018 [17]. It was found that all the coasts of the Gulf of Finland and the Neva Bay were polluted with plastic litter of all fractions – from macro- to microlitter. A parallel study at the stations of RSHU in 2019 [18] showed a distribution of microplastic concentrations in beach sediments from 15 to 210 particles per kilogram of dry mass in the Neva Bay. Model studies in 2019 revealed the trends in the distribution of microplastics in the Neva Bay [19]. In general, studies in the Neva Bay and the Gulf of Finland indicate much higher concentrations of microplastics on the Russian coast compared to the coastal zone of other Baltic countries.

In this region, only the Russian State Hydrometeorological University annually investigates the contamination of beaches with microlitter, which makes it possible to analyze dynamic characteristics and perform statistical processing of data. Therefore, the purpose of this study is to analyze the contamination of the beaches of the Neva Bay and the eastern part of the Gulf of Finland with marine litter microparticles based on the seasonal surveys of the RSHU in 2019–2020. In this regard, the following tasks were performed: the features of the distribution of marine microlitter on the beaches of the Russian coast of the Gulf of Finland were considered, the beaches were classified according to their contamination degree in 2019–2020, and the data obtained were compared with the results of other studies in the region.

The selected materials used in the preparation of this work were previously presented at the conference [2)].

Materials and methods

The eastern (Russian) part of the Gulf of Finland is the final reservoir of accumulation of substances from Lake Ladoga and the Neva River. In this part of the bay, the Neva Bay deserves special attention, as it is a man-made lagoon bounded by the Western High-Speed Diameter, a the Flood Protection Barrier of St. Petersburg and the Marine Facade, which contributes to the accumulation of material coming with the waters of the Neva River. The eastern part of the Gulf of Finland is experiencing a strong anthropogenic impact, as more than 5 million people live on the shores of this water body.

Almost everywhere within the Eastern Gulf of Finland and its coastal zone, the upper part of the geological section is represented by late and postglacial Quaternary deposits. On the beaches, these deposits are represented by medium-grained river sands, and within the boundaries of the Neva Bay – by coarse-grained river sands [20].

The studies were carried out on 13 beaches of St. Petersburg and the Leningrad region (Fig. 1) in the summer months of 2019–2020.

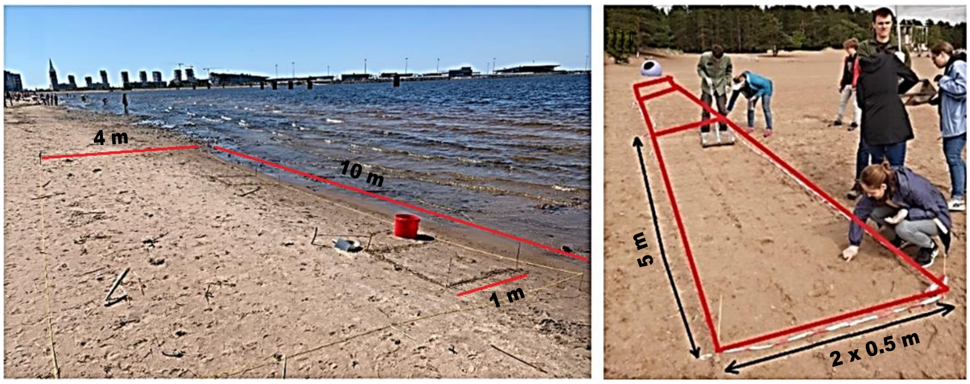
[2)] Kuzmina, A.S. and Ershova, A.A., 2021. Comparative Characterization of Marine Microlitter Monitoring Techniques for Sandy Beaches of the Gulf of Finland in the Baltic Sea. In: IBSS, 2021. *Pont Evksinskiy – 2021 : Materials of XII All-Russian Scientific and Applied Conference for Young Scientists on the Water Systems Problems, Dedicated to the 150 th Anniversary of the Sevastopol Biological Station – A. O. Kovalevsky Institute of Biology of the Southern Seas of RAS. Sevastopol, 20–24 September, 2021*. Sevastopol: IBSS, p. 78–80. doi:10.21072/978-5-6044865-8-0 (in Russian).

F i g . 1 . Microlitter sampling locations on the coasts of the Eastern Gulf of Finland

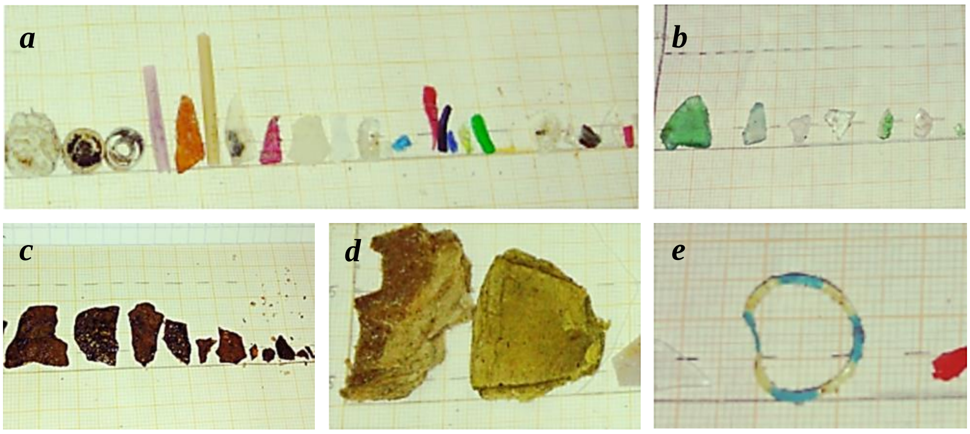
When sampling microlitter, two international beach survey methods [10, 21] were used. These methods were developed for the Baltic coasts based on the monitoring experience of the *OSPAR* project. The first is the Frame-method, which aims at wrack zone with a 40 m^2 survey polygon for collecting large litter (more than 5 mm) with two squares of 1 m^2 for collecting microlitter 2–5 mm in size (using a sieve with a 2 mm cell). The second is the Rake-method, which involves the entire coast from the waterline to the vegetation line with an areaof at least 50 m^2; the sand is sieved with the use of a special rake with a cell of 2 mm (Fig. 2). Both methods aim at a visually distinguishable fraction of micro-litter (2–5 mm), but in the two functionally different zones of the beach.

The selected particles of microlitter were counted and classified according to the type of material: plastic, glass, paper, metal and other materials (Fig. 3).

The obtained data were entered into protocols (by beaches) and processed using Microsoft Excel and PAST4 software (Ward's method). This algorithm uses methods of dispersion analysis to estimate distances between clusters. It minimizes the sum of the squares of the distance for the two clusters that are formed at each step. Ward's method leads to the formation of clusters of approximately equal sizes with minimal intraclass dispersion. In general, Ward's method is effective, but it tends to create small clusters, which has almost no effect on the quality



F i g . 2 . Microlitter sampling methods: *a* – Frame-method, *b* – Rake-method



F i g . 3 . Types of microlitter particles on the beaches of the Eastern Gulf of Finland: plastic (*a*), glass (*b*), metal (*c*), paper (*d*), other (*e*)

of classification with a relatively small size of the original selection [3]. This method was applied because in 2019-2020 the survey was carried out once a year and the dataset included no more than 20 values of microlitter concentrations in the wrack zone.

Results

The studies were carried out for the two functionally different parts of the beach. On all coasts, contamination of the wrack zone was studied, that is, the presence of microlitter directly at the waterline. Most likely, the source of microlitter was sea waves splashing the material onto the shore. The entire width of the beach (including the dry part) was surveyed by the Rake-method only

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[3] Soshnikova, L.A., Tamashevich, V.N., Uebe, G. and Shefer, M., 1999. *Multidimensional Statistical Analysis in Economics*. Moscow: Unity, 598 p. (in Russian).

on selected representative beaches in order to establish the significance of other sources of beach contamination (waste from tourists, wind transfer, etc.).

Wrack zone

Among all the studied beaches in the summer seasons of 2019 and 2020, the largest amount of microlitter particles per square meter in the wrack zone was found on the beach in the very center of St. Petersburg on Dekabristov Island in the Neva Bay. Within the same period, the smallest amount of microlitter particles was found on the beaches remote from the center – on Laskovy beach in the village of Solnechnoye in the open part of the Gulf of Finland in 2019 and on the beach in Lomonosov in 2020 (Fig. 4). At the same time, less microlitter was found on the beaches in the wrack zone in 2020 than in 2019.

On the beaches of the Neva Bay, microlitter is mainly represented by plastic, with the exception of the beach in Alexandria Park, where it is represented only by glass. Outside the Neva Bay, the situation is different – the microlitter mainly consists of metal on the beaches of Kronstadt, and it consists of glass on the northern coast of the open part of the bay (Fig. 5). Most of the microplastic particles were found on Dekabristov Island, while plastic was absent in the samples from the village of Solnechnoye and Alexandria Park. In general, more microplastics can be found in the wrack zone of the beaches in the Neva Bay than in the open part of the gulf behind the Flood Protection Barrier.

During the study, the number of microlitter particles and, in particular, microplastics on the beaches of the Neva Bay and the open part of the Gulf of Finland was determined. The obtained data were analyzed using statistical

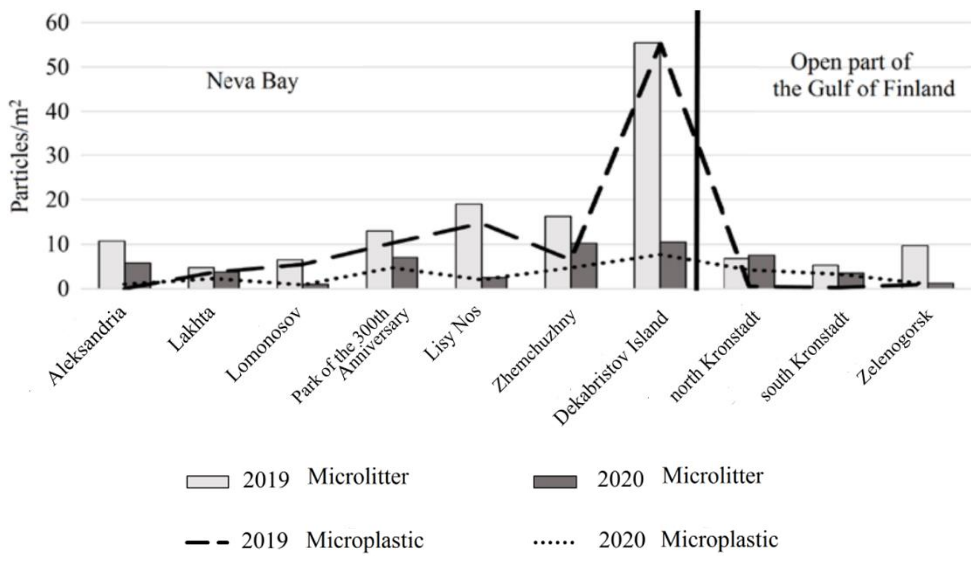


Fig. 4. The number of particles of microlitter and microplastics in the wrack zone, 2019–2020

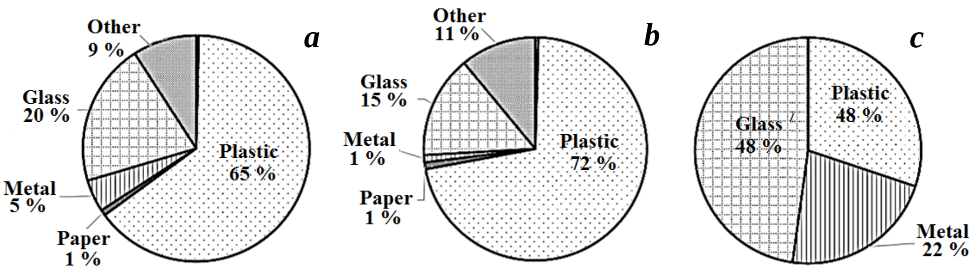


Fig. 5. The percentage of microlitter of each type on all the studied beaches in 2019–2020 (*a*), in the Neva Bay (*b*), in the open part of the Gulf of Finland (*c*)

processing methods. The average statistical characteristics for these sections of the coastal zone of the Eastern Gulf of Finland were obtained: arithmetic mean ($\bar{x}$), median (M_e), standard deviation (σ), maximum and minimum (Table 1). Thus, in the Neva Bay, the average number of particles ($\bar{x}$) is higher than in the open part of the gulf, while the standard deviation σ exceeds the average value, which indicates large differences between the beaches of the Neva Bay. Indeed, in 2019, 55.5 particles/m^2 were found on the beach on Dekabristov Island, and 1 particle/m^2 was found in Alexandria Park. At the same time, in the open part of the Gulf of Finland, the standard deviation does not exceed the mean value, and the median is much closer to the mean than for the data from the Neva Bay, which indicates greater data homogeneity.

Table 1. The number of detected particles of microlitter on the beaches of the eastern part of the Gulf of Finland in 2019–2020, particles/m^2

Beach location	$\bar{x}$	M_e	σ	max	min
Microlitter					
Neva Bay	11.9	8.6	13.6	55.5	1.0
Open part of the Gulf of Finland	5.7	6.0	3.0	9.8	1.3
Including microplastics					
Neva Bay	8.5	4.8	14.4	55.3	0.0
Open part of the Gulf of Finland	1.7	1.0	1.6	4.3	0.3

A classification of data on microlitter contamination for 2019–2020 was carried out using Ward's method together with the Euclidean distance. A division into three classes was chosen: the most contaminated beaches, moderately contaminated beaches and the least contaminated beaches. The average values in each class were calculated (Table 2) and a comparison was made between the 2nd and 3rd classes according to Student's *t*-test. As a result, it was found that t^* (2.64) > t_{cr} (2.12) (calculated at a significance level of $\alpha = 0.05$), which means that the classes should not be combined with each other. It is advisable to consider them as separate groups.

The most contaminated is the beach on Dekabristov Island, located in the city center (Fig. 6) right at the confluence of one of the largest branches of the Neva River into the Neva Bay, which, apparently, determines the large amount of microlitter found. At the same time, the beach is one of the most contaminated with macro- and mesolitter, according to our observations [22], and is not cleaned by municipal services. Moderately polluted beaches are also located within the city on the coasts of the Neva Bay. The least contaminated beaches are located either outside the Neva Bay, or at a considerable distance from the center of St. Petersburg. The exception is the beach in the village of Lakhta, which turned out to be the least contaminated according to the above classification, which may be due to the presence of dense reed beds that partially trap particles.

Table 2. Beach classification by microlitter concentrations in the Eastern part of the Gulf of Finland in 2019–2020

Class	$\bar{x}$, particles/m^2	Beach location
1 (most contaminated)	33	Dekabristov Island
2 (moderately contaminated)	10.6	Alexandria Park of the 300th Anniversary Lisy Nos Zhemchuzhny
3 (least contaminated)	5	Lakhta Lomonosov North Kronstadt South Kronstadt Zelenogorsk

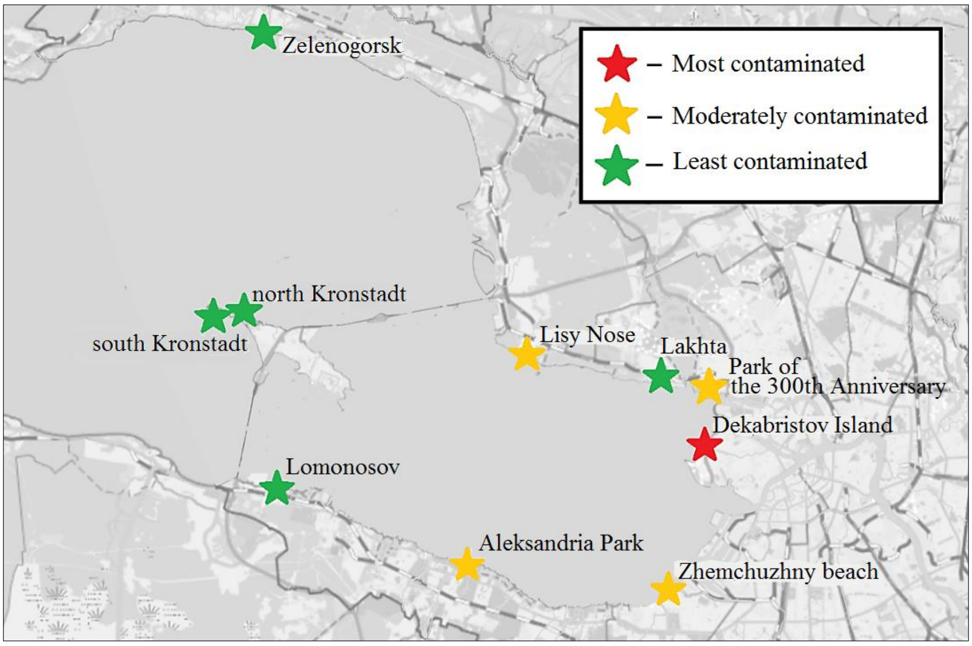


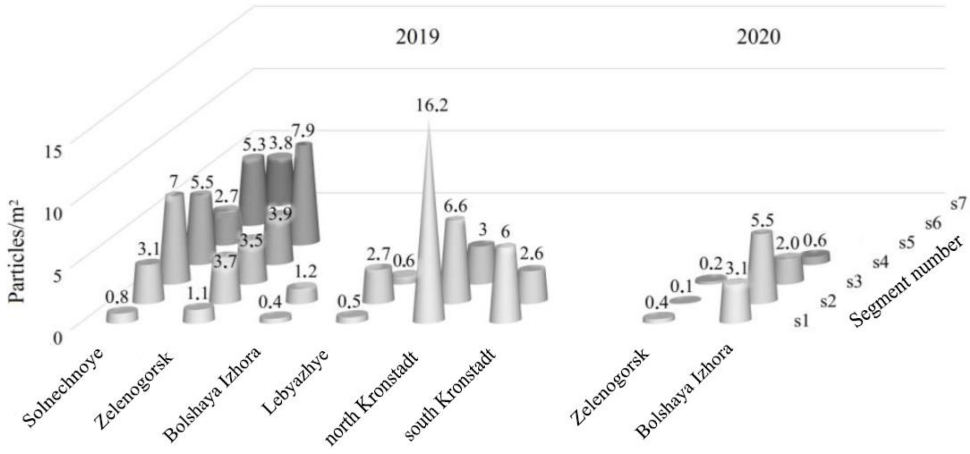
Fig. 6. Classification of the Gulf of Finland beaches according to the degree of microlitter contamination

Selective study of beaches across the entire width

In addition to the wrack zone, in 2019 and 2020, beaches on the northern and southern coasts of the open part of the Gulf of Finland were selectively studied using the Rake-method to assess the contamination of the beach along the entire width from the waterline to the vegetation line (Fig. 1), including its entire dry part. At the same time, in contrast to 2019, in 2020 only two beaches, characterizing the situation on the southern and northern coasts of the eastern part of the Gulf of Finland, were selected for the study. The selected beaches differ not only in hydrodynamic conditions, but also in the level of recreational load, as well as in the cleaning frequency.

In 2019–2020, the number of microparticles varied within a very wide range: in 2019, the largest number of microlitter particles per square meter was found on the northern beach of Kotlin Island, and the least – on the beach in Bolshaya Izhora, while in 2020 the most of the particles were found on the beach in Bolshaya Izhora, and the least – on the beach in Zelenogorsk. The microlitter from the beaches of Kronstadt (Kotlin Island) is mostly represented by metal, while on the other beaches of the open part of the Gulf of Finland the microlitter is mostly plastic. In general, more microplastics are observed on the northern coast of the open part of the gulf, and relatively many microplastic particles (more than 1 particle/m^2) were found on the southern beach of Kotlin Island in 2019.

The amount of microlitter from the waterline to the vegetation line varies from beach to beach (Fig. 7). Thus, in 2019 on the beaches of Kronstadt



F i g . 7 . Distribution of microlitter by beach segments from waterline (S1) to vegetation line (S7) in 2019 and 2020

(Kotin Island) the amount of microlitter decreases with distance from the water line, that is, most likely, the microlitter on the beach is of marine origin and comes with waves; this is also indirectly indicated by its composition – mostly rusty metal. It should be noted that here, on the territory of the *Western Kotlin* Nature Reserve, regular cleaning of large litter is carried out and this reserve is visited infrequently due to the large distance from the city – the number of tourists here is much smaller than on the coasts of the mainland of the Gulf of Finland. On the beaches of Zelenogorsk and the village of Solnechnoye on the northern coast of the Gulf of Finland, the situation is reverse – there is more microlitter far from the water, although Zelenogorsk and Solnechnoye are the popular beaches of the Kurortny District of St. Petersburg that are daily cleaned. A large amount of microlitter in the sands of these beaches probably indicates the insufficiency of mechanical cleaning tools that allow small fractions of litter (for example, the remains of cigarette butts) to pass through, collecting only large litter. However, another reason for the accumulation of microparticles (mainly plastic) in the dry part of these beaches cannot be indicated– spring and autumn storms, throwing suspended material far into the beach. This is evidenced by a large number of pellets in the microlitter composition, the source of which is the washout into the sea from construction sites.

The beaches of the southern coast of the Gulf of Finland – Bolshaya Izhora and Lebyazhye – are the so-called wild beaches, which are cleaned only by local volunteers. Both beaches have a high recreational load in the summer, however, in 2019, the lowest amount of microlitter was found there along the entire width of the beach. Using the example of these beaches, the theory of influence of the dominant currents in the Gulf of Finland is confirmed, according to which the suspended material coming from the city and the Neva River, is carried out to the northern coast [23].

The 2020 study showed a different pattern of microlitter distribution on the beaches of the northern and southern coasts: more litter was found in Bolshaya Izhora with the maximum accumulation in the middle of the beach, and the smallest amount of microparticles was observed on Zelenogorsk beach, which may be due to an artificial renewal of the beach with clean imported sand.

Discussion

The conducted studies showed that microlitter in one form or another was found on all the beaches of the Eastern Gulf of Finland and the Neva Bay. The most contaminated beaches with particles smaller than 5 mm are located within the boundaries of St. Petersburg, closer to its center, in the area of one of the main branches of the Neva River. A similar situation is observed in other parts of the Baltic Sea: in the Kaliningrad region, the most microplastics were found in the wrack zone on the most visited beaches, as well as on the Vistula Spit [17]; the beaches of Finland are also characterized by higher contamination of urban beaches [9]. Thus, the beaches of urban areas are the most contaminated with microlitter in the Baltic region.

The studies conducted within the *MARLIN* project showed that the most contaminated beaches in the Baltic were the beaches of Finland, located on the northern coast of the Gulf of Finland [9], and more than half of all objects found there were plastic. In this work, it is revealed that the northern coast of the Gulf of Finland and the Neva Bay is more contaminated with microlitter than the southern one, and microplastics are the predominant type of microlitter here – approximately 65% of the total volume. In general, the variety of materials that make up the microlitter of the Gulf of Finland is great; in addition to microplastics, there are microparticles of metal, glass, plaster and other materials, while, for example, on the coast of the Kaliningrad region in the South-East Baltic, anthropogenic marine litter consists mainly of plastic – a total of about 90% of all collected samples [17].

The comparison of concentrations of microlitter and microplastics found on the Baltic coasts of Germany, Lithuania [11] and Russia using the methods discussedin this study showed that, unlike the beaches of Germany and Lithuania, in the Neva Bay of the Gulf of Finland, the maximum number of microparticles in the Baltic region was discovered. On the beaches of the Russian coast of the Gulf of Finland, an average of 11.5 particles/m^2 was found in the wrack zone and 3 particles/m^2 – along the entire width of the beach, while in Germany and Lithuania these values are on average 0.1 and 3.9 particles/m^2, respectively, for the wrack zone and 0.2 and 0.02 particles/m^2 – for the entire width of the beach. The beaches of the Neva Bay and Germany are characterized by the predominance of plastic particles in the wrack zone.

Unlike the Baltic coasts of other countries, where the main source of marine litter is tourism, in the Neva Bay and the open part of the Russian coast of the Gulf of Finland, the sources of microlitter vary from beach to beach and may probably depend on the type of industrial activity nearby. Thus, for example, the predominance of metal particles in the microlitter structure of the beaches of

Kronstadt (Kotlin Island) can be explained by active navigation and ships moored in the immediate vicinity of sampling sites, and the source of glass on the beach in Alexandria Park (regularly cleaned) can be the Petrovsky Glass Manufactory, located on the shore near the park. A large amount of plaster residues on some beaches (the "other" category) also indicates the proximity of construction sites and places where construction waste is disposed of. It is also impossible to exclude the role of incompletely treated municipal and industrial wastewater as a source of microplastics on the studied coasts: the microplastic samples were often represented by nurdles or pellets, and by fragments of household hygiene items. Due to the predominance of southwestern winds, as well as complex currents, the northern coast of the open part of the Gulf of Finland is more contaminated with microlitter than the southern one, since the particles coming from the Neva River runoff are transferred to the north [23].

Conclusion

On the whole, the conducted study confirms the main pattern of microparticle distribution in the waters of the Neva Bay and on its coasts: higher concentrations of microlitter are typical of the Neva Bay and the northern coast of the open part of the Gulf of Finland, which is explained by the peculiarities of currents and prevailing winds. Quite naturally, the beaches closer to the city center are more contaminated. However, the conducted research also shows a significant variability in the concentrations and conditions for the formation of microplastic load on the beaches; a more detailed research, obviously, requires more frequent studies, taking into account the seasons and hydrometeorological phenomena.

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