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Microplastic pollution in the Black Sea Coast of the Anatolian side of Istanbul, Turkey

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ABSTRACT

This study was carried out to investigate plastic pollution in the Black Sea Coast of the Anatolian side of Istanbul, Turkey. In the study, the plastic particles in the collected samples (beach sands) were classified depending on size. The abundance of microplastics (1–5 mm) and large plastics (>5 mm) by number and weight were determined. The spatial and seasonal variations in the abundance by number and weight were also reported. The highest abundances by number were found at Riva station, whereas the lowest abundances by number were found at Sile Port.

Keywords: Black Sea Coast; Marine pollution; Microplastic; Plastic debris

1. Introduction

The microplastics at sea are formed as a result of the fragmentation of plastics. Due to the ocean currents and hydrodynamic processes along with their buoyant and persistent properties, microplastics are widely dispersed in the marine environment [1]. Weathering-related fracturing and surface embrittlement of plastics in beach environments can be stated as the primary mechanism leading to the formation of microplastics [2].

Microplastics have been assigned to various size ranges. This can sometimes be confusing and hinder data comparisons. In general, plastic particles having diameters smaller than 5 mm, including nanoparticles, are defined as microplastics [3]. The route of entering the sea and ocean of microplastics may be via terrestrial pathways (migration with surface water flow and river channels) and anthropogenic activities at sea (e.g. fishing, shipping, and sports).

Both primary microplastics and secondary microplastics are even harmful to the aquatic ecosystem. This is because they may transfer to the food chain since they have the potential to biomagnify and bioaccumulate within the aquatic organisms [4]. Besides, microplastics represent a higher environmental risk to the marine organisms since they adsorb hydrophobic substances such as polycyclic aromatic hydrocarbons and polychlorinated biphenyls [5]. Accordingly, it can be said that special attention should be paid to plastic pollution in lakes, rivers, seas, and oceans.

Since sandy beaches host a variety of marine organisms, they are a very important component of the marine environment. They are in direct interaction with the sea. Therefore, sandy beaches serve as permanent or transient reservoirs of plastic debris [6].

In this study, plastic pollution was investigated at various beaches along the Black Sea Coast of the Anatolian side of Istanbul, Turkey. Seasonally, samples (sand samples) were taken from the stations chosen in the study area between May 2017 and February 2018. Preliminary data was reported on size classification and abundance of microplastics and large plastics by number and weight in the sand samples, including microplastic debris (1–5 mm) and large plastic debris (>5 mm). Seasonal and spatial variations of plastics in the study area were discussed. As far as we know, except for a study on pollution of beach sediments from Romanian

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Black Sea Coast with microplastic fibers carried out by Săvucă et al. [7], there is no published paper so far on microplastic contamination on beaches of the other coastal countries of the Black Sea (Bulgaria, Georgia, Romania, Russia, and Ukraine), as well as the beaches of the Black Sea Coast of Turkey. Therefore, this study appears to be one of the first reports related to the pollution of microplastics on sandy beaches along the Black Sea Coasts.

2. Materials and methods

2.1. Study area and sampling

The present study was carried out on the Black Sea Coast of the Anatolian side of Istanbul, Turkey. This coast, which is a favorite vacation destination in Istanbul, is known by the broad sandy beaches that are mostly preferred for recreational activities such as swimming, picnicking, etc. Rivers flowed into the Black Sea from this coastal area are Cayagız (Riva), Türknil (Kumbaba), Yesilcay (Kurfalli), and Göksu (Agva).

Within the scope of this study, beach sand samples were collected from six locations between May 2017 and February 2018 on the Black Sea Coast of the Anatolian side of Istanbul, Turkey. The beach samplings were carried out in spring (May 2017), summer (August 2017), autumn (November 2017), and winter (February 2018) seasons. Consequently, the study was conducted with a total of 24 samples (beach sands).

The samples were collected by creating a composite sample of 2 m × 2 m [5,8,9] three square areas which were determined to be parallel to the shoreline in the supratidal zone [10,11]. They were collected from the center and the four corners of the square areas with metal spoons to 5 cm depth [11,12]. The samples were then placed in glass bottles and transferred to the laboratory.

The map of the sampling sites is shown in Fig. 1. In Table 1, the sampling stations and their characteristics are given.

2.2. Sample analysis

The beach samples transferred to the laboratory were subjected to sieving and density separation. Firstly, each dry beach sample (sand, 1 kg) were sieved with sieves in five size classes: 1–2 mm, 2–3 m, 3–4 mm, 4–5 mm, and >5 mm. Sieving has been used so far by numerous researchers in plastic (microplastic, large plastic) analyses [13–15].

The plastics (1–5 mm and >5 mm) in the samples were separated using the density separation procedure, which is described by Martins and Sobral [9], Hidalgo-Ruz et al. [10], Dobaradaran et al. [13], and Piñon-Colin et al. [16], with slight modifications. In this procedure, the remaining particles on the sieves were discarded to NaCl solution (140 g/L) and stirred vigorously for 5 min. 15 min were allowed to complete the sedimentation process. The plastics floating on the surface of the NaCl solution were collected using forceps and placed in glass Petri dishes. For each sample, this extraction process was repeated three times. The plastics identified by size were then also weighed using an electronic balance to 0.0001 g to determine the abundance by weight [9,14].

The abundance by number and weight of the plastics were presented as the number of plastics per kg of dry beach

Fig. 1. Map of the study area (1: Riva, 2: Alacali, 3: Kumbaba, 4: Sile Port, 5: Kurfalli, 6: Agva).

Table 1
Sampling stations and their characteristics

Station number	Station name	Characteristics of sampling stations	Latitude (degrees north start/end) and longitude (degrees east start/end)
1	Riva	Cayagız (Riva) Stream is located in Riva. Dense fishing activities are carried out along this stream.	41° 13′ 28.632′′N 29° 12′ 57.0672′′E
2	Alacali	Doğancalı biological wastewater treatment plant and a camping site are located in Alacali. Treated wastewater from Doğancalı biological wastewater treatment plant is discharged to the Alacali Stream.	41° 11′ 45.6756′′N 29° 27′ 36.0426′′E
3	Kumbaba	Türknil (Kumbaba) river, a camping site, and the Sile Kumbaba wastewater pretreatment plant are located in Kumbaba. Treated wastewater from the Sile Kumbaba wastewater pretreatment plant is discharged to Türknil (Kumbaba) River.	41° 10′ 15.7476′′N 29° 34′ 37.6746′′E
4	Sile Port	Sile Port is located in the center of Sile near the newly built cruise port project. The area in the vicinity of Sile Port is constantly cleaned. Fishing activities are carried out in Sile. There is also a breakwater in this port.	41° 10′ 29.2974′′N 29° 36′ 12.3078′E
5	Kurfalli	In the east of Kurfalli, Yesilcay (Kurfalli) and Göksu (Agva) Rivers are located. Agva biological wastewater treatment plant and a camping area are also located in Kurfalli.	41° 8′ 19.7556′′N 29° 50′ 40.6032′E
6	Agva	Agva is located between two rivers, with Yesilcay (Kurfalli) River in the west, and Göksu (Agva) River in the east.	41° 8′ 23.049′′N 29° 51′ 7.9128′′E

sand (particle/kg d.w.), and the weight of plastics per kg of dry beach sand (weight/kg d.w.), respectively.

3. Results and discussion

3.1. Seasonal and spatial distributions (%) of plastic abundance

The seasonal distributions of the total plastic (microplastic and large plastic) abundances by number and weight (%) are presented in Table 2. The plastic abundance by number was found to be 841 particles in total. When the seasonal distribution of plastics (%) was investigated, it was seen that the maximum plastic abundance by number was observed in summer (34.70%). This was followed by autumn (32.00%) and spring (18.80%). It was determined that the lowest plastic abundance by number was found in winter (14.50%). The plastic abundance by weight was determined as 105.1063 g in total. It was determined that the plastic abundance by weight was the highest in summer (39.58%), followed by autumn (32.49%) and winter (18.01%). The lowest value by weight was determined in spring (9.91%). The plastic abundance by number was minimum in winter (Table 2), whereas the least plastic abundance by weight was determined in spring. It is thought that the increase in the human population living in the summer houses in the coastal areas, and the increase in the number of people coming to the beaches for recreational activities (swimming, picnicking around the seaside, etc) increase the plastic abundance (%) in summer. The lowest abundance of plastics in winter can be attributed to the significantly decreased resident and tourist population, and their decreased recreational activities in winter and the higher wind speed in winter compared to the other seasons.

The spatial distributions of the total plastic (microplastic and large plastic) abundances by number and weight (%) are given in Table 3. The maximum abundance of plastics in beach samples by number (%) was observed at Riva (26.04%), followed by Kumbaba (24.14%), Kurfalli (17.36%), Agva (13.08%), Alacali (10.70%), and Sile Port (8.68%). As can be seen from Table 3, the highest plastic abundance by weight (%) in total was found at Alacali (26.16%), followed by Kurfalli (17.45%), Kumbaba (15.15%), Riva (14.86%) and Agva (14.52%). It was determined that the lowest plastic abundance by weight was observed in Sile Port (11.86%).

It can be stated that the reasons of the maximum abundance by number of plastics (%) in Riva may be that the region is exposed to pollutants brought by the Cayagız (Riva)

Table 2
Seasonal distributions of plastic abundances by number and by weight

Abundance	Seasons			
	Spring	Summer	Autumn	Winter
Abundance by number (%)	18.80	34.70	32.00	14.50
Abundance by weight (%)	9.91	39.58	32.49	18.01

Table 3
Spatial distributions of plastic abundances by number and by weight

Abundance	Sampling stations					
	Riva	Alacali	Kumbaba	Sile Port	Kurfalli	Agva
Abundance by number (%)	26.04	10.70	24.14	8.68	17.36	13.08
Abundance by weight (%)	14.86	26.16	15.15	11.86	17.45	14.52

Stream, the dense fishing activities in the region, and the region is located at the abutment of the Yavuz Sultan Selim Bridge connection road which made it easier to reach the region. As was stated by Cheung et al. [17], drainage systems such as river systems may be important vectors for the transport of land-based plastic debris into marine environments. In addition to fishing activities, the region is an attractive area in terms of tourism and recreational activities such as swimming, picnicking around the seaside, etc. These characteristics of Riva explain the reason for the maximum abundance of the plastics by number (%) found in this region. Similarly, Filho and Monteiro [18] reported that sources of microplastics in Corvina Beach, which is an Amazon macrotidal sandy beach, were fisheries, tourists and local beachgoers. In a study carried out by Sathish et al. [19], it was reported that coastal activities such as fishing, recreation, and tourism contributed to the microplastic pollution in their sampled beaches. Dowarah and Devipriya [20] revealed that fishing activities were the major determining factor for microplastic abundance in their sampled beaches.

Kumbaba is a region where the population is crowded all year round due to the summer houses and a private university located in this region. The high plastic abundance in Kumbaba can be attributed to the pressure of the recreational and anthropogenic activities in the region. Similarly, Sathish et al. [19] revealed that the high recreational and anthropogenic activities caused higher accumulation tendencies of microplastics in their sampled beaches. Koongolla et al. [21] reported that both the highest number and the highest weight of microplastics were found at a busy public recreational beach in their study area. In Kumbaba, there is also a continuous discharge to the Türknil (Kumbaba) River due to the Sile Kumbaba wastewater pretreatment plant in the region. It can be stated that this may be one of the reasons for the high plastic abundance in this region. Up to now, various researchers revealed in their studies that wastewater treatment plants contribute to microplastic pollution in aquatic environments [22–25]. For example, in a study conducted by Talvitie and Heinonen [25], it was reported that microplastics coming from wastewater treatment plants were being discharged to receiving environments without being removed in the treatment plants. Murphy et al. [23] stated that although microplastic particles can be effectively removed from the municipal wastewater in wastewater treatment plants, a considerable amount of microplastics reach the aqueous environment even if a small amount of microplastic releases per liter since large volumes are being treated. Sun et al. [24] indicated that microplastics enter natural aquatic environments via wastewater treatment plants, which are considered as important pathways of microplastics. McCormick et al. [22] stated that effluents from wastewater treatment plants were important due to being a point source of microplastics. Besides, potentially pathogenic bacteria common in wastewater was reported to have an affinity for microplastics.

Sile Port was found to have the lowest abundance by the number and weight of plastics. It is located near the cruise port project, which is being newly built in the center of Sile and is located on a coastal strip, which is located at the northeast, open to the winds of the region and is constantly cleaned by the municipalities and the nearby enterprises due to its location. The lowest plastic abundances by number (%) and weight (%) in this sampling site may be explained by these environmental factors. Topçu et al. [26], investigated the origin and abundance of marine litter along sandy beaches of the Turkish Western Black Sea Coast. They revealed that Sile was the second cleanest beach in the study area.

3.2. Seasonal and spatial variation of plastic abundances for various size ranges

Seasonal variations in the plastic abundances by number for various size ranges are presented in Fig. 2a. The highest value of plastics by number was seen to be in the size of >5 mm (135 particles/kg) in summer, followed by plastics with >5 mm size in autumn (116 particles/kg), and microplastics in the size range of 3–4 mm in summer (69 particles/kg). The lowest microplastics by number was obtained to be in the size range of 1–2 mm in winter (3 particles/kg). It can be said that in the size of >5 mm, the highest plastic abundance by number in summer gives pre-understanding related to the extent of the plastic pollution in the study area. As stated by Lee et al. [27], the investigation of mesoplastics by sieving the sand with a 5 mm sieve is efficient and useful for the determination of the ''hot-spots'' on the beaches contaminated with large microplastics. They also revealed the strong correlation of the abundance of large microplastics with the abundance of mesoplastics.

The plastic abundances of >5 mm in summer and autumn may be attributed to the wastes created by tourists and local beachgoers. The beaches in the Black Sea Coast of the Anatolian side of Istanbul are used extensively by many people in summer and early autumn. Hence, marine litter in these coastal areas is increased dramatically in this period. Terzi and Seyhan [28] revealed that land-based marine litter in the southeastern Black Sea Coast increased by 90% in summer, while the lowest land-based marine litter was observed in winter. On the other hand, Topçu et al. [26] stated that high litter densities on the Turkish Western Black Sea Coast in autumn were probably related to the increased fishing activities during this season.

Seasonal variations in the plastic abundances by weight for various size ranges are presented in Fig. 2b. The weights of plastics larger than 5 mm in all seasons were found to be higher than the plastic weights in the other size ranges. A similar trend was reported by Martins and Sobral [9], and Frias et al. [29]. Microplastic weights in the range of 3–4 mm in spring and autumn seasons were more than the microplastic weights in the size range of 4–5 mm. The reason for this is that the number of microplastics in the size range of 3–4 mm is greater than the number of microplastics in the size range of 4–5 mm.

Considering spatial variations in the plastic abundance by total number for various size ranges, it was seen that the most common plastic size was >5 mm. The abundance by a total number of plastics >5 mm in size was the maximum in Riva (89 particles), followed by Kumbaba (78 particles), and Kurfalli (63 particles). The microplastic abundance by total number was followed by Kumbaba (77 particles) and Riva (52 particles) in the size range of 3–4 mm. It was determined that the lowest value by total number was found in Alacali (3 particles) in the size range of 1–2 mm (Fig. 3a). Similar to the results of our study, in their study on sandy beach Ámbar, Canary Islands, Spain, Edo et al. [30] observed that the microplastic abundance decreased with decreasing size. They revealed that among the different size ranges (3–4 mm, 2–3 mm, 1–2 mm, and <1 mm) of microplastic particles, the size range of 4–5 mm contributed to the highest abundance by number.

For >5 mm size, the high abundance by total number in Riva, Kumbaba, and Kurfalli may be because these sampling points were close to river mouths as well as dense recreational activities (swimming, picnicking around sea side, etc) in the beach areas by tourists and local beachgoers. This suggests that these beach areas are also influenced by the rivers as a land-based source. It is known that plastics entering river systems directly as well as wastewater effluents, and leachates generated from solid waste dumpsites are then transported out to the sea [31]. In a study on disposal of solid waste in Istanbul and along the Black Sea Coast of Turkey by Berkun et al [32], it was reported that the Black Sea Coast of the Anatolian side of Istanbul is also under threat in terms of the pollutants carried by the rivers. However, it is thought that the high plastic abundances in Riva, Kumbaba, and Kurfalli were caused primarily by tourists and local beachgoers since the highest plastic abundances were found in summer and autumn (Fig. 2a), especially for >5 mm plastics. Erüz et al. [33] reported that the pollution caused by packaging materials on the southeastern

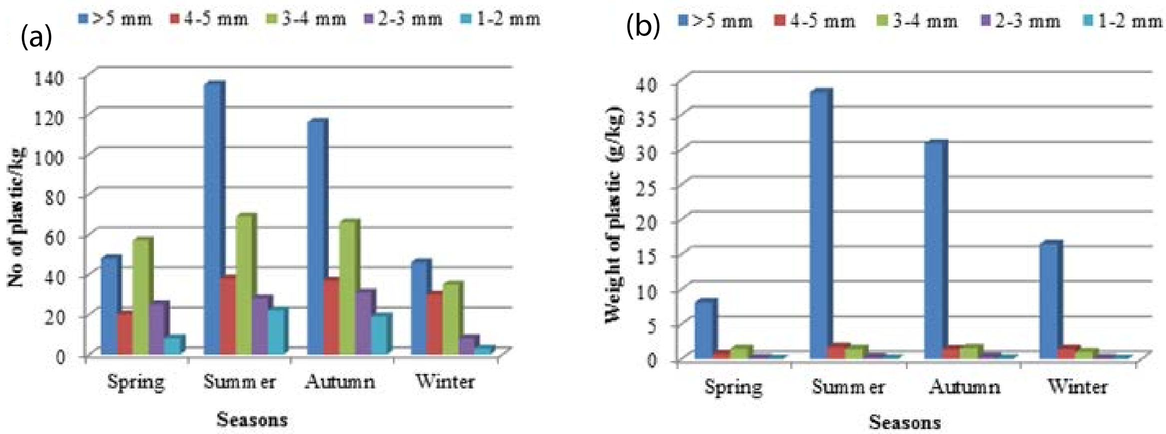

Fig. 2. Seasonal variation of the plastic abundance by number (Fig. 2a) and weight (Fig. 2b) according to the size.

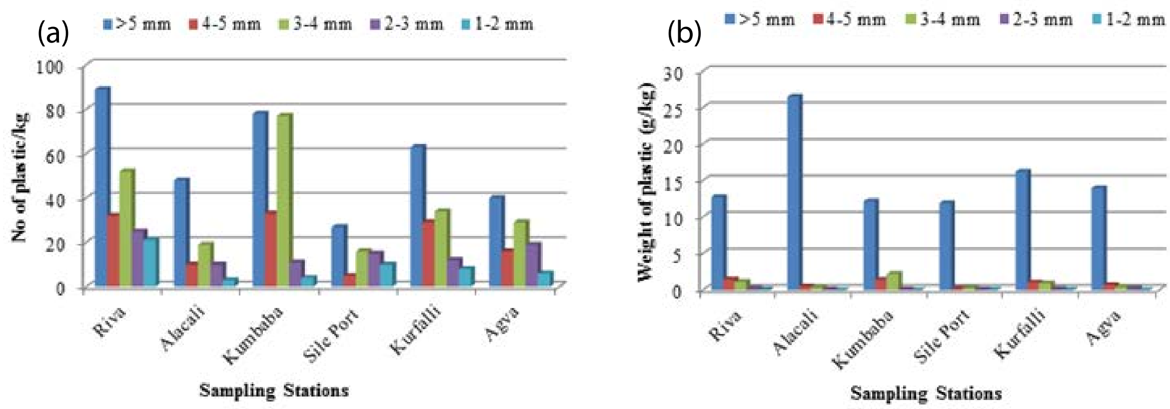

Fig. 3. Spatial variation of the plastic abundance by number (Fig. 3a) and weight (Fig. 3b) according to the size.

Black Sea Coast was dominant. They stated that these coasts, which were frequently used for recreational activities, were under the threat of larger size plastics (>5 mm) such as packaging wastes.

A high abundance of large size plastics in these beaches is of very importance since secondary microplastics arose due to the degradation of the large size plastics, mostly due to the weathering degradation [3]. Sagawa et al. [34] carried out a study on the abundance and size of microplastics, and their polymer types in the surface water and the bottom and beach sediments of Hiroshima Bay. They reported that being irrespective of the polymer type, the microplastic distributions were considerably affected by the size of the microplastics. On the other hand, the larger microplastics were expected to be on the beaches rather than being on the sea bottoms. The reason for the highest abundance of >5 mm plastics in the beaches of our study area can also be explained based on the comments of Sagawa et al. [34].

The spatial variation of the plastic abundance by weight for various size ranges is presented in Fig. 3b. The abundance of plastics larger than 5 mm by weight in all stations were found to be higher than the plastic abundance by weight in the other size ranges. In general, the weight values of plastics were proportional to the size ranges. Similarly, for comparison, Karthik et al. [35] reported that among the different size categories of microplastic particles, the class of 2.36–4.75 mm was more abundant by weight than the other classes (1.18–2.36 mm, 0.6–1.18 mm, and 0.3–0.6 mm).

In a study carried out on distribution and characterization of microplastics in three different sandy beaches from Indian coastal environments by Tiwari et al. [36], the abundance of microplastics by weight in beach sands from Mumbai, Tuticorin, and Dhanushkodi were found to be 3.54 ± 0.01 mg/kg, 2.75 ± 0.03 mg/kg, and 1.05 ± 0.01 mg/kg, respectively. In 2015, a study was carried out with sand samples taken from 5 and 10 cm depths from four beaches located on the northern coast of Taiwan (2 beaches were sampled in August, 1 beach was sampled in September, and one beach was sampled in June). In this study, 8 samples with a volume of 0.0125 m^3, a total of 1,097 particles, and 0.771 g plastic were identified [37]. Lozoya et al. [8], conducted a study in October and November 2013 (to avoid the tourist season), collecting sand samples from 2 cm depth from 10 beaches located on both sides of the Punta del Este peninsula of Uruguay. A total of 2,966 particles and 384 g were collected from 120 m^2 of the study area.

Considering the abundance by number and weight of plastics (microplastics and large plastics) in samples collected from our study area, it can be said that the plastic abundance by number and weight varied both seasonally and spatially, which is, as stated by Karkanorachaki et al. [6], possibly due to the sea-surface circulation, weather patterns, local pollution accidents and human activities (tourism, fishery).

The Black Sea is defined as a “Special Area” under Annex V of the MARPOL convention [26,38]. It is known that the Black Sea, which is a semi-closed sea, is especially sensitive to pollution due to its slow rate of water renewal. Namely, the contaminants tend to accumulate without degrading [39]. Up to now, in various studies on marine litter pollution regarding the Black Sea, it was revealed that plastics are the most abundant materials of marine litter in the Black Sea [26,28,38,40–43]. Suaria et al [38] revealed that the abundance of floating macro-debris in the north-western part of the Black Sea is as high as in the other parts of the world. Aytan et al. [44], for the first time, reported the occurrence and distribution of microplastics for the South Eastern Black Sea waters. They revealed that microplastic concentrations were relatively high, and the Black Sea was a hotspot for microplastic pollution. Bat et al. [39] found a large amount of microplastics in the sea surface and water column in Sinop Sarıkum Lagoon coast of the Southern Black Sea. Săvucă et al. [7] revealed that in the sediment samples collected from four different sites of the Romanian Black Sea Coast, high amounts of microplastic fibers with different lengths and colors (green, red, black, blue) were observed. Based on the background above, and the assessment of the outcomes of our study, it can be said that plastic pollution in the Black Sea and its coastal areas seem to be of concern.

Table 4
Comparison of the abundance of microplastics in various beach samples around the world

Location	Sample type	Size	Mean abundance (particles/kg d.w.)	References
Coastal marine environment, Singapore	Beach sediment	>1.6 μm	2.8	[1]
Slovenia beaches	Beach sediment	<250 μm	177.8–170.4	[15]
Baja California Peninsula, Mexico	Sand	>1 mm	135 ± 92	[16]
Bohai Sea, China	Sand	1 μm	102.9–163.3	[45]
Wanning, China	Beach sediment	<5 mm	5,000–8,714	[46]
National park beaches, Alaska	Sand	2–4.75 mm	21.3–128.8	[47]
National park beaches, Northeast, USA	Sand	2–4.75 mm	63.8–126.3	[47]
National park beaches, West Coast, USA	Sand	2–4.75 mm	38.8–140.0	[47]
National park beaches, Pacific islands, USA	Sand	2–4.75 mm	98.8–187.5	[47]
Beaches on the Isle of Rügen (Baltic Sea), Germany	Beach sediment	63 μm–5 mm	77.9–107.3	[48]
Northwestern Mediterranean Sea (Northern site)	Beach sediment	0.063–5 mm	60–182	[49]
Northwestern Mediterranean Sea (Northern site)	Beach sediment	0.063–5 mm	56–150	[49]
Black Sea Coast of the Anatolian side of Istanbul	Sand	1–5 mm	20.7	This study

3.3. Comparison of the microplastics abundance with other studies

The results of our study were compared with the previous studies reporting results in the same quantitative unit as ours (particles/kg d.w.) and presented in Table 4. According to this comparison, the mean abundance by number of microplastics on the beaches of the Black Sea Coast of the Anatolian side of Istanbul was found to be lower than those on the beaches of the Bohai Sea (China) [45], Wanning (China) [46], national park beaches (Alaska), national park beaches of Northeast and West coast (USA), national park beaches of Pacific islands (USA) [47], Baja California Peninsula [16], beaches on the Isle of Rügen (Baltic Sea) (Germany) [48], Slovenia beaches [15], and the beaches of Northwestern Mediterranean Sea [49]. On the other hand, the mean abundance by number of microplastics on the beaches of the Black Sea Coast of the Anatolian side of Istanbul was higher than those on Singapore coastal marine environments [1]. However, it should be considered that there is more or less difference in the methodology (sampling, extraction) and the size categories among these studies. For example, while microplastic abundance by number of 1 μm was considered in the beaches of the Bohai Sea (China), abundance by number of microplastics between 1 and 5 mm were considered in the beaches of the Black Sea Coast of the Anatolian side of Istanbul (Table 4).

4. Conclusions

The findings of this study indicated that the Black Sea Coast of the Anatolian side of Istanbul was exposed to plastic pollution. Measurable amounts of microplastic (1–5 mm in size) and large plastic (>5 mm in size) abundances in various degrees were detected at all beaches sampled in the study area. Large plastics were the most commonly observed size fraction. A further study on this issue is currently underway. Depending on the preliminary data of this study, it can be inferred that precautions should be taken against plastic contamination in the Black Sea Coast of Istanbul. As pointed out by Dobaradaran et al. [13], since effectively removal of microplastic particles from neither sand and sediments in coastal areas nor seawater is possible, decreasing the plastic release to marine environments is the only way to reduce their abundance. Coastal cleanup activities carried out from time to time and advancement of environmental consciousness of citizens and tourists may help to reduce the microplastic pollution [15]. This study provides the first report related to the temporal and spatial distribution of microplastics and larger plastics in sandy beaches of the Black Sea Coast of the Anatolian side of Istanbul, Turkey. We hope that the results of our study will present useful background information for further studies to be conducted along the coast of the Black Sea.

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