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RESEARCH ARTICLE **ARAŞTIRMA MAKALESİ**

Benthic marine litter in the Marmara Sea, Turkey

Marmara Denizi'nde bentik deniz çöpü

Murat Şirin[1] ● İsmail Burak Daban[2] ● Ali İşmen[3] ● Mukadder Arslan İhsanoğlu[4*]

[1]General Ministry of Agriculture and Forestry, 61040, Trabzon, Türkiye https://orcid.org/0000-0003-3556-7472
[2]University of Çanakkale Onsekiz Mart, Faculty of Marine Science and Technology, 17100, Çanakkale, Türkiye https://orcid.org/0000-0002-2973-5698
[3]University of Çanakkale Onsekiz Mart, Faculty of Marine Science and Technology, 17100, Çanakkale, Türkiye https://orcid.org/0000-0003-2456-0232
[4]University of Çanakkale Onsekiz Mart, Faculty of Marine Science and Technology, 17100, Çanakkale, Türkiye https://orcid.org/0000-0003-0072-5848

*Corresponding author: mukadderarslan@gmail.com

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Abstract: This study presents the first data on benthic marine litter in the Marmara Sea, Turkey. To obtain the data, bottom trawl surveys were conducted at 34 sites between May 2017 and February 2018. The litter items were sampled and sorted following the MEDITS' relevant instructions. 660 pieces of litter, weighing 434.9 kg, were sampled. The litter density was found to range between 27.5 n/km^2 and 661.2 n/km^2, averaging 73.9 n/km^2, and the obtained items' weights ranged between 0.03 kg/km^2 and 1597.8 kg/km^2, averaging 48.7 kg/km^2. The plastic group L1 constituted 71.7% of the trawled litter. The highest mean litter density was detected in the Northeastern Marmara Sea in the spring and summer of 2018. The mean benthic litter density was found to be higher than the nearby areas. It was concluded that more effort should be invested in reducing marine pollution.

Keywords: MEDITS, benthic litter, plastic waste, marine pollution, Marmara Sea

Öz: Bu çalışma, Marmara Denizi'ndeki bentik deniz çöpüne ilişkin ilk verileri ortaya koymaktadır. Bu amaçla Mayıs 2017-Şubat 2018 tarihleri arasında 34 istasyonda dip trolü araştırması yapılmıştır. Çöplerin kategorize edilmesi ve sınıflandırılması MEDIT standardına göre belirlenmiştir. Toplam 660 adet ve 434,9 kg çöp tespit edilmiştir. Çöp yoğunluğu 27,5 adet/km^2 - 661,2 adet/km^2 arasında değişirken, ortalama 73,9 adet/km^2 tespit edilmiştir, ağırlık değerleri 0,03 kg/km^2 - 1597,8 kg/km^2 arasında değişmiş ve ortalama 48,7 kg/km^2 belirlenmiştir. Plastik (L1) grubu toplam çöp bolluğunun %71,7'sini oluşturmuştur. 2018 yılında, ilkbahar ve yaz mevsimlerinde ve Marmara Denizi'nin kuzeydoğu kesiminde daha yüksek çöp yoğunluğu tespit edilmiştir. Deniz kirliliğini azaltmak için daha etkin mücadele gerektiği görülmüştür.

Anahtar kelimeler: MEDITS, bentik çöp, plastik atık, deniz kirliliği, Marmara Denizi

INTRODUCTION

Marine litter is defined by UNEP as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment. It may be indirectly introduced into marine environments by rivers, sewage, storm water, waves, or winds, but it is mainly anthropogenic (UNEP, 2016). Marine litter has been discussed in the last 60 years. Derraik (2002) states that plastics are the essential pollutants among all other known components. Plastic production is estimated to amount to 368 million tonnes (Plastics Europe, 2020) and the increase rate corresponds to 4% a year. Besides, the plastic production of Turkey was recorded to be 9.8 million tonnes in 2020 (PAGEV, 2020). The most pollutant plastic polymers are arranged as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polyvinyl chloride (PVC) (Godoy et al., 2020). Marine species get entrangled in plastic debris such as plastic food wrappers, bottles, and ghost fishing nets, which leads to lethal consequences, e.g., injuries or death due to entanglement. A notable portion of this debris covers sea bottom and prevents gas exchange between the substrate and the overlying water column (Corcoran, 2015) and primarily affect sessile living organisms, such as corals, algae, etc. Besides, aquatic species (fish, crustaceans, cephalopods, etc.) accidentally consume plastic debris as prey. Besides, microplastics formed after decomposition causes damage, especially in the early developmental stages of marine animals. (Ribeiro et al., 2019).

Benthic marine debris is determined with bottom trawling in many areas of the world. The most general understanding is that marine bottom pollution has been increasing in recent years, and plastics are the most common pollutants materials. Benthic marine litter density was found to be 102 n/h on the Malta Shelf (Misfud et al., 2013), 4424 n/h in Spain (Sanchez et al., 2013), 79.6 n/h in the Central Mediterranean Sea (Garofalo et al., 2020), 72-437 n/h in the Echinades Gulf (Koutsodendris et al., 2008), 0-2145 n/h in the Adriatic (Fortibuoni et al., 2019), and 125-594 n/h in Algeria (Mankou-Haddadi et al., 2021). However, the amounts and temporal variations of litter have not yet been known in many great geographical areas. Unless the main problem is known, it is very difficult to take local measures, which results from the lack of scientific research in the relevant local areas.

The Marmara Sea is regarded as a special area that connects the Mediterranean and the Black Sea via the Dardanelles and Bosphorus Straits. In addition to being one of the most important maritime traffic areas globally, it is also home to a metropolis, i.e., Istanbul. In 2018, the number of vessels that passed through the Bosphorus and Dardanelles Straits was 41.103 and 43.999, respectively (TUIK, 2019). Besides, Istanbul's population in 2018 was reported to be 15.7 million by TUIK (2019). In addition, 3000 registered fishing vessels with varied capacities fish in the Marmara Sea (Anonymous, 2018). A considerable number of unlicenced fishing vessels operate in the Marmara Sea. Besides, the industrial facilities in Turkey are mainly located in the Marmara Region (48%), a great majority (31%) of which are stationed in the city of İstanbul (Plastics Europe, 2020). These facilities discharge their waste into the Marmara Sea through a liquid waste process called deep-sea discharge. Maryam and Büyükgüngör (2019) state that only nine of 77 wastewater treatment plants around the Marmara Sea are capable of advanced biological treatment. Most waste is discharged as coarse and fine particulates after physical treatment only (Burak et al., 2021). Besides, İstanbul's Golden Horn (Haliç) estuary, which is one of the most delicate areas in the world, easily becomes polluted and is in constant need of improvement in water quality. Furthermore, the pollutants accumulated in the estuary flow into the Marmara Sea. Additionally, Orhon et al. (2021) argue that the Black Sea Current in the Bosphorus Strait discharges highly polluted water bodies from the Black Sea into the Marmara Sea. Thus, the nutrient load of the Marmara Sea exceeds the capacity of the Marmara's marine ecosystem (Okuş et al.,2002; Taş et al., 2016; Çardak et al., 2015) and results in environmental disasters such as mucilage (Savun-Hekimoğlu and Gazioğlu, 2021).

Another problem that causes inceased marine pollution in the Marmara Sea and Turkey is the plastic imports from the developed countries (Gündoğdu and Walker, 2021). By the end of 2020, Turkey's annual plastic waste import reached 772,831 tonnes (PAGEV, 2021). Gündoğdu and Walker (2021) note that while Turkey's rate of recycling its own waste is very low (<1%), the mismanagement of high amount of imported plastic waste can pose serious environmental problems, particularly increased pollution.

Previous research on marine litter has been mostly conducted in the Northeast Levantine Coasts of Turkey (Güven et al., 2013; Eryaşar et al., 2014; Aydın et al., 2016; Gündoğdu et al., 2017; Olguner et al., 2018, Gündoğdu and Çevik, 2019; Mutlu et al., 2020; Büyükdeveci and Gündoğdu, 2021). Some published data are also available about the neighboring seas. Topçu and Öztürk (2010) have studied the Western Black Sea and Gönülal et al. (2016) have researched the vicinity of the Gökçeada Island, Northeastern Aegean Sea. In most of these studies, benthic marine litter abundance is determined with a swept area of bottom trawl sampling. Aydın et al. (2016) and Artüz et al. (2021) focus on coastal macrolitter around beaches. All in all, no previous studies were found to have researched benthic marine litter abundance in the Marmara Sea.

This research is the first to investigate benthic pollution in the Marmara Sea and to present data on the abundance and spatial and temporal variations of the benthic marine litter in it. Besides, the study also intended to reveal the associated pollution sources to gain a deeper insight into the cause and effect relationships influential in the emergence of seabed pollution in the research area.

MATERIAL AND METHODS

This study is a part of a research project entitled "Determination of the population status and the stock estimation of economically valuable demersal fish in the Marmara Sea". The litter samples were obtained by 246 bottom trawl hauls at 34 sites in the Marmara Sea between March 2017 and December 2018. The surveys conducted in March, July, October and December were tagged with Spring, Summer, Autumn and Winter, respectively (Table 1).

The sampling strategy and technical properties of the trawl nets (polyethylene codend with 200 mesh length with a mesh opening 44 mm; equipped with polyamide cover with 250 mesh length with a mesh opening 20 mm; 200 kg and 1*2 m steel doors) were determined based on "MEDITS International bottom trawl survey in the Mediterranean – Instructional Manual". The sampling sites were characterized by varying depths (10-50, 50-100, 100-200, and >200 m) and a great diversity of geographical features. The bottom trawl hauls were conducted with the commercial trawl vessel Yalçınoğlu at three nautical miles for 30 m.

The marine litter items were counted and weighed to the nearest 0.5 g. The litter items were sorted following the instructions by the MEDITS. They were grouped into eight different categories: plastic, metal, rubber, glass, textile, wood, paper, and others. The swept area method was used to calculate the abundance of litter on the seabed in the number of items per unit area (km^2) and the total weight and item number (n) of items per unit area (km^2). Catch per Unit Effort (CPUE: kg/km^2) was calculated by dividing the catchweight (Cw) by the swept area (a) for each species and each haul (Sparre and Venema, 1992).

CPUE: Cw/a

The swept area (a) or the 'effective path swept' for each hauling was estimated thus:

$a = D.h.X_2$

where h (m) refers to the length of the head rope and D to the distance covered. X is the fraction of head rope length, with 0.5 as the best compromise (Pauly, 1980).

The non-parametric Kruskal-Wallis test was used to test differences between categories of marine debris and depth stratum and between the categories of marine debris and seasons. Besides, The Mann-Whitney U test was applied to see between-group differences. The statistics were conducted with PAST v. 2.17c.

Table 1. Coordinates and depths of sampling sites in the Marmara Sea

Site	Tow Beginning Coordinate		Tow Ending Coordinate		Tow Beginning Depth	Tow Ending Depth
	Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	Depth (m)	Depth (m)
1	40 55 724	28 44 679	40 56 045	28 46 286	78.33	78.28
2	40 56 953	28 34 991	40 56 784	28 36 783	48.98	52.68
3	40 55 142	28 34 970	40 54 925	28 36 745	77.13	74.85
4	41 01 180	28 26 091	40 01 098	28 26 227	38.4	37.19
5	40 58 102	28 22 312	40 37 839	28 24 234	71.46	72.57
6	41 00 894	28 05 947	41 01 510	28 06 992	29.44	29.93
7	40 57 614	28 02 645	40 57 765	28 04 497	78.66	79.03
8	40 58 583	27 46 273	40 58 192	27 48 136	41.8	42.19
9	40 53 377	27 29 329	40 54 162	27 30 739	70.02	69.23
10	40 39 249	27 15 660	40 40 156	27 17 338	41.86	43.66
10-A	40 39 826	27 24 210	40 40 622	27 25 500	143.9	159.61
11	40 36 835	27 15 725	40 37 449	27 17 332	79.8	80.86
12	40 35 096	27 04 729	40 35 727	27 06 410	38.55	35.48
13	40 28 529	27 14 960	40 28 994	27 13 236	53.5	55.01
14	40 31 627	27 11 006	40 32 457	27 09 492	64.53	65.31
15	40 21 595	27 25 062	40 22 415	27 23 617	24.07	23.48
16	40 26 953	27 27 998	40 27 467	27 25 159	52.25	54.54
17	40 20 730	27 35 946	40 20 614	27 34 093	28.08	29.55
18	40 26 263	27 35 990	40 26 293	27 34 132	42.55	42.49
19	40 33 362	27 40 876	40 32 531	27 39 394	59.68	61.48
20	40 39 328	27 50 478	40 39 333	27 50 457	83.77	83.38
21	40 33 357	27 51 834	40 33 631	27 46 610	59.46	62.49
23	40 37 582	28 12 254	40 37 491	28 14 654	81.18	80.83
24	40 24 418	28 12 361	40 24 407	28 12 713	33.14	33.85
25	40 30 429	28 11 398	40 30 73	28 13 73	51.62	50.48
26	40 38 618	28 22 448	40 38 791	28 20 597	99.44	102.07
27	40 24 988	28 26 746	40 24 834	28 24 969	30.34	26.18
28	40 30 851	28 24 857	40 31 758	28 23 390	46.96	46.22
29	40 30 652	28 40 400	40 28 784	28 41 372	37.88	37.91
30	40 26 149	28 40 994	40 25 788	28 42 880	57.88	58.28
31	40 24 881	28 49 816	40 24 939	28 47 867	63.62	63.24
32	40 41 004	29 18 997	40 40 460	29 17 739	60.08	73.27
33	40 49 001	29 14 539	40 50 317	29 13 643	60.24	59.49
34	40 50 143	29 03 633	40 49 616	29 05 508	91.22	90.06

RESULTS

Marine litter was found at 32 of 34 sites. 246 trawl hauls conducted in the Marmara Sea yielded a total of 660 pieces of litter, amounting to 434.9 kg. The litter density ranged between 27.5 n/km^2 and 661.2 n/km^2, averaging 73.9 n/km^2, and the weight values between 0.03 kg/km^2 and 1597.8 kg/km^2, corresponding to 48.7 kg/km^2 on average. The mean abundance and weight values of the litter categories are given in Table 2. The mean CPUE values of the litter groups varied according to numerical abundance and weight. The analyses of the numerical abundance (n/km^2) showed that the plastic group (L1) constituted 71.7% of the total litter abundance. The metal (L3) and textile materials (L5) represented 11.4% and 6.6%, respectively. The rubber, glass, wood, and paper litter groups had rather low numerical litter abundance.

Table 2. The marine litter biomass of the Marmara Sea by main categories and subcategories per the instructions by MEDITS

Mean Abundance	n/km^2	n%	kg/km^2	W%
L1 Plastic (including PVC, polypropylene, polyethylene)	**53**	**71.7**	**8**	**16.4**
L1a. Bags	26.3	35.6	2.6	5.3
L1b. Bottles	6.2	8.4	0.9	1.8
L1c. Food wrappers	15.3	20.7	2.6	5.3
L1d. Sheets (table cover, etc.)	0	0	0	0
L1e. Hard plastic objects (crates, containers, tubes, ashtrays, lids, etc.)	1.9	2.6	1.5	3
L1f. Fishing nets	0.8	1.1	0.1	0.2
L1g. Fishing lines	0	0	0	0
L1h. Other fishing related (pots, floats, etc.)	0	0	0	0
L1i. Synthetic ropes/strapping bands	0	0	0	0
L1j. Others	2.5	3.4	0.3	0.6
L2 Rubber	**1.2**	**1.7**	**15.5**	**31.8**
L2a. Tyres	1	1.4	15	30.8
L2b. Others (gloves, floats, boots/shoes, olskins, sanitaries)	0.2	0.3	0.5	1
L3 Metal	**8.4**	**11.4**	**6.5**	**13.4**
L3a. Beverage cans	5.5	7.4	0.6	1.2
L3b. Other food cans/wrappers	0.8	1.1	0.3	0.6
L3c. Middle-size containers (of paint, oil, chemicals)	1.3	1.8	1.6	3.2
L3d. Large metalic objects (barrels, pieces of machinery, electric appliances)	0.7	0.9	3.5	7.1
L3e. Cables	0	0	0	0
L3f. Fishing-related gears (hooks, spears, etc.)	0.1	0.1	0.5	1
L3g. War remnants	0	0	0	0
L4 Glass/Ceramic/Concrete	**1.3**	**1.7**	**0.5**	**1**
L4a. Bottles	1.2	1.6	0.5	1
L4b. Pieces of glass	0.1	0.1	0	0
L4c. Ceramic jars	0	0	0	0
L4d. Large objects (ceramic basins, etc.)	0	0	0	0
L5 Cloth (textile)/Natural fibres	**4.9**	**6.6**	**9.7**	**19.9**
L5a. Clothing (clothes, shoes, etc.)	2.8	3.8	1	2
L5b. Large pieces (carpets, mattresses, etc.)	1.3	1.8	8.5	17.4
L5c. Natural ropes	0.1	0.1	0.1	0.2
L5d. Sanitary products (diapers, cotton buds, etc.)	0.7	0.9	0.1	0.2
L6 Processed wood (palettes, crates, etc.)	**2.6**	**3.5**	**7.8**	**16**
L7 Paper and cardboard	**1**	**1.4**	**0**	**0**
L8 Others	**1.5**	**2**	**0.8**	**1.6**
L9 Unspecified	**0**	**0**	**0**	**0**

Whereas the highest CPUE in weight (kg/km^2) (15.5%) was detected in the rubber group (L2). The textile and wood items were the other abundant litter groups (9.7% and 7.8%, respectively). The subgroups plastic bags, plastic food wrappers, plastic bottles, and metal beverage cans had the highest numerical CPUE values, corresponding to 26.3 n/km^2, 15.3 n/km^2, 6.2 n/km^2, and 5.5 n/km^2, respectively. Although the numerical CPUE values were found to be lower, the CPUE in weight (kg/km^2) was higher in the subcategories rubber tires, large textile pieces, and wood items and calculated to be 15 kg/km^2, 8.5 kg/km^2, and 7.8 kg/km^2, respectively (Table 2, Figure 1).

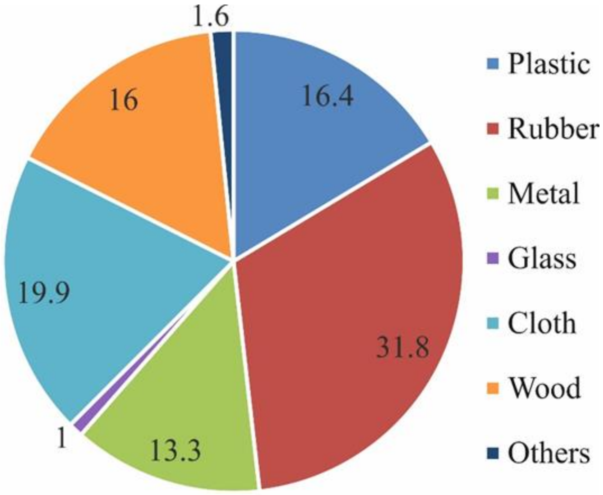

Figure 1. Percentages of marine litter biomass (kg/km^2) in the Marmara Sea by main categories (MEDITS)

The seasonal variations of the mean CPUE values are shown in Table 3. In 2018, the CPUE values were observed to be higher than the ones in 2017. The mean CPUE values were 56.2 n/km^2 in 2017 and 93.8 n/km^2 in 2018. The highest CPUEs in weight (kg/km^2) were detected in Spring 2017 and Spring 2018. The analysis of the mean CPUE values revealed no statistically significant between-season variations (F: 0.5906; df: 3; p>0.05).

Table 3. The seasonal variations in mean density values of marine litter in the Marmara Sea

Season	2017		2018	
	n/km^2	kg/km^2	n/km^2	kg/km^2
Spring	40.91	67.00	192.84	141.23
Summer	31.72	37.46	66.65	23.67
Autumn	109.36	17.13	49.77	27.7
Winter	41.77	9.82	56.3	73.62
Mean	56.16	33.21	93.81	66.07

According to the non-parametric Kruskal-Wallis analyses, the mean CPUE values showed statistically significant variations between the locations. The Mann-Whitney U test was performed to understand the interregional differences. The mean CPUE values showed no statistically significant variations between the Northeastern and Northwestern Marmara Sea and between the Northeastern and Southeastern Marmara Sea (p>0.05). The spatial variations in the mean CPUE values recorded in both the north and south parts and the west and east parts were statistically different. Among the 34 sites, the highest CPUE values were found at the sites 4 and 34. The mean CPUE at these locations was calculated to be higher than 300 n/km^2. The sites 1, 2, 31, and 32 too offered relatively higher CPUE – higher than 200 n/km^2. In the Western Marmara Sea, the highest litter was found at the sites 10, 11, and 12 located around the Hoşköy-Mürefte region (Figure 2).

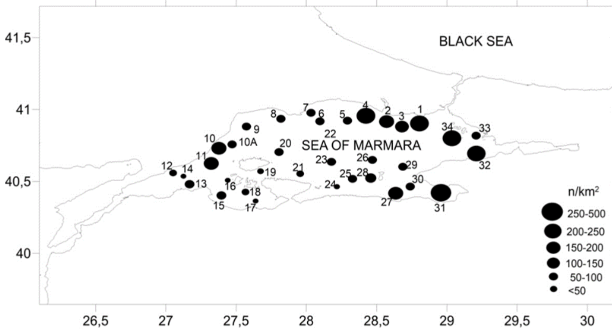

Figure. 2. The spatial variations of marine litter in the Marmara Sea

The mean CPUE values showed no statistically significant variations in terms of the depth strata. The mean CPUE values were observed to be 64.7 n/km^2, 71.7 n/km^2, and 45.9 n/km^2 at the depths of 23-50 m, 50-100 m, and >100 m, respectively.

DISCUSSION

Marine litter causes a great variety of issues. The accumulation of marine debris in coastal areas may create unpleasant sights for visiting tourists. Still, marine organisms are most exposed to and adversely affected by pollution. There is too much evidence for this phenomenon and it cannot be ignored. In addition, other living organisms, including birds, mammals, and invertebrates, too suffer injuries and suffocation from physical entanglement in marine litter items. In the related literature, 660 species are reported to have been physically affected by marine litter so far (Derraik, 2002). Although the degree of species-specific impact of marine litter is well-known, how pollutants affect communities and populations is still unclear. Therefore, the body of information required by managing authorities remains incomplete. For example, it is reported that 70% of plastic litter collapses in the demersal habitat. However, there is almost no research on how this dense plastic accumulation affects the bottom environment or damages the primary production and nutritional cycle (Barnes et al., 2009). In one of the rare studies, Gündoğdu et al. (2017) have found 17 different fouling species of six phyla (Annelida, Arthropoda, Bryozoa, Chordata, Cnidaria, and Mollusca) on plastics. They have revealed the negative impacts of plastics on the bottom environment. Light is vital for the phytobenthos, which plays a significant role in primary production. Due to the collapsed litter, the phytobenthos may be a severely affected group. Katsanevakis et al. (2007) and Akoumianaki et al. (2008) have investigated the nutrient exchange between sediment and water. The authors state that many creatures were adversely affected by anoxic conditions of the benthos arising from the collapsed litter items. Further, the biochemical process of decomposition of organic matter may also be adversely affected, and ammonium and nitrate levels can increase. Green et al. (2015) have identified that the community structure and abundance of species hinged on sediment have decreased in less than nine weeks.

As the results of our study suggest, almost all of the previous studies on the marine environment remark that the most abundant marine litter is plastic items. Plastic products have become an integral part of everyday life in many countries. Undoubtedly, plastics make life easier. It is preferred in every walk of life due to its cheapness, lightness, and flexibility. It has been identified that the annual plastic production of Turkey is approximately 10 million tonnes. Besides, Turkey is in sixth place globally in terms of plastic production (PAGEV, 2019). Due to the high worldwide demand, it is not surprising that the most abundant pollutant is plastic.

This study, conducted at 34 sites located in the Marmara Sea, offers the first comprehensive data on seabed pollution. The results showed key indicators through the spatial distribution of marine litter. There is no doubt that the Marmara Sea is a particular geographic area defined as a semi-closed basin. With the aid of the Bosphorus and the Dardanelles Straits, the Marmara Sea interconnects the Aegean Sea and the Black Sea, which drastically changes the aquatic characteristics of the respective bodies of water. Hence, it creates a system in which current intensity and direction are more effective than in the other seas. However, there are some factors such as human population density, dense industrial areas, marine traffic, anchor areas, fisheries activities, and river systems prevalent in all the seas with which marine pollution is directly associated. Considering the potential pollutants, the Northeastern and Eastern Marmara Sea contain almost all the sources together. According to the General Directorate of Population and Citizenship of Turkey, the Marmara region with a population of 24.5 million people accommodates 30% of Turkey's population and the metropolis Istanbul, holding 15 million people, is inhabited by 18% of Turkey's population (PAGEV, 2019). Besides, the highest number of industrial facilities are stationed in the cities such as İstanbul, Kocaeli, and Yalova, which are located in the Eastern Marmara Region. Due to high industrial production, these areas have dense marine traffic, commercial ports, and many anchorage areas such as Ambarlı, Pendik, Gebze, and Gemlik. What's more, old vehicle tires are used as a collision mat on the handrails of fishing boats, ferries, etc. In this study, the mean CPUE of rubber tyres (L2a) was calculated to be 1 n/km^2, and all were solely collected in the Eastern Marmara Sea. This result proves the impact of maritime traffic stemming from cargo ships and fishing vessels on marine pollution. In addition, the Kocaeli Dilovası Stream discharges the pollutants of the industrial facilities into the Marmara Sea. Istanbul Water and Sewerage Administration (ISKI) reports that only 25% of industrial wastewater undergoes high-tech biological treatment.

In contrast, the remaining 75% is discharged into the Marmara Sea only after pre-treatment (PAGEV, 2019). Besides, fisheries-related pollution caused by such items as jackboots, fisherman gloves, through-hull fitting, vessel upholstery, etc. was observed to be higher in these areas than in the others. Moreover, it was observed from the physical conditions of the collected plastic debris that the plastic food wrappers were newly introduced in to the site. When all these factors are considered, it can be stated that the high marine litter density at the site 1, 2, 3, 4, 31, 32, 33, and 34, which are located around the east part of the Marmara Sea, was not remarkable (Figure 1). The relatively higher litter density around the sites 10 and 11 (in the northwest part) may have arisen from the current system. Owing to the low population in the Northeastern Marmara Region, the absence of streamflow, and relatively fewer industrial activities, the litter may be carried to the area by currents. Although lower litter density was detected around the Southwestern Marmara Sea, relatively higher litter was found at the sites 13 and 15, which is under the incessant influence of the Gönen Stream. The Gönen Stream may have transported the landfills to the sea. Besides, a great number of fishing vessels operate in this area. Thus, fishing vessels may be contributing to the increasing population density.

Besides, the temporal variations in the litter abundance serve as a warning for the managing authorities. Compared with the rates in 2017, a statistically significant increase was detected in the litter abundance in 2018. A relatively higher litter abundance was observed in the spring and summer of 2018. Possible reasons should be the growing population, increasing recreational tours on the Bosphorus in these two seasons, and higher discharge of the Dilovası Stream with the rain-induced faster-flowing currents in spring. Conversely, commercial legal fishery is prohibited between April and August, when the highest pollution was observed. Thus, it may be argued that fishing can be thought to be a secondary pollution source after tourism and population.

The spatial and temporal variations in the mean litter abundance were compared with those in the other areas. In this study, 246 trawl tows yielded a total of 660 litter items (n), weighing 434.9 kg, at 34 sites in the Marmara Sea. 32 of 34 sites were found to contain benthic litter. The mean litter abundance was calculated to be 136.7 n/km^2 and 90.1 kg/km^2. In two recent studies, Mancini et al. (2021) have recorded the benthic litter density between 312.5 and 2125 n/km^2 around the Northern Tyrrhenian Sea, Italy and Saladié and Bustamante (2021) report the same parameter to occur between 71.5 and 192 n/km^2 around the Gulf of Sant Jordi (Western Mediterranean Sea). Relatively few studies have been conducted on the benthic litter abundance in Northern Turkey. The studies were mostly centred around the Mediterranean coasts of Turkey (Büyükdeveci and Gündoğdu, 2021; Mutlu et al., 2020; Olguner et al., 2018; Gündoğdu et al., 2017; Eryaşar et al., 2014). Erüz et al. (2022) and Topçu and Öztürk (2010) have conducted a research study in the Black Sea and Gönülal et al. (2016) in the vicinity of the Gökçeada (Imbros) Island, the North Aegean Sea. A similar sampling method was used in these two studies (Table 4). High litter densities are reported in all the studies conducted in Turkish seas. Compared with the density values in the present study, the litter density has been found to be lower in the Antalya Bay, Turkey (Olguner et al., 2018), while higher in the İskenderun Bay, Turkey (Büyükdeveci and Gündoğdu, 2021). However, higher benthic litter density is featured in the studies performed in the Black Sea (Topçu ve Öztürk, 2010; Erüz et al., 2022). Among all the studies conducted in the Turkish waters, the lowest benthic litter density has been recorded around the Gökçeada Island, the Northeastern Aegean Sea Gönülal et al. (2016). This may have stemmed from a relatively lower population and the absence of industrial facilities on the Gökçeada Island. It is known that the coastline of the Northeastern Marmara Sea is among the most polluted areas in Turkey. This is one of the reasons why higher litter density rates are observed in the respective areas. For instance, the litter groups plastics and rubber tyres were determined to be most abundant in terms of count and weight. These results corroborate the data in the previous studies.

Table 4. Spatial and temporal variations of litter abundance in the other areas

Authors	Sampling Year	Study Area	Sampling Type	Density		Major Pollutant
				n/km²	kg/km²	
Topçu and Öztürk (2010)	2007-2008	Western Black Sea	Bottom Trawl	128 - 1320	8 - 217	Plastics
Büyükdeveci and Gündoğdu (2021)	2009-2010	İskenderun Bay, Northeastern Mediterranean	Bottom Trawl	Mean: 450.94	Mean: 90.34	Plastics
Gönülal et al. (2016)	2013-2015	Gökçeada Island	Bottom Trawl	0 - 1.6		Plastics
Olguner et al. (2018)	2014-2015	Antalya Bay, Northeastern Mediterranean	Bottom Trawl	13.3 - 651.1	0.02 - 559	Plastics
Erüz et al. (2022)	2016	Southern Black Sea	Dredge and	460.7	80.68	Plastics
This Study (2022)	2017-2018	Marmara Sea	Bottom Trawl	27.5 - 662.2 (Mean:73.9)	0.03 - 1597.8 (Mean:48.7)	Plastics
Mutlu et al. (2020)	2019	Southeastern Aegean Sea	SCUBA	19	18	Plastics
Mancini et al. (2021)	2020	Northern Tyrrhenian Sea	Bottom Trawl	312.5 - 2125		Plastics
Saladié and Bustamante (2021)		Gulf of Sant Jordi (Western Mediterranean Sea)	Bottom Trawl	71.5 -192 (Mean:130)		Plastics

In recent years, people in Turkey and in the world have gained a better awareness of marine pollution. Some good regulations have been enforced in Turkey, such as automated garbage collectors, paid shopping bags, etc. The European Union (EU) projects such as MARLISCO and Clean Up Med are good practices that aim to motivate people to act more responsibly and make them more aware of the marine pollution-related damages. Besides, some state-funded projects (Zero Waste Blue Project; Regional Waste Management and Marine Litter Action Plan) have been implemented, e.g., to collect ghost fishing nets and garbage collection on the coasts of 28 Turkish provinces. Additionally, non-governmental organizations such as BORABDER, TÜDAV, Mediterranean Conservation Society actively work in this field. Contrary to these, nowadays the Marmara Sea suffers from marine mucilage and/or sea snot, and the mucilage is expanding to cover larger areas day by day. Mucilage is defined as phytoplankton exudation of photosynthetically-derived carbohydrates with a structure consisting of exopolymeric compounds with highly colloidal properties released from marine organisms under stressful conditions (Danovaro et al. 2015). Although environmental pollution is listed as a primary cause, natural factors and hydrological conditions are regarded as important (Mecozzi et al., 2012). Even though it is known that benthic litter and mucilage are not directly related, bottom environments covered with benthic litter and mucilage combined create more problems for benthic creatures. Owing to mucilage-covered benthos, the potential food items of demersal fish disappear. Besides, accumulated mucilage asphyxiates less mobile organisms (e.g., crustaceans, coelenterates, and molluscs) and clogs their siphons and burrow openings (Rinaldi et al. 1995; Pellegrini et al. 2003).

Consequently, it is stated that all stakeholders who contribute to this pollution should be informed of the possible dangers of marine pollution. Water resources protection education should be offered at primary schools. Besides, Turkey should immediately desist from importing plastic items from developed countries. Annex V–Prevention of Pollution by Garbage from Ships–of MARPOL (International Convention for the Prevention of Pollution from Ships) prohibits commercial vessels from disposing of all forms of plastics into the sea. Annex V should be applicable to fishing vessels as well. As Wang et al. (2014) state, a reward system may be implemented to collect and deliver vessels' solid waste in inland and international seas. Coastal tourism areas and facilities, such as beaches and cafes, should be inspected and kept under constant control, and administrative sanctions should be increased.

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AUTHORSHIP CONTRIBUTIONS

All authors contributed to the idea and design of the study. Material preparation and investigation were performed by Ali İşmen, Mukadder Arslan İhsanoğlu, Murat Şirin and İsmail Burak Daban. The writing/editing was carried out by İsmail Burak Daban and Mukadder Arslan İhsanoğlu, and all authors have read and approved the article.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest or competing interests.

ETHICS APPROVAL

No specific ethical approval was necessary for this study. We have research permission from the Ministry of Agriculture and Forestry General Directorate of Fisheries and Aquaculture with 67852565-140.03.03-E.121379 number and 11/01/2018 date.

DATA AVAILABILITY

The data sets generated during and/analyzed during the current study will be provided by the corresponding author upon the request of the editor or reviewers.

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