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From source to sink: A comparative study of streamside and beach litter in the Black Sea

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ABSTRACT

The increasing amount of marine litter pollution and its impact on the marine environment raises global concern. This study aims to reveal the effect of streams on marine litter density and composition. A total of ten stations on the southeastern Black Sea and six stations on the Manahoz stream were seasonally surveyed. The litter density ranged between 0.838 ± 0.33 and 4.01 ± 0.55 items/m^2 in the beach stations, and 0.93 ± 0.27 2.40 ± 2.18 items/m^2 in the streamside stations. No significant difference was determined among the seasons for both beach and streamside (Kruskal-Wallis test, $p > 0.05$). On the other hand, the litter density was also similar in beach and streamside stations in the same season. The litter composition consisted of > 75% plastic. Principal component analysis and PERMANOVA determined no significant difference in litter composition among beach and streamside stations. The litter items mostly consisted of single-use items. Among them, plastic beverage containers were the most abundant litter subcategory during the study (ranging between 18.79% and 34.50%). The subcategory composition exhibited a significant difference among beach and streamside stations (ANOSIM, $p < 0.05$), which was mainly explained by plastic pieces, beverage containers, and foams according to SIMPER analysis. Personal protection equipment that was not reported before the COVID-19 pandemic emerged. The results of our study can be used for marine litter modeling studies and legislation for restriction or ban of most abundant single-use litter items.

1. Introduction

Marine litter has become a global concern in the last decades with growing research on the subject. Comprehensive studies were conducted on the distribution, composition, and effects of litter items in the marine environment. So far, it is known that marine litter exists in every part of the oceans (Haarr et al., 2022). In addition, current policies and other initiatives are appeared to be insufficient to tackle the problem which requires a unified approach to the solution (Rangel-Buitrago et al., 2022). Reduction at source is one of the long-term solutions. Thus, identifying the composition of litter items would help management, reduction, and mitigation practices.

Coastal areas and rivers are known as the most densely populated areas where two-thirds of the world's population live within 100 km of the coastline. Human activities in this region have significantly contributed to the abundance of anthropogenic litter in the marine environment and brought the term marine litter (Castro-Jiménez et al., 2019; Schmidt et al., 2017). Marine litter is transported from the land to the marine environment by wind, rain, streams, storm events, sewage pipes, direct discharge from ships, and fishing activities etc. (Ioakeimidis et al., 2014; E. O. Okuku et al., 2021; Rech et al., 2014; Sadri & Thompson, 2014). Litter in coastal areas is abundant due to recreational activities, illegal dumping, and high riverine input (Lechner et al., 2014; Morritt et al., 2014; Wei et al., 2012).

The Black Sea has a limited habitable water mass due to the hydrogen sulfate (H_2S) layer starting 100–150 m depth. The contamination of habitable surface layer is a major threat. The Black Sea receives pollutants from the largest rivers of the Europe (Danube, Dnieper, and Don). Moreover, the Turkish Black Sea rivers has also received high pressure from human activities for decades (Sezgin et al., 2017). Development for settlements, sand mining, hydroelectric power, etc. in the watershed are some examples. Solid waste dumping on riverbeds

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and coastal zones is not allowed by regulation. However, due to the low levels of enforcement, public awareness, inappropriate disposal, collection and, storage; solid waste, and wastewater are disposed of indiscriminately into the watershed and follow the river flow to the sea (Berkun et al., 2005).

Efforts to collect marine litter data in the southeastern Black Sea have been conducted on beaches (Terzi et al., 2020; Terzi & Seyhan, 2017; Topçu et al., 2013), sea surface (Suaria et al., 2015), and seafloor (Erüz et al., 2022; Topçu & Öztürk, 2010). Riverine outflows have a considerable impact on litter pollution in the Black Sea (Stoica et al., 2020). However, their contribution to marine litter in the Black Sea has not been researched. Previous studies have examined the composition, density, and possible sources of marine litter in a short and extended period on the southeastern Black Sea coast (Erüz & Özşeker, 2017; Terzi et al., 2020; Terzi & Seyhan, 2017). However, litter studies in the inland water ecosystems are lacking (Çevik et al., 2021), although, rivers are known to be one of the major sources (Lebreton et al., 2017; Meijer et al., 2021; E. O. Okuku et al., 2022). To our best knowledge, this is the first study comparing the riverine and beach litter density and composition in the Black Sea. The main objective of this study is to evaluate the abundance and composition of the anthropogenic litter found on the Manahoz stream and Sürmene-Of coasts and understand the possible composition overlaps. The litter density and composition are crucial information for future actions on solid waste management, mitigation, and reduction in the area.

2. Materials and methods

2.1. Study area

The study area is situated on the southeastern Black Sea coast of Türkiye. The southeastern Black Sea region is geographically characterized by narrow coastal areas. Most of the settlements and public facilities were built in the coastal area and riverbanks. Local people are depending on natural resources like the soil and the sea for a living. The area is dominated by the fishing, aquaculture, boat industry, agriculture, and seasonal tourism activities. The Manahoz stream is one of the biggest streams in the eastern Black Sea region of Türkiye (Satılmış, 2015) and connects to the Köprübaşı district upstream. There is also a hydroelectric plant on the stream. The downstream of Manahoz stream is in the district of Surmene, inhabited by a population of 26,161. Of district is in east of Sürmene district and inhabited by 44,212 people. The district is one of the popular touristic destinations during summer and holidays by domestic and international tourists. The city centers of districts Sürmene and Of are situated in the coastal area. Likewise, the center of Köprübaşı is on the riverbank.

2.2. Litter collection and classification

In this study, marine litter survey locations are divided by beach and stream. The Manahoz stream in Sürmene was selected as a sampling area for marine litter in the stream as it is one of the biggest and most significant discharges in the region. The sampling station's distance ranges up to 25 km upstream of the Manahoz stream (M0 to M5). The transect length of the sample stream varies between 5 m and 10 m depending on the width of the streambed. While the sampling stations distance on Sürmene and Of coasts ranges from 1 km up to 22 km from the Manahoz stream (M0 to O5). Data stations were defined by location, in particular distance to the stream mouth.

Four seasonal sampling surveys were conducted during the period of Autumn 2020 to Summer 2021. Before the seasonal samplings an initial cleaning was conducted in Summer 2020. Marine litter samples have been collected from ten data stations along Surmene and Of coasts and six data stations along the Manahoz stream. Except for stations M4 and M5, data collection was not carried out during winter due to the blockage of access by ice snow. The marine litter survey location on the stream and beach is given in Fig. 1.

All anthropogenic litter found on the transect at each station within the area of 50 to 100 m^2 was collected depending on the coast width, visually identified and weighed. The litter items between the shoreline and tideline in the beach stations and, from streamside to vegetation zone in the stream stations were collected. Natural litter (i.e., seaweed, animal bones, wood) and buried litter items were not counted. Litter items greater than 2.5 cm were counted, and categorized into nine categories (plastic, rubber, cloth, wood, paper, metal, glass, sanitary, and medical waste) and 42 subcategories. Then, categorized litter items were separately weighed. Few of the litter items were wet, especially the litter items which can soak water such as cloth and paper were squeezed to remove the excess water. The collected litter items were removed from the stations after each survey.

2.3. Data analyses

The normal distribution of the density by number and weight data was tested with the Shapiro-Wilk test by using *shapiro.test()* function from base R. Due to the data failing the normality test, nonparametric tests; the Kruskal-Wallis test and Mann-Whitney *U* test were used to compare the density by number and weight between the stations and seasons using *kruskal_test() and wilcox.test()* functions from base R respectively. Following a significant difference determined by the Kruskal-Wallis test, Dunn's post hoc test was used to determine the differing station or season using *dunn_test()* function from *rstatix* (Kassambara, 2021) package. *PCA()* function from the FactoMineR (Husson et al., 2016) and fviz_pca_biplot() from factoextra (Kassambara & Mundt, 2017) packages were used for Principal Component Analysis (PCA) and drawing the PCA biplot respectively. was used to visualize the overlap of litter composition of beach and streamside stations. For further analysis of the litter composition, the data were subjected to permutational multivariate analysis of variance (PERMANOVA) to determine the difference between beach and streamside stations. Litter sub-category data were subjected to ANOSIM and SIMPER tests respectively to determine composition difference and the contribution of litter subcategories to the difference. The data analyses and visualizations were performed using R programming language (ver. 4.2.0) (R Core Team, 2022) packages; *rstatix* (Kassambara, 2021), *vegan* (Oksanen et al., 2020), *factoextra* (Kassambara & Mundt, 2017), and *ggplot2* (Wickham, 2016). The data were expressed as mean ± standard error of the mean.

3. Results

3.1. Litter density

During our seasonal surveys, 11,249 litter items weighing 313.02 kg were collected and removed from the stations. Of these 9389 items (214.76 kg) were from the beach and 1860 items (98.26 kg) were from the streamside stations.

3.1.1. Beach stations

The highest average litter density in terms of number was estimated at O3 (4.01 + 0.55 items/m^2), followed by O5 (3.52 ± 1.02 items/m^2), and O1 (3.14 ± 2.42 items/m^2) while the lowest average densities estimated at S3 (1.83 ± 1.23 items/m^2), S1 (1.04 ± 0.23 items/m^2), and S5 (0.838 ± 0.33 items/m^2). There was a significant difference in litter density among the stations (Kruskal-Wallis, $\chi(9) = 20.65$, $p < 0.05$). Dunn's test determined a significant difference only between O3 and S5 which were the most and less polluted stations respectively. The highest litter densities by number in the beach stations were estimated at O4 (7.33 items/m^2), O1 (6.55 items/m^2), O5 (4.85 items/m^2), and O3 (4.78 items/m^2) in autumn, respectively (Fig. 2A). A seasonal assessment of the litter density revealed that the seasonal overall highest average litter density was estimated in autumn (3.47 ± 2.35 items/m^2), winter (2.34

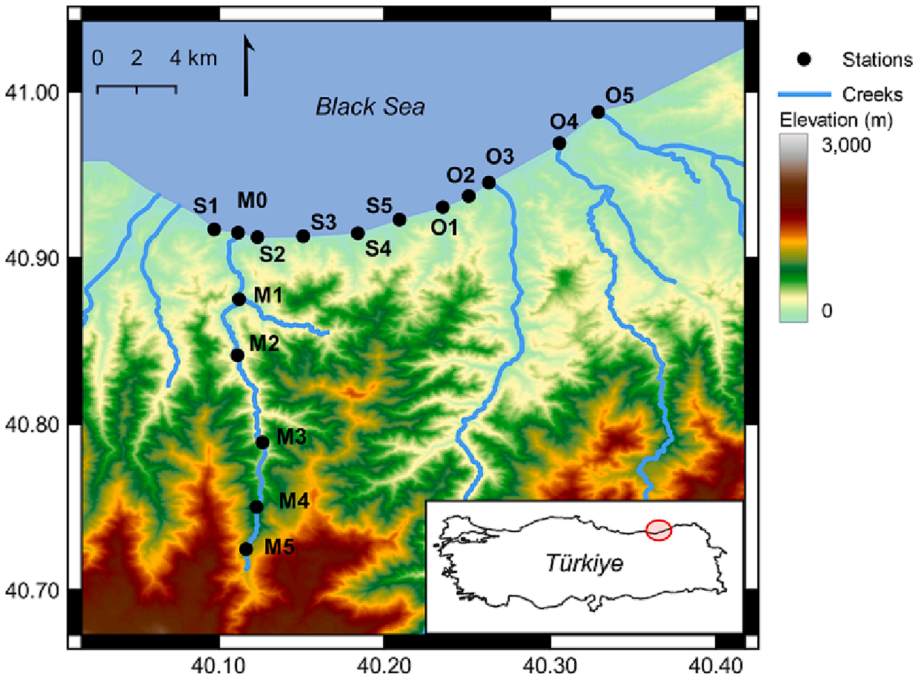


Fig. 1. Map of the study area and the sampling stations. The stations marked with S, O, and M are in Sürmene district, Of district, and Manahoz Stream respectively.

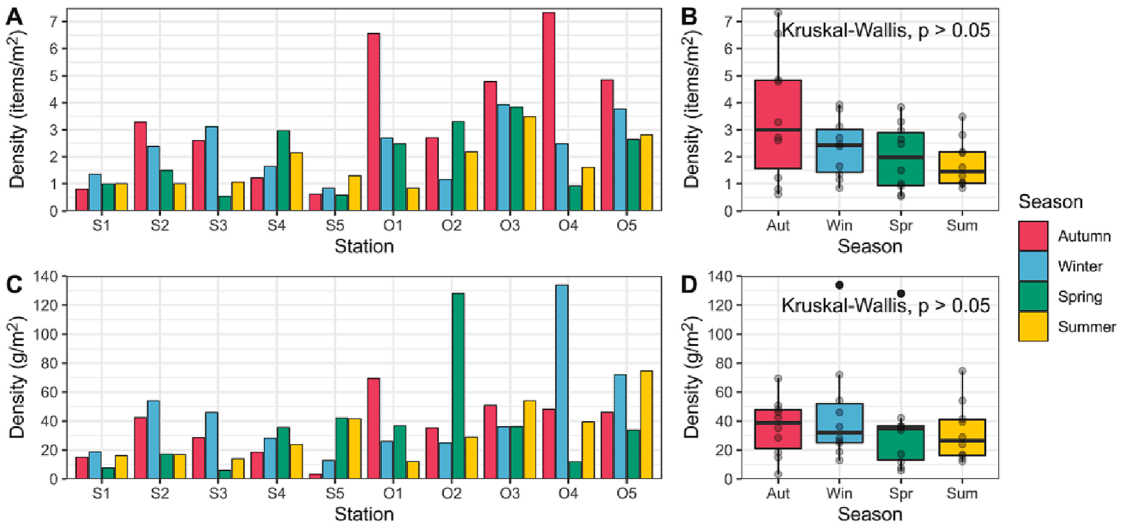


Fig. 2. The seasonal litter density at beach stations by number (A) and weight (C). The comparison of the litter density by number (B) and weight (D) among the seasons at beach stations.

± 1.07 items/m^2), spring (1.98 ± 1.21items/m^2), and summer (1.75 ± 0.87 items/m^2). However, there was not a significant difference between the seasons by number (Kruskal-Wallis, $\chi(3) = 3.20$, $p = 0.36$) (Fig. 2B). In terms of weight, the denser stations were O4 (89.45 ± 26.42 g/m^2), O3 (89.38 ± 13.11 g/m^2) S2 (72.81 ± 16.63 g/m^2), and O5 (70.71 ± 21.69 g/m^2). Kruskal-Wallis test determined no statistical difference in density among the stations ($p > 0.05$). However, the litter abundance by weight did not show a similar pattern as the density by number among the seasons. It is worth mentioning that the tires were assessed as outliers and excluded from the calculations. The highest weight per square meter was estimated at O4 (133.76 g/m^2) in winter, followed by O2 (128.03 g/m^2) in spring, O5 (74.53 g/m^2) in summer, and O5 (71.86 g/m^2) in winter (Fig. 2C). The density did not show a significant difference among the seasons (Kruskal-Wallis test, $\chi(3) = 1.72$, $p = 0.63$) (Fig. 2D).

3.1.2. Streamside stations

The highest litter densities by number were estimated at M0 (5.62 items/m^2) in autumn, M5 (4.36 items/m^2) in autumn, and M2 in summer (2.88 items/m^2), winter (2.76 items/m^2) and spring (2.76 items/m^2) (Fig. 3A). The average density in each station over the seasons from high to low was 2.40 ± 2.18 items/m^2 (M0), 2.33 ± 0.94 items/m^2 (M2), 2.08 ± 2.02 items/m^2 (M5), 1.43 ± 0.71 items/m^2 (M4), 1.13 ± 0.81 items/m^2 (M3), and 0.93 ± 0.27 items/m^2 (M1) which were not statistically significant (Kruskal-Wallis test, $\chi(5) = 4.58$, $p = 0.47$). The highest average litter density was estimated in autumn (2.66 ± 0.80 items/m^2), followed by summer (1.50 ± 0.29 items/m^2), winter (1.30 ± 0.51 items/m^2), and spring (1.26 ± 0.37 items/m^2). Comparing the seasons in terms of litter density by number did not result in a significant difference (Kruskal-Wallis test, $\chi(3) = 3.20$, $p = 0.36$) (Fig. 3B). The litter density by weight was much higher at M2 (153.88 g/m^2) in

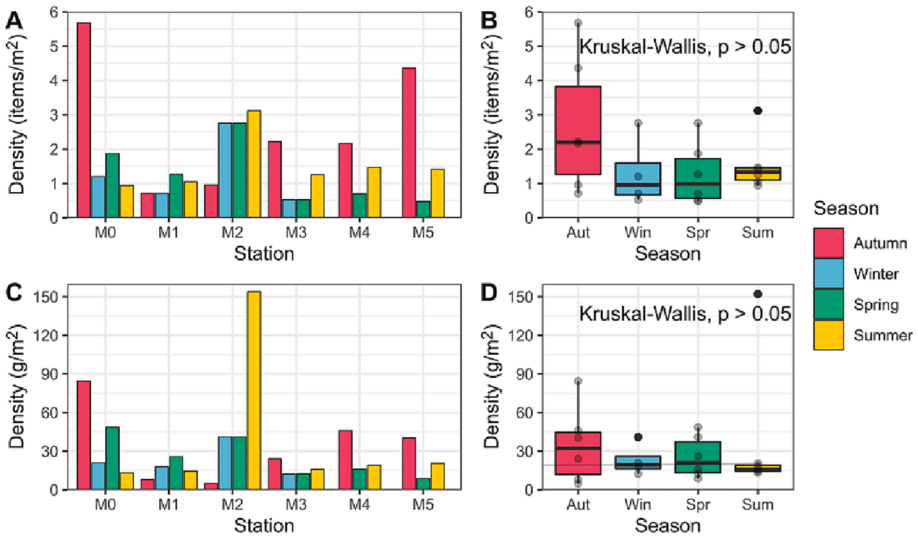


Fig. 3. The seasonal litter density at streamside stations by number (A) and weight (C). The comparison of the litter density by number (B) and weight (D) among the seasons at streamside stations.

summer. The other highest stations were M0 in autumn (84.54 g/m^2) and spring (48.58 g/m^2) (Fig. 3C). The mean litter abundance by season was 39.53 ± 22.90 g/m^2 in summer, 34.66 ± 12.04 g/m^2 in autumn, 25.46 ± 6.60 g/m^2 in spring, and 23.03 ± 6.25 g/m^2 in winter from high to low. The litter densities by weight were found to be similar among the seasons (Kruskal-Wallis test, $\chi(3) = 0.11$, $p = 0.92$) (Fig. 3D).

The litter density in beach and streamside stations by number varied between 1.74 ± 0.28 items/m^2 to 3.47 ± 0.74 items/m^2 and 1.26 ± 0.37 to 2.66 ± 0.80 items/m^2 among the seasons respectively. Relatively the highest densities in terms of the number were estimated in autumn (Fig. 4). However, there was no significant difference between the seasons for both beach and streamside stations (Kruskal-Wallis test, $p > 0.05$). The estimated average densities in terms of weight ranged between 32.10 ± 6.43 g/m^2 to 45.19 ± 11.33 g/m^2 for beach stations and 16.65 ± 1.12 g/m^2 to 34.66 ± 12.05 g/m^2 for the streamside stations (Fig. 4). Density by weight did not show a significant difference among the seasons as well (Kruskal-Wallis test, $p > 0.05$). Although the average litter density was relatively higher in the beach stations in each season, it was found to be similar at the beach and streamside stations (Mann-Whitney *U* test, $p > 0.05$) (Fig. 4).

3.2. Marine litter classification

The average overall litter composition in the beach and streamside stations was dominated by plastic, metal, paper, and cloth. Overall, 80.49 ± 1.18% of the beach, and 86.36 ± 2.18% of the streamside litter were consisted of plastics (Table 1). On the other hand, paper (4.28 ± 0.92% in beach, 5.02 ± 1.90% in streamside), metal (6.63 ± 0.53% in beach, 3.32 ± 0.72% in streamside), and cloth (4.42 ± 0.59% in beach, 3.13 ± 0.52%) exhibited different distributions among the seasons on both beach and streamside (Table 1). The share of plastic items was relatively higher in the streamside stations. Principal component analysis (PCA) biplots explaining > 50% cumulative percentage of variance in each season were constructed. A visually significant overlap in litter composition of beach and streamside stations was observed (Fig. 5). Although the centroids in winter visually exhibited some degree of segregation in Fig. 5, PERMANOVA results revealed that the litter composition was similar in beach and streamside in all seasons ($p >$

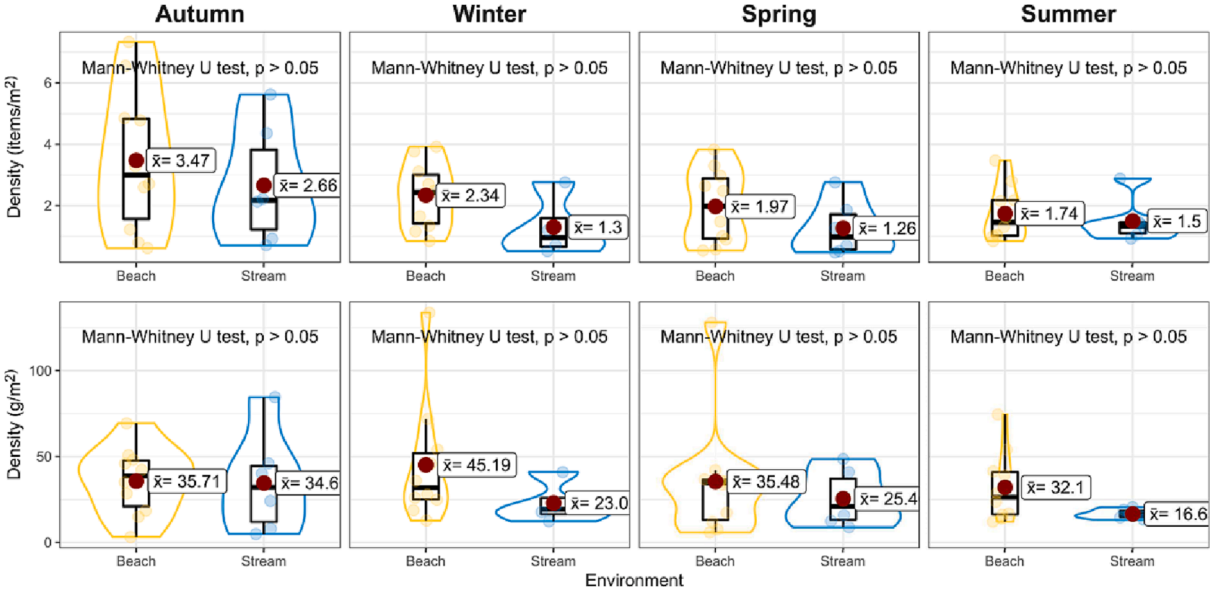


Fig. 4. Comparison of litter density between the beach and streamside. Density by number and weight in each season are placed in top and bottom rows respectively.

Table 1
Composition of the litter items collected from the beach and streamside stations in each season. The numbers in the table represent the percentage of each category by number.

	Beach				Streamside			
Category	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum
Plastic	**76.45**	**82.43**	**81.36**	**81.70**	**80.05**	**90.55**	**90.28**	**84.55**
Bags	5.35	4.91	8.03	5.61	3.41	8.09	17.73	12.09
Beverage containers	18.79	22.26	24.26	18.90	28.78	34.50	25.41	22.32
Caps/lids	0	0.94	2.07	2.00	0.14	4.62	0	0
Cigarette lighters	0.39	0.38	0.40	0.63	0	0	0	0
Cleaner containers	2.25	1.62	3.64	1.95	2.19	0.39	0.70	1.01
Containers / tubes	0	0.94	0.08	0.11	0	0	0.83	0
Cosmetic packages	0.11	0.85	0.51	1.03	0	0	0	0
Cups	13.40	1.54	1.16	0.46	3.48	2.31	5	1.08
Medication containers	0.30	0	1.32	0.86	1.38	0	0	0.24
Engine oil containers and drum	1.28	0.34	0.05	0.17	0	0	0	0
Fertilizer/animal feed	0	0.04	0	0.17	0	0	0	0
Fishing nets	0.16	0.04	0.20	0	0.12	0	0	0
Floats/Buoys	0	0	0	0.11	0	0	0	0
Foam	9.38	11.79	15.51	14.95	11.18	19.69	16.48	19.23
Gloves	1.05	0.30	0.25	0.46	0.62	0.39	0	0.72
Hanger	0	0	0	0.11	0	0	0	0
Hard Plastics	1.55	0.81	0.05	2.86	0.70	0	1.76	1.44
Mask	0.67	2.14	3.20	5.04	2.95	8.22	5.75	4.27
Other bottles, containers, and drums	3.89	2.73	0.62	3.72	4.11	1.16	1.76	3.99
Other sanitary items: cologne	0	0	0.20	0.11	0	0	0	0
Other sanitary items: wet wipes	0.02	0	0.35	1.37	2.11	0	0	0
Packages	2.50	7.69	1.21	0.97	1.16	1.63	5.06	4.59
Pipes	0.37	0.26	1.60	2.12	0.25	0.77	0.70	0.58
Plastics pieces	12.88	19.22	12.44	15.41	13.22	1.93	1.49	3.27
Razor	0	0	1.11	0	0	0	0	0
Rope	0	0.34	0.20	0.23	0	1.93	1.05	0.87
Sacks	1.50	1.50	0.86	0.46	4	4.92	6.17	5.17
Sanitary pad	0	0	0	0.11	0	0	0	0
Strapping bands	0	0	0	0	0	0	0	0
String cord	0	0	0.30	0.46	0	0	0	0
Syringes	0	0.13	0.10	0.06	0	0	0	0
Toys & party poppers	0.61	0.98	1.64	1.26	0.25	0	0.39	0
Other sanitary items	0	0.68	0	0	0	0	0	3.68
Paper	**7.20**	**2.09**	**4.09**	**3.72**	**10.81**	**0.77**	**2.72**	**5.80**
Cartons e.g., tetra Pak (other)	2.28	0.73	1.21	1.37	2.29	0	2.19	3.32
Cigarette packets	4.90	0.85	1.67	1.26	8.31	0.77	0.53	2.48
Newspapers & magazines	0.02	0.51	1.21	1.09	0.21	0	0	0
Metal	**7.54**	**6.20**	**5.10**	**7.67**	**4.14**	**4.63**	**0.88**	**3.64**
Big metal pieces	0	0.09	0.10	0.23	1.49	0	0	0.87
Bottle caps	0	0	0.05	0.11	0	0	0	0
Drink cans	7.40	3.80	2.87	6.01	0	0	0	0
Electric appliances	0.02	0.43	0.10	0.34	0.75	0	0.18	0.58
Food cans	0	0.17	0.66	0.29	0.28	4.24	0.44	0.6
Other metal pieces	0.12	1.71	1.32	0.69	1.62	0.39	0.26	1.59
Cloth	**4.77**	**6.16**	**3.08**	**3.67**	**1.82**	**2.91**	**4.75**	**3.04**
Bags	0.09	0.09	0.05	0.06	0	0	0	0
Clothing	0.47	1.24	0.15	0.69	0.58	1.71	2.00	1.65
Other textiles	2.58	1.20	0.91	1.32	1.24	1.20	1.43	1.39
Shoes/sandals	1.63	3.63	1.97	1.60	0	0	1.32	0
Glass	**1.62**	**1.33**	**4.56**	**1.60**	**2.11**	**1.16**	**0.66**	**0.69**
Glass bottles	1.62	0.94	3.14	0.57	2.03	1.16	0.66	0.69
Jar	0	0.13	0.61	0.74	0	0	0	0
Other glass items	0	0.26	0.81	0.29	0.08	0	0	0
Rubber	**2.43**	**1.15**	**1.57**	**0.8**	**0.97**	**0**	**0.13**	**1.84**
Other rubber pieces	2.40	0.98	1.32	0.63	0.14	0	0	0
Tires	0.03	0.17	0.25	0.17	0.83	0	0.13	1.84
Wood	**0**	**0.64**	**0.20**	**0.80**	**0.08**	**0**	**0.57**	**0.47**
Processed wood	0	0.64	0.20	0.80	0.08	0	0.57	0.47

0.05).

Litter subcategories were evaluated to further analyze the litter diversity between the beach and streamside. Plastic beverage containers were the most common sub-category in the beach and streamside which consisted of 18.79% to 34.50% of the total litter items (Table 1). Following the plastic beverage bottles, plastic pieces (14.99 ± 1.56%), foam (12.90 ± 1.43%), bags (5.97 ± 0.70%), and drink cans (5.02 ± 1.03%) were the most common sub-categories in beach stations. On the other side, foam (16.64 ± 1.96%), bags (10.33 ± 3.03%), face masks (5.30 ± 1.13%), and sacks (5.07 ± 1.13%) were the most dominant sub-categories in the streamside stations. The litter subcategory composition was found to be significantly different between the beach and streamside stations (ANOSIM, $R = 0.69$, $p < 0.05$). Following a significant ANOSIM, the SIMPER test revealed a 51.27% overall average dissimilarity in litter subcategory composition. Plastic litter items appeared to be the prominent contributor to the difference in composition. The first three contributors were plastic pieces, beverage containers, and foam which were higher in the beach stations (Table 2). The average Shannon index on the beach (2.76 ± 0.04) was higher than on the streamside (2.44 ± 0.10) (*t*-test, $t = 3.08$, $p < 0.05$) which indicates the litter

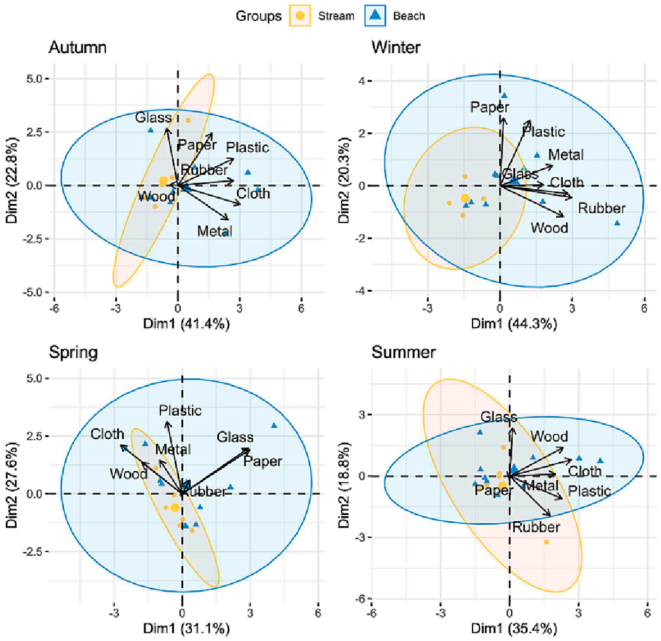


Fig. 5. Principal component analysis (PCA) biplots showing the litter composition overlap of beach and streamside in each season.

diversity was higher in the beach stations.

4. Discussion

The litter density showed a high variation between the beach stations during the study (Fig. 2A, B). A higher density of litter items was recorded at the beach stations located in the eastern part of the study area (O1 to O5) (Fig. 2A). Those stations are under the effect of streams other than the Manahoz stream (Fig. 1) which can be also considered marine litter sources. Additionally, the easterly prevailing rim current with 50 km width in the coastal area of the Black Sea (Özsoy & Ünlüata, 1997; Staneva et al., 2001) can transport the floating litter items entering the marine environment from western part of the study area. We suggest that these two factors are the main drivers of higher litter density in the eastern part of the study area. Previous studies focusing on the benthic marine litter (Erüz et al., 2022) and beach marine litter (Terzi & Seyhan, 2017) covering the eastern Black Sea coast of Tukey including our study area reported an increasing trend in litter abundance from the west to east as well. On the other side, Topçu et al. (2013) reported an increasing litter density from east to west on the southwestern Black Sea coast which was attributed to local coastal anticyclonic eddies. Although the litter density was different among the stations, no significant difference was determined between the seasons. A relatively higher litter density was observed in autumn as reported by (Terzi & Seyhan, 2017). The previous studies conducted on the eastern part of the Black Sea documented no significant difference in marine litter density among the seasons (Oztekin et al., 2020; Terzi & Seyhan, 2017). Contrarily, seasonal variations in marine litter density were reported from the western side of the Black Sea. Topçu et al. (2013) demonstrated significantly higher marine litter density in autumn which was attributed to intensive fishing activities during the season. The other study conducted on the Bulgarian coast of the Black Sea indicated that the marine litter density peaked in the summer due to recreational and touristic activities (Simeonova et al., 2017). From this perspective, the seasonal differences in marine litter density were attributed to human activities. The effect of seasonal changes such as the weather, wind, and currents might be seen in large-scale modeling studies (Macias et al., 2019; Mansui et al., 2020). The permanent circulation systems and winds in the marine environment are one of the main drivers shaping marine litter transportation (Hardesty et al., 2017; Krelling et al., 2017). The circulation systems (Gunduz et al., 2020; Stanev, 1990; Zalesny et al., 2012; Zalesnyi et al., 2016) and winds (Rusu et al., 2014; Rusu & Butunoiu, 2014; van Vledder & Akpinar, 2015) in the Black Sea are well understood. A few studies are simulate the movement of litter items in the Black Sea (Miladinova et al., 2020; Stanev & Ricker, 2019). However, the studies conducted lack abundance and composition data collected from the field studies. The buoyancy of litter items may affect the transportation route in the marine environment (Yoon et al., 2010). Thus, understanding the density and composition of litter items transported by rivers is vital for more consistent simulation studies to predict marine litter transportation in the Black Sea.

Rivers and streams are considered as one the major contributors to marine litter (Rech et al., 2014; Schmidt et al., 2017). The Manahoz stream is one of the streams along the study area that have the potential to transport and be the source of land-based marine litter in the Black Sea (Erüz & Özşeker, 2017; Rech et al., 2014; Simeonova & Chuturkova, 2019). The overall highest average litter density was estimated at the mouth of the stream (M0). Bruge et al. (2018) determined a significant decrease in litter density with distance from the river mount in Adour River (Southwest France). Although a relatively decreasing trend from the river mouth to upstream was observed as expected in our study, the spearman rank correlation determined no significant relationship between the distance from the stream mount and litter density ($p > 0.1$). The litter density at the streamside stations was also found to be statistically similar. That is likely because of direct discharges from the dispersed settlements along the basin. Station M2 is in one of the largest settlements in the basin, so the litter density was the highest due to direct discharge from the surrounding houses. A relatively higher litter

Table 2
SIMPER results of overall litter sub-category composition.

Material	Sub-category	Av. dissim	Contrib. %	Cumulative %	Mean Beach	Mean Streamside
Plastic	Plastic pieces	8.90	17.37	17.37	3.53	0.66
Plastic	Beverage containers	7.71	15.04	32.41	4.96	2.60
Plastic	Foam	4.61	8.99	41.39	2.92	1.46
Metal	Drink cans	3.63	7.09	48.48	1.27	0
Plastic	Cups	2.96	5.77	54.25	1.33	0.29
Plastic	Bags	1.86	3.62	57.87	1.39	0.86
Plastic	Packages	1.78	3.48	61.34	0.77	0.27
Paper	Cigarette packets	1.65	3.22	64.57	0.61	0.41
Cloth	Shoes/sandals	1.50	2.92	67.49	0.52	0.03
Plastic	Other bottles, containers, and drums	1.42	2.76	70.25	0.69	0.31
Plastic	Cleaner containers	1.33	2.59	72.84	0.56	0.13
Rubber	Other rubber pieces	0.97	1.89	74.72	0.35	0.01
Glass	Glass bottles	0.89	1.73	76.45	0.38	0.13
Plastic	Hard Plastics	0.79	1.55	77.99	0.31	0.09
Plastic	Sacks	0.77	1.50	79.49	0.28	0.46
Plastic	Face mask	0.77	1.50	80.99	0.56	0.43

density in autumn was determined similar to the beach stations, but the difference among the season was not significant.

The litter density in streamside and beach stations was seasonally compared. Considering the marine environment as a sink for the marine litter higher litter density is inevitable. However, although the litter density was higher at the beach stations, the observed difference between beach and streamside stations was not significant (Fig. 4). There are more factors affecting the transportation of litter in the marine environment compared to the stream. Large dispersal areas and a variety of effecting factors in the marine environment can be the cause of fewer litter items per unit area.

PCA and PERMANOVA results indicated that the litter material composition was similar among the beach and streamside (Fig. 5). This result provides strong evidence that the litter composition in the coastal area is highly influenced by riverine inputs in the area. Beach and streamside litter sampling revealed that plastic was the most abundant type of litter item in the area, representing>75% of the collected items. Plastic pollution in the marine environment has been long recognized as a serious environmental problem all over the globe (Pawar et al., 2016; Rochman et al., 2016). Its ecological, social, and economic impacts have been comprehensively documented (Beaumont et al., 2019). Previous studies reported marine litter is dominated by plastic in the Black Sea (Erüz et al., 2022; Ioakeimidis et al., 2014; Miladinova et al., 2020; Ozturk and Altinok, 2020; Topçu and Öztürk, 2010) as well. Besides, the microplastic studies in the Black Sea revealed that most of the particles were fiber and fragments (Eryaşar et al., 2021, 2022; Gedik & Eryaşar, 2020; Gedik & Gozler, 2022; Terzi et al., 2022) which are generally resulted from washing machines and decomposition of larger plastic items in the marine environment respectively. The abundance of plastic pieces and foams among the top five litter found on beaches and streamside is believed to be the result of bigger plastic. This litter is the result of the disintegration of larger plastic items due to weathering and other meteorological conditions. The litter can easily be transported by winds, rains, and waves from a distant area and enter the marine environment or be washed back to the beach and could be found far away from its primary sources. Thus, understanding the sources, composition, and density transported by the rivers and streams is crucial for the management and reduction of plastic waste in the Black Sea.

The litter composition by subcategories exhibited statistically significant differences among streamside and beach. Plastic beverage containers were found to be the most abundant among the litter subcategories contributing approximately 20% of the total litter in the stations. Plastic water bottles, especially the 500 ml ones are being used commonly in which was reflected in the litter composition. SIMPER test revealed the subcategories causing the difference (Table 2). Accordingly, plastic pieces, beverage containers, and foams were the subcategories highly contributing to the difference in composition. Beverage containers and foams were comparatively higher in the streamside stations. These are highly buoyant items that can be easily transferred to the marine environment. During our surveys, it was observed that these items accumulate in certain areas in the streamside and are transported to the sea during high flow. The high number of plastic pieces in the beach stations is an indicator of the physical fragmentation of the large plastic items in the marine environment which may result in secondary microplastics in the long term and contaminate the coastal areas (Yazir et al., 2022). The subcategory composition gives a point of view on the human activities in the area. For instance, sacks which are originated from agricultural activities were higher in the streamside stations. They are generally stuck between the rocks or tree roots and branches and decompose over time. These can contribute to the fiber microplastics in the area which were abundant in the Black Sea (Terzi et al., 2022). The other notable observation during our study was the sudden increase of the facemasks, gloves, syringes, and medication containers. In the previous studies conducted on the coastal area of the Black Sea, such items were not reported or very rare, however, during the pandemic COVID-19 pandemic, a significant increase in personal protective equipment (PPE) was observed (Terzi et al., 2020; Terzi & Seyhan, 2017). Strict measures taken during the COVID-19 increased the use of PPE. Therefore, a significant increase of PPE in the marine litter was expected (Canning-Clode et al., 2020). Several studies proved the litter composition change during the pandemic. Recent study by Özşeker et al. (2022) comprehensively reported the litter composition change in inland waters during COVID-19. Similarly, COVID-19 related litter items were increased during the pandemic in marine coastal areas (Okuku et al., 2021). The PPE was found to be sourced from beach visitors and related to release of microplastics, transportation of alien species, and release of chemical pollutants (De-la-Torre et al., 2021).

5. Conclusions

This research provides a comprehensive comparison of litter density and composition in the marine and stream environments. The litter density and material composition were similar for the beach and streamside which indicates the contribution of streams to the marine litter. The litter items mostly consisted of single-use items. The composition of litter items can be a baseline for the restriction or ban of the most common litter items. Furthermore, better waste management, control and increasing local people's awareness are essential to reduce the marine litter. Our findings may support the application of possible mitigation measures to reduce plastic pollution along the Turkish Black Sea coast from streamside and application in the existing Turkish legislation.

The study focuses on comparing stranded litter items on beach and streamside. However, the litter items in the sea environments are subjected to various effects such as currents, winds, and biofouling determining their fate. Those effects were not included in this study. Thus, more comprehensive studies are needed to understand the contribution of the rivers to the marine litter in the Black Sea.

CRediT authorship contribution statement

Coşkun Erüz: Conceptualization, Funding acquisition, Project administration, Writing – review & editing. **Yahya Terzi:** Conceptualization, Methodology, Investigation, Writing – original draft, Data curation, Formal analysis, Visualization. **Neira Purwanty Ismail:** Conceptualization, Methodology, Investigation, Writing – original draft. **Koray Özşeker:** Investigation. **Nurettin Başkan:** Investigation. **Fatma Telli Karakoç:** Funding acquisition, Project administration.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Coskun Eruz reports financial support was provided by European Union.

Data availability

Data will be made available on request.

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