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# Macro- and microplastic abundance from recreational beaches along the South Aegean Sea (Türkiye)

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ABSTRACT

This study aimed to evaluate the abundance and diversity of macro- and microplastics in sand samples collected during summer and winter from eight different beaches used for recreational purposes located on the South Aegean coasts of Türkiye. According to the results, microplastic in fiber shape was dominant on all the beaches. The highest microplastic abundance was determined at Ölüdeniz Kumburnu Beach (360.00 ± 237.66 particles $kg^{-1}$ dw) in summer and at Aktur Beach (358.33 ± 397.24 particles $kg^{-1}$ dw) in winter. A significant positive correlation was found in the winter between microplastic amounts and wind speed. The study area is an important touristic center faraway from major cities and industrial areas. Thus, plastic pollution in this area may be the result of tourism activities in the summer, discharge waters from wastewater treatment plants or transportation by meteorological factors (like waves, wind or river flows).

## 1. Introduction

The term plastic is used to describe a subcategory of a larger class of material, called polymer that can be softened and molded by heating (Derraik, 2002; GESAMP, 2015; Crawford and Martin, 2020). Although most plastics are derived from petroleum and other fossil materials, biodegradable plastics are also obtained from sources such as protein, cellulose and corn starch (Tripathi et al., 2012; Mangaraj et al., 2019; Marichelvam et al., 2019). Global plastic production was 1.7 million tons in total in the 1950s and reached 367 million tons in 2020 (PlasticsEurope, 2008; PlasticsEurope, 2021). Due to the durability and low cost of plastic products, their use has become widespread throughout the world; following this, it has emerged in recent years that they pose a risk to the environment (Pinto Da Costa et al., 2020). Since many plastics are not biodegradable, they can remain in the environment for centuries and continue to pose a threat (Lambert and Wagner, 2017; Gebre et al., 2021).

Several studies in the literature report that 60–95 % of the wastes in the seas around the world consist of plastics (Alessi et al., 2018; Schnurr et al., 2018; Yenici and Turkoglu, 2023). It is estimated that approximately 14 million tons of plastic waste enter the world's oceans annually (IUCN, 2021). Distribution and hotspots/accumulation zones of plastics reaching aquatic ecosystems in different ways are affected by currents, tides, and winds (Galgani et al., 2015; Forsberg et al., 2020). Plastic waste, which has become a major problem in the oceans, especially in coastal areas, causes negative effects on wildlife, fisheries, food security, maritime activities, and tourism (Krelling et al., 2017; IUCN, 2021).

Large plastics lose their structural integrity over time through fragmentation, forming microscopic plastic particles (Barnes et al., 2009). A single macroplastic material can break down to form millions of microplastic particles (Yao et al., 2019). Due to this attitude, plastics are divided in two different categories according to their size: plastic materials with dimensions >5 mm are called "Macroplastic" whereas plastic particles ranging in size from 0.1 μm to 5 mm are defined as "Microplastic" (Driedger et al., 2015; GESAMP, 2015; Masura et al., 2015; EFSA, 2016; Lusher et al., 2017; Van Emmerik et al., 2018; Lebreton et al., 2019).

Mediterranean is reported to be one of the most important plastic pollution burdens worldwide and this pollution threat is increasing gradually (Alessi et al., 2018; Gündoğdu et al., 2018). According to the reports published by Alessi et al. (2018) and the World Wildlife Fund for Nature (2020), 95 % of the waste in the Mediterranean is composed of plastic waste, and, with 144 tons per day, Türkiye is the country dumping the most plastic waste into this basin. South Aegean Sea is situated at the intersection between the Aegean and Mediterranean Seas. In this location marine current movements are mostly under the influence of Mediterranean surface waters (Lykousis et al., 2002; Yabanlı et al., 2019). For this, it is important to regularly monitor the macro- and

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microplastic pollution in this region, which is exposed to many pollutants originating from land and sea.

This study aimed to investigate the abundance and diversity of macro- and microplastics on eight different beaches located along the Aegean coast of Türkiye (Ölüdeniz Kumburnu Beach, Sarıgerme Beach, İztuzu Beach, İçmeler Beach, Aktur Beach, Akyaka Beach, Bitez Beach, Yahşi Beach) that are intensively used for recreational purposes. Moreover, a further aim was to determine the effects of meteorological parameters and intense summer tourism on the distribution of macro- and microplastics by comparing their accumulation in two different seasons (summer and winter). Macro- and microplastics extracted from sand samples were grouped in terms of shape, color, and size and counted. The results of the current study represents the first attempt of a comprehensive monitoring of macro- and microplastic accumulations in different beaches located along the South Aegean coasts.

## 2. Material and methods

### 2.1. Study area

This study was carried out along the coasts of Muğla Metropolitan City, that is located in the southwest of Türkiye and is surrounded by the Mediterranean Sea to the south and the Aegean Sea to the west. The coastal line has an indented structure and contain many large and small islands and rocks. With the coastline of 1479 km, Muğla has the longest coastline in Türkiye and extends from the city of Bodrum to the Northwest to the city of Fethiye to the South-east. Muğla coastal waters are located at the intersection of the Mediterranean and Aegean waters and under the influence of Mediterranean currents (Lykousis et al., 2002). Muğla, dominated by the Mediterranean climate, is the third most visited city in Türkiye in terms of tourism (Yücel and Ertin, 2019; Anonymous, 2021). The region is also famous for yacht tourism and the presence of many marinas. According to the data published by Muğla Governorship Provincial Culture and Tourism Directorate, Muğla was visited by 3.266.650 in 2019, and in 2020, this number decreased to 695.314 due to the pandemic. Moreover, Muğla province also has an important place in Türkiye in terms of aquaculture and hosts many small, medium and large sized enterprises (Yıldırım and Okumuş, 2004; Akova, 2020).

For the purpose of this study, the beaches most intensively used for recreational purposes were selected. Accordingly, eight beaches from the Aegean coast of Muğla were chosen (Fig. 1).

The coordinates of the sampling beaches are presented in Table 1.

Except for the İztuzu Beach, all the other selected seven beaches have

**Table 1**
Geographical coordinates of the sampling stations.

| Beach | Coordinates | | Sand type | Length (km) | Width (km) |
|---|---|---|---|---|---|
| | Latitude | Longitude | | | |
| Ölüdeniz Kumburnu | 36° 32′ 58,17″ | 29° 6′ 38,73″ | Pebbles | 0.4 | 0.03 |
| Sarıgerme | 36° 51′ 59,44″ | 28° 45′ 4,88″ | Coarse sand | 4 | 0.1 |
| İztuzu | 36° 47′ 42,72″ | 28° 36′ 57,95″ | Coarse sand | 4.5 | 0.17 |
| İçmeler | 36° 48′ 10,64″ | 28° 14′ 2,61″ | Coarse sand | 1 | 0.01 |
| Aktur | 36° 45′ 25,41″ | 27° 53′ 10,66″ | Coarse sand | 1 | 0.15–0.02 |
| Akyaka | 37° 3′ 5,23″ | 28° 19′ 25,30″ | Medium sand | 0.22 | 0.025 |
| Bitez | 37° 1′ 38,78″ | 27° 22′ 28,86″ | Granules | 0.9 | 0.02 |
| Yahşi | 37° 1′ 5,58″ | 27° 20′ 19,34″ | Coarse sand | 1 | 0.018 |

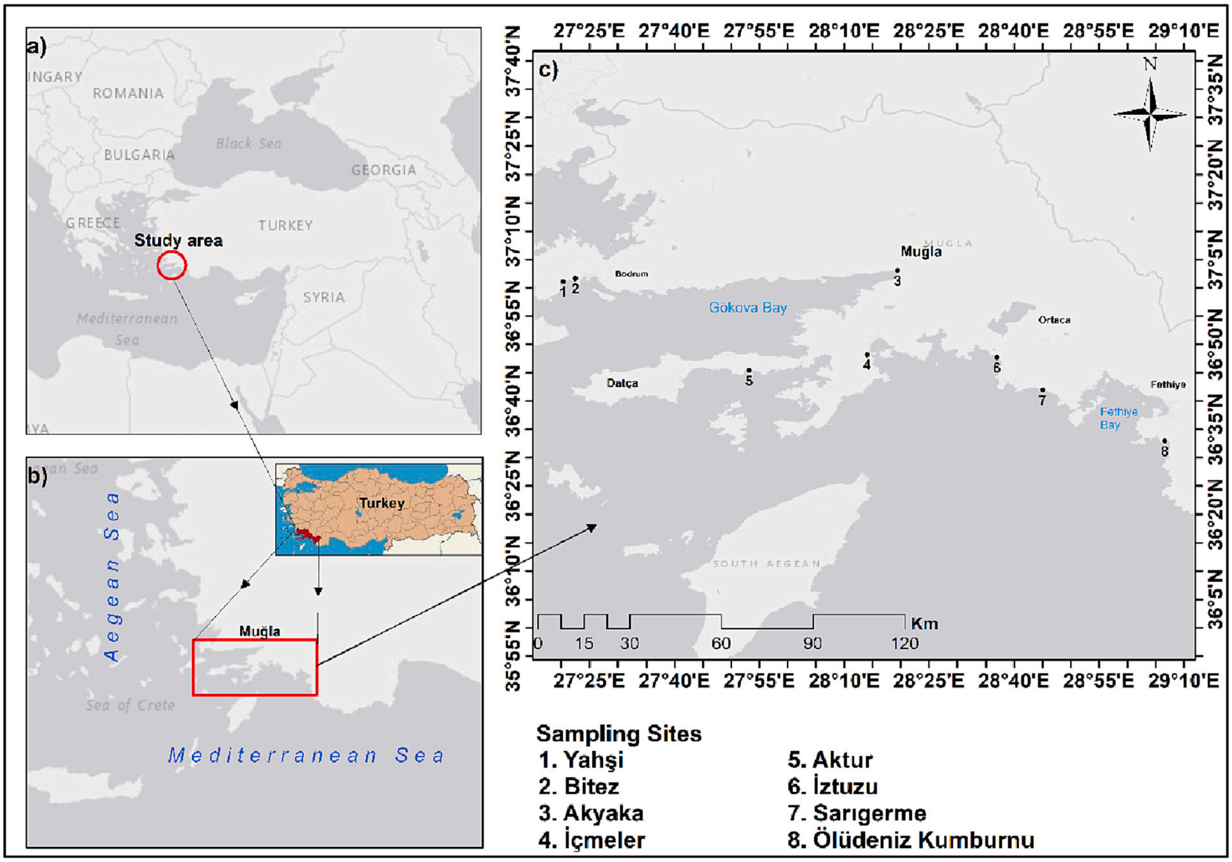

**Fig. 1.** Study area and stations.

the Blue Flag award (Anonymous, 2023a). İztuzu Beach has been declared as a "Special Environmental Protection Area" with the decision of the Council of Ministers (Anonymous, 2023b). İztuzu Beach is an important nesting site for the loggerhead turtle (*Caretta caretta*), which is in danger of extinction. Considering this situation, the beach is closed to visitors in the evening. Since İztuzu Beach has been declared a protected area, there are no accommodation facilities such as hotels and motels in the region.

Ölüdeniz Kumburnu and Akyaka beaches were declared as "Special Environmental Protection Area" with the Council of Ministers Decision (Anonymous, 2023b). İçmeler, Yahşi and Bitez beaches are among the most visited beaches of the region in summer. There are many big touristic hotels and restaurants around these beaches.

Sarıgerme Beach has been declared as a "Sensitive Area to be Strictly Protected" by the Presidential Decree (Republic of Türkiye Official Gazette, 2020). At the back of the beach, there is a large wetland with small streams, a camping area, International Dalaman Airport and agricultural fields.

Aktur Beach has been declared as "Datça-Bozburun Special Environmental Protection Area" by the decision of the Council of Ministers (Anonymous, 2023b). The Datça Peninsula, which is far from the big cities, industrial areas and commercial ports, is located at the intersection of the Aegean and the Mediterranean. There are many summer houses in the area as well as camping areas for tents and caravans.

For a better understanding of the mechanisms of plastic deposition, relevant local municipalities and beachfront business owners were asked to report when they cleaned the beaches. According to the information collected, Akyaka, Yahşi, Bitez, İçmeler, İztuzu and Ölüdeniz Kumburnu beaches are cleaned every day only during the swimming season. Aktur and Sarıgerme beaches were probably cleaned at least at the beginning and end of the summer season.

### 2.2. Sampling

The sampling stations on each beach were chosen from different points, starting from the high tide towards the back of the shoreline, and trying to include strategic points such as river/rivers inputs, if any. Beach sand samples were collected from 10 different points on each beach. Samplings were carried in two different seasons: September–October 2019, the last period of tourism activities for the summer season, and for the winter season in June 2020 when the curfew applied due to the pandemic ends. Since some points of Ölüdeniz Kumburnu Beach are oversized pebbles, on this beach sampling was carried out only from 6 points. In June 2020, the date when the curfews had just ended, the tourism season had not yet started. In the following parts of the study, the seasons in which the samplings were carried out were expressed as "Summer" for the period of September–October 2019 and as "Winter" for the period of June 2020. Sand samples ~3–4 cm deep and at a weight of about 3 kg were taken using a stainless-steel shovel (rinsed with filtered distilled water and dried) at randomly selected locations within a 50 × 50 $cm^2$ (250 $cm^2$) quadrat and put into ziplock bags (Mathalon and Hill, 2014; Besley et al., 2017; Herrera et al., 2018; Tiwari et al., 2019; Yabanlı et al., 2019; Bissen and Chawchai, 2020; Maynard et al., 2021). The sand samples were transported to the laboratory and stored at room temperature until further analyses.

### 2.3. Prevention of contamination during the laboratory process

All the equipment (beaker, petri dishes, spatula, etc.) used during the analyses carried out in the laboratory were rinsed with pre-filtered distilled water and stored in a fume hood. During the laboratory process, cotton aprons was worn, and all the doors and windows of the laboratory were constantly kept closed in order to prevent airborne interference (Torre et al., 2016; Crawford and Quinn, 2017). Also, 3 filter papers were placed at different points of the laboratory during the study in order to detect any contamination that may occur through air. During the laboratory analyses, it was calculated that the average time for each sample to be ready for analyses was approximately 1 h (±5 min). Based on the average number of microplastics detected on the filters placed in different points of the laboratory for control purposes, that could interfere in a 1-hour period, airborne interferences were calculated and the most accurate findings were tried to be reached by deduced them from all the results obtained (Lusher et al., 2014; Catarino et al., 2017; Yozukmaz, 2021). The amount of microplastics counted on the control filters put in the laboratory during the process was <1 for the whole sample and was then ignored (Table S1) (Kapp and Yeatman, 2018; Lam et al., 2022).

### 2.4. Extraction of macro- and microplastics in sand samples

Wet/humid beach sand samples were placed in beakers and were then washed with pre-filtered distilled water, dried, covered with aluminum foil and left to dry in an oven at 40 °C for 24 h (Jiwarungrueangkul et al., 2021). Sand samples were passed through a sieve with a 5 mm mesh size and separated according to particle sizes. The macroplastics in the sand samples with a size of >5 mm were taken manually using a spatula, grouped into color, shape and archived in labeled glass vials after counting (Esiukova, 2017). 3 subsamples of 100 g (3 × 100 g = 3 repetitions) of sand were taken from each of the sand samples below 5 mm and placed in separated beakers (Lots et al., 2017; Alam et al., 2019). 130 ml of hydrogen peroxide ($H_2O_2$-Merck for analysis EMSURE® ISO 30 %) was added onto each of the 100 g sand samples to remove organic matter from the samples and kept at room temperature for one night. Sodium chloride (NaCl-Merck for analysis EMSURE®) solution was added onto pre-treated samples until the final density of the solution reached 1.2 g $cm^{-3}$ in order to ensure the separation of microplastics in sand samples according to the differences in density and the samples were thoroughly mixed with an aluminum spatula and kept at room temperature for one night. Then, the liquid layer of the samples was carefully filtered through GF/F Whatman® filter papers (47 mm diameter and 0.7 μm pore size) using a vacuum pump. The filter papers were dried in an oven at 40 °C for 24 h. Filter papers were then examined under a stereo microscope (BOECO MST 606, Germany) and the microplastics were counted and grouped according to their color and shape (Hidalgo-Ruz et al., 2012; Nuelle et al., 2014; Constant et al., 2019; Yabanlı et al., 2019). During the counting, both microplastics and macroplastics were classified and grouped in term of colors (as red, blue, green, yellow, white and other) and in terms of shape (as fragment, fiber, film, pellet and foam).

### 2.5. Polymer identification

For a subsample of 100 macro- and microplastic particles (>1 mm) of different colors and shapes (50 particles from each sampling season), polymer structures were determined using Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (Thermo Scientific Nicolet iS10 ATR-FTIR). According to the method determined by Yabanlı et al. (2019), the plastic particles were pretreated in a pre-cleaned stainless-steel press machine, and the polymer analyzes were carried out after the surfaces were smoothed, thinned and their light transmittance increased.

### 2.6. Statistical analysis

StatSoft® Statistica STAT 7.0 software was used for the statistical analysis of data. Analysis of Variance (ANOVA), followed by Tukey post-hoc test, was used for each parameter (macro- and microplastic abundance), to compare different groups (two different sampling periods) and different sampling locations (eight different beaches) in order to determine whether there was statistical significance in term of macro- and microplastics abundances. In addition, Spearman correlation test was used to determine whether there was a correlation between microplastic abundance on beaches and some meteorological parameters (total precipitation amount and wind speeds). Obtained results were evaluated at $p < 0.05$ significance level.

All the results were finally reported on graphical map using ArcGIS 10.7.1 (ESRI) software.

## 3. Results

### *3.1. Abundance of macro- and microplastics*

Macro- and microplastic amounts determined from the eight beaches and the comparison between the amounts on the beaches in the two seasons were reported in Table 2. A total of 29.07 macroplastic particles (3.79 ± 5.30 particles kg$^{-1}$ dw) for the summer season and 28.67 particles (3.74 ± 7.45 particles kg$^{-1}$ dw) for the winter season were detected in all the beaches. There was no statistical difference in terms of macroplastic amounts between summer and winter seasons ($p = 0.960$) (Table 2).

With regard to the microplastics, a total of 1490 particles (177.11 ± 121.29 particles kg$^{-1}$ dw) for summer season and 1389.56 particles (170.53 ± 168.87 particles kg$^{-1}$ dw) for the winter season were detected in all the beaches and no statistical differences were found between the summer and winter seasons ($p = 0.633$) (Table 2). Statistically significant differences were detected between Ölüdeniz Kumburnu Beach and all beaches in terms of microplastic amounts in the summer season ($p < 0.05$). In the winter season, statistical differences were found between Ölüdeniz Kumburnu Beach and İçmeler and Akyaka beaches ($p < 0.05$). In addition, significant differences were revealed between Aktur Beach and all other beaches except Ölüdeniz Kumburnu Beach in the winter season ($p < 0.05$). The order of the stations with regards to number of macro- and microplastics was: Ölüdeniz Kumburnu > Aktur > Yahşi > İçmeler > Akyaka > İztuzu > Bitez > Sarıgerme for summer; Aktur > Ölüdeniz Kumburnu > Yahşi > Sarıgerme > İztuzu > Bitez > Akyaka > İçmeler for winter season (Table 2).

The GIS map showing the seasonal distributions of microplastics are presented in Fig. 2.

### *3.2. Distribution of macro- and microplastics in terms of shape, color and size*

In the summer season, 74.43 % of all macroplastics detected were fragment, followed by fibers (9.52 %), pellets (8.26 %), film (7.11 %) and foam (0.69 %). In the winter season, 78.95 % of the total macroplastics were fragment, followed by fibers (7.09 %), film (6.28 %), foam (3.84 %) and pellets (3.84 %) respectively (Fig. 3). The amount of macroplastics on the beaches in terms of color and shape according to summer and winter seasons are presented in Table S2.

The numerical distributions of microplastics on the beaches in terms of color, shape and size according to summer and winter seasons are presented in Table S3. 61.07 % of all microplastics detected in summer and winter seasons were fiber followed by fragment (32.12 %), styrofoam particle (2.49 %), film (2.38 %) and pellet (1.94 %), respectively (Fig. 3). In terms of color, blue colored microplastics were dominant with a rate of 54.39 %, followed by white (22.08 %), red (11.17 %), green (4.96 %), yellow (4.43 %) and other (2.96 %) color groups respectively. Regardless of the station, 63.62 % of all microplastics detected in the summer season and 56.73 % in the winter season were microplastics in the size range of 1 mm - 5 mm (118.49 ± 49.16 particles kg$^{-1}$ dw for summer, 98.54 ± 74.16 particles kg$^{-1}$ dw for winter).

Considering the shape, plastics categorized as fibers were dominant in both sampling seasons, followed by fragment. A total of 1055.67 fibers were detected on eight beaches in the summer season and 702.89 in the winter season. The results were calculated by averaging the stations on the beaches. A statistically significant difference was found between the two seasons in terms of fiber regardless of the station ($p < 0.001$) (Fig. 4a). The highest average fiber amounts were determined at Ölüdeniz Kumburnu Beach in both summer and winter seasons (306.67 ± 228.32 particles kg$^{-1}$ dw for the summer season, 185.56 ± 73.74 particles kg$^{-1}$ dw for the winter season) (Fig. S1). The maximum amount of microplastics at Ölüdeniz Kumburnu Beach was detected in a station in the lagoon area connected to the open sea by a narrow strait in the summer season (706.67 ± 86.22 particles kg$^{-1}$ dw) and a significant difference was found between this station and the two stations on the open sea side ($p < 0.05$). In terms of fragment, a total of 543.22 particles in the winter season and 381.67 particles in the summer season were detected at all the beaches. A significant difference was determined between the two seasons considering the whole sample ($p = 0.025$) (Fig. 4b). Fragment shaped microplastics detected in Aktur Beach in both sampling periods (141.33 ± 82.03 particles kg$^{-1}$ dw for summer season, 241.67 ± 254.22 particles kg$^{-1}$ dw for winter season) were higher than other beaches (Fig. S2). Statistical differences emerged between Aktur Beach and all other beaches in terms of fragments ($p < 0.05$).

### *3.3. Statistical relationship between meteorological parameters (wind speed and total precipitation) and microplastic accumulations on beaches*

A positive and significant correlation was determined in the winter season between wind speed and microplastic accumulations on the beaches ($r = 0.778$, $p = 0.023$) but no significant correlation was found in the summer season ($r = -0.192$, $p = 0.648$).

A negative but not significant correlation was determined between the total amount of rain and the amount of microplastics detected on the beaches in both seasons ($r = -0.665$, $p = 0.072$ for summer; $r = -0.248$, $p = 0.354$ for winter).

### *3.4. The results of ATR-FTIR analysis*

100 particles (50 particles for each sampling season) of different colors and shapes were selected and their polymer structures were

**Table 2**
Comparison between macro- and microplastics abundances (mean ± standard deviation particles kg$^{-1}$ dry weight) in sand samples collected from the eight stations in different seasons (Summer – Winter).

| Stations | Microplastic | | | Macroplastic | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | *p* values | Summer | Winter | *p* values |
| Aktur | 248.67 ± 90.96 | 358.33 ± 297.24 | 0.058 | 11.80 ± 6.37 | 12.50 ± 16.01 | 0.899 |
| Akyaka | 154.33 ± 114.94 | 97.00 ± 77.33 | [a]0.027 | 0.70 ± 1.57 | 0.30 ± 0.67 | 0.468 |
| Bitez | 124.33 ± 66.32 | 126.00 ± 64.79 | 0.922 | 5.20 ± 5.79 | 3.10 ± 2.42 | 0.304 |
| İçmeler | 165.33 ± 77.85 | 76.00 ± 49.52 | [a]0.001 | 2.70 ± 2.54 | 0.40 ± 0.70 | [a]0.013 |
| İztuzu | 130.33 ± 45.67 | 136.33 ± 90.19 | 0.746 | 0.40 ± 0.52 | 2.60 ± 2.07 | [a]0.004 |
| Ölüdeniz Kumburnu | 360.00 ± 237.66 | 233.89 ± 94.19 | 0.044 | 0.67 ± 0.82 | 0.67 ± 0.82 | 1.000 |
| Sarıgerme | 117.33 ± 79.95 | 156.33 ± 172.14 | 0.265 | 3.10 ± 3.60 | 6.40 ± 7.63 | 0.232 |
| Yahşi | 189.67 ± 76.68 | 205.67 ± 143.93 | 0.593 | 4.50 ± 5.64 | 2.70 ± 2.83 | 0.379 |
| TOTAL | 177.11 ± 121.29 | 170.53 ± 168.87 | 0.633 | 3.79 ± 5.30 | 3.74 ± 7.45 | 0.960 |

[a] Marks indicate the significant differences ($p < 0.05$) in summer and winter seasons.

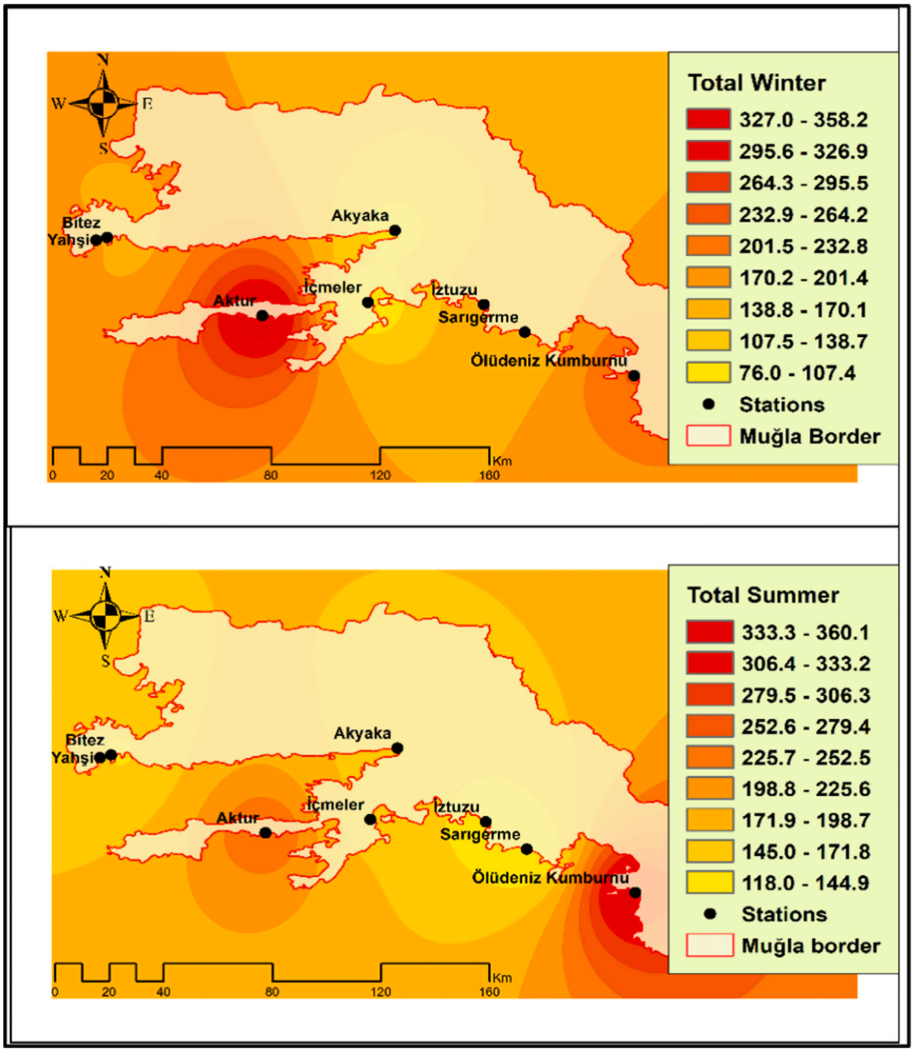

**Fig. 2.** Seasonal distribution map of the average amount of microplastics (particles kg$^{-1}$ dw).

analyzed by ATR-FTIR. Low Density Polyethylene (LDPE) was determined intensively in both seasons (66 % for summer and 50 % for winter). LDPE is followed by Atactic Polypropylene (aPP) (14 %), Polyethylene (PE) (6 %), Polypropylene (PP) (4 %), Atactic Polystyrene (aPS) (4 %), Polyvinyl Chloride (PVC) (2 %), Polyester (PES) (2 %), and Polyethylene Vinyl Acetate (PEVA) (2 %) respectively for the summer season. For the winter season, LDPE is followed by aPP (26 %), aPS (6 %), Ethylene propylene diene monomer (EPDM) (6 %), PE (4 %), PA (4 %), PP (2 %) and aPS (2 %) respectively. The results of the ATR-FTIR analysis of the most detected LDPE and aPP polymer types in current study, together with their match rates, are reported in Fig. 5.

## 4. Discussion

In this study, occurrence and diversity of macro- and microplastic pollution on eight beaches along the South Aegean coasts of Türkiye extensively used for recreational purposes were examined. No significant differences emerged in the amount of both microplastics and macroplastics detected in summer and winter seasons. Similarly, Oztekin et al. (2019) reported no statistical differences between different seasons in their study on beach litter in Sarıkum Lagoon (Southern Black Sea coast of Türkiye). In the Canary Islands (Spain), Hernández-Sánchez et al. (2021) also reported no statistical difference in terms of macroplastic amounts between spring/autumn and winter seasons. Another study conducted on the Atlantic coast of France in two different seasons, confirmed that there was no statistical difference in terms of average microplastic amounts between seasons (Phuong et al., 2018). Unlike this study, Şahin et al. (2018), in their study on plastic litter on a beach in Rize (Southern Black Sea, Türkiye), reported a significant higher amount of plastic litter in summer than in winter and they stated that this high abundance in the summer may be due to long-term accumulation. Likewise, in another study conducted on the Portuguese coast, the accumulation of microplastics detected in the autumn/winter period was higher than in the spring period, and this was due to the high rainfall, wind and wastewater treatment plants in the region (Antunes et al., 2018). In a study conducted on the coast of Uruguay, microplastics detected in the beach sand in winter were found to be significantly higher than in summer (Rodríguez et al., 2020). Researchers stated that most of the microplastics detected were sea-based and seasonal changes on the beaches, depending on natural geomorphological dynamics, affect the microplastic abundance.

Similar studies on microplastic pollution in beach sand in Türkiye and around the world are presented in Table 3.

The differences between Ölüdeniz Kumburnu Beach and all the beaches in summer season, and especially the higher microplastic accumulation in the interior of the lagoon, may be related to the accumulation of pollutants coming into the lagoon area, since the water circulation with the open sea is provided by a narrow and shallow strait, intensive use of the beach for recreational purposes and transport by wind and surface water currents (Öztürk et al., 2005; Gündoğdu and

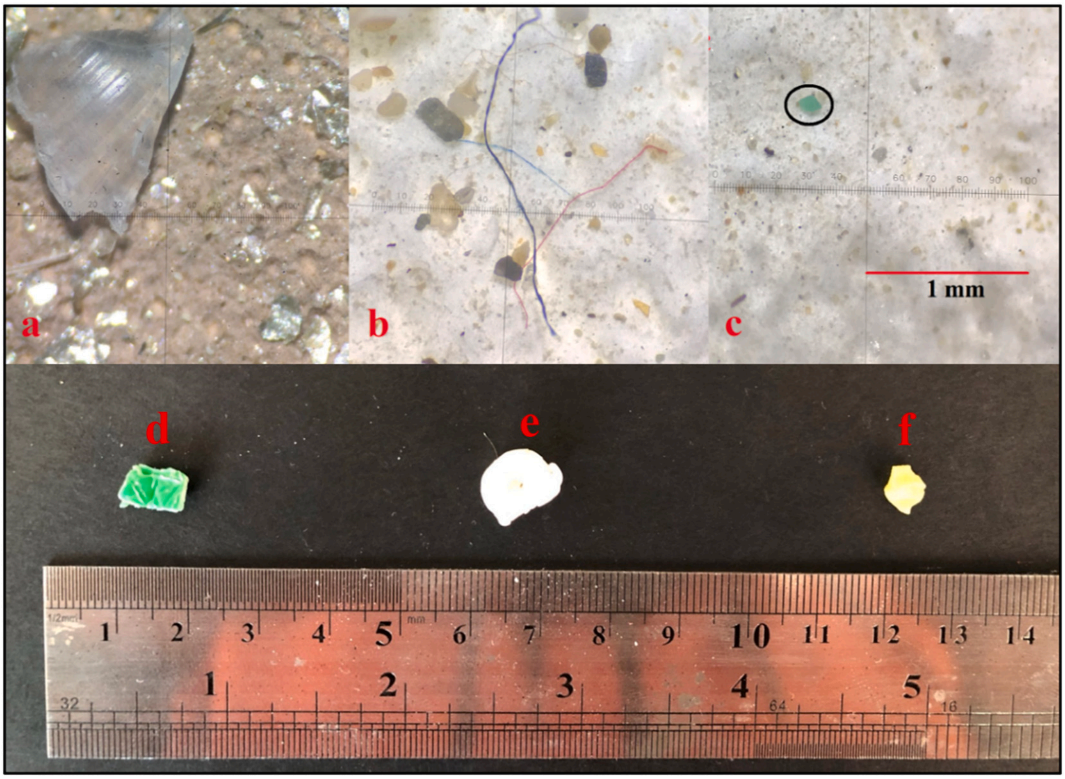

**Fig. 3.** Some macro- and microplastics in different colors and shapes extracted from sand samples (a, b, c: microplastic detected under microscope, d, e, f: macroplastic).

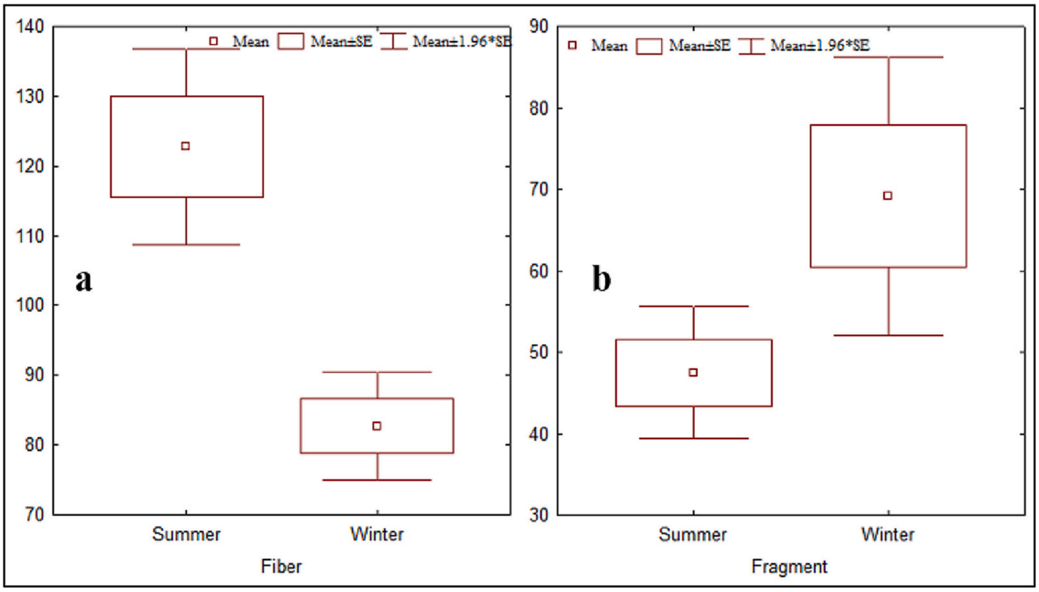

**Fig. 4.** Box & Whisker of the microplastic amount in terms of shape and the differences between sampling seasons (a: Fiber, b: Fragment).

Cevik, 2019; Mazariegos-Ortíz et al., 2020). In a study conducted in the Venice Lagoon, the maximum amount of microplastics was determined as 2175 particles kg$^{-1}$ dw at the station in the interior of the lagoon, and it was stated that the lagoon areas tend to accumulate microplastics due to their low hydrodynamic properties (Vianello et al., 2013). In another study, Toumi et al. (2019) emphasized that lagoon areas represents reservoir areas for microplastic pollution.

Analyzing the results obtained from Aktur Beach, it is interesting to underline that this beach is located remotely from major cities, big commercial ports or industrial zones. Thus, the high amount of primary pellet and fragment shaped secondary microplastics detected in the winter season, compared to the other examined beaches, may be caused by the transport to the coastline via the winds from opensea to the northwest and the surface water currents, maritime transport (McDermid and McMullen, 2004; Lots et al., 2017; Antunes et al., 2018; Duncan et al., 2018). Moreover, the pollution may be caused by land-based such as mechanical breakdown of plastic debris in beach, the geographical features of the region, intense use of the beach due to the camping areas

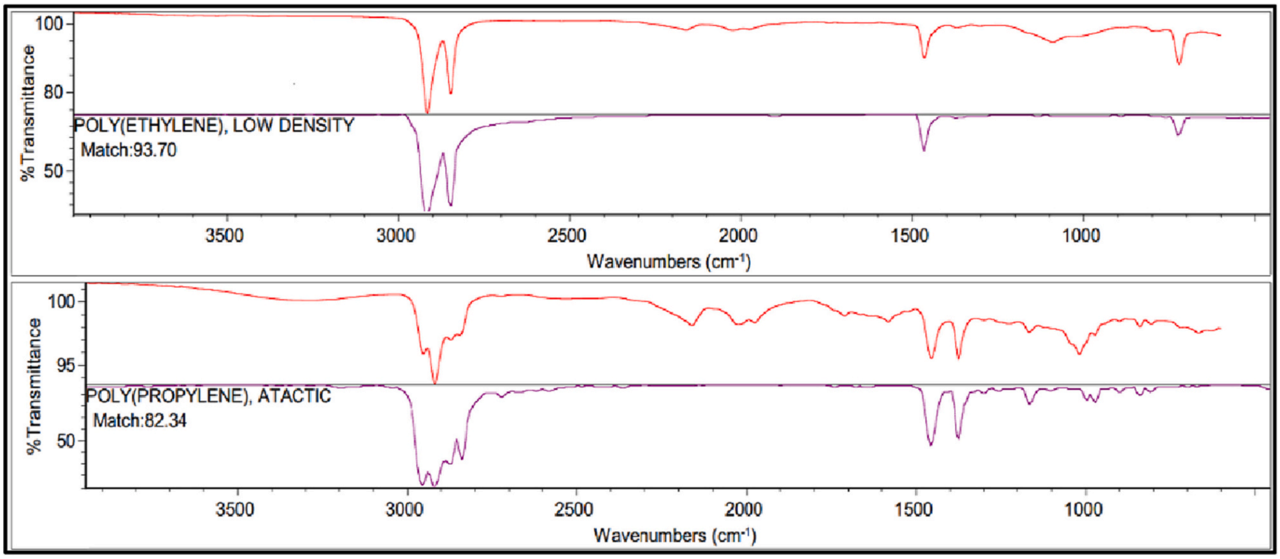

**Fig. 5.** ATR-FTIR analysis results of the two most detected polymer types (LDPE and aPP).

**Table 3**
The minimum and maximum amounts of microplastics determined in beach sands from various regions around the world.

| Location | Abundance (particles kg$^{-1}$ dw) | References |
|---|---|---|
| Venice Lagoon, Italy | 672–2175 | Vianello et al., 2013 |
| Kea Island, Greece | 0–575[a] | Kaberi et al., 2013 |
| Sinop Sarıkum Lagoon, Black Sea | 5–24 | Visne and Bat, 2016 |
| European Coasts | 72–1512 | Lots et al., 2017 |
| South Baltic Sea, Poland | 25–53 | Graca et al., 2017 |
| Northern Crete Island, Greece | 2.5–1197.5[a] | Karkanorachaki et al., 2018 |
| Baja California Peninsula, Mexico | 16–312 | de Jesus Piñon-Colin et al., 2018 |
| Rügen Island, Baltic Sea | 8.5–318.5 | Hengstmann et al., 2018 |
| Caribbean Beaches | 68–620 | Bosker et al., 2018 |
| Qinzhou Bay, China | 15–12.852 | Li et al., 2018 |
| Hiroshima Bay, Japan | 5–1245 | Sagawa et al., 2018 |
| Gulf of Lion, France | 12–798 | Constant et al., 2019 |
| Black Sea Coasts, İstanbul | 2–124 | Şener, 2019 |
| Datça Peninsula, Southern Aegean coast of Türkiye | 593.3–2073.3 | Yabanlı et al., 2019 |
| North Crete Island, Greece | 5–85 | Piperagkas et al., 2019 |
| West Portuguese Coast | 15–320 | Chouchene et al., 2021 |
| Mediterrranean Coastline of Israel | 5.9 | Rubin et al., 2022 |
| Costa Nova (Portugal) | 142–362 | Godoy et al., 2023 |
| South Aegean Coasts | 76–360 | Current study |

[a] Particles m$^{-2}$.

(caravans and tents) and summer houses in the region (Zhao et al., 2015; Esiukova, 2017; Keerthika et al., 2022). According to the reports published by Alessi et al. (2018) and UNEP/MAP (2015), Türkiye is the country that dumps the most plastic garbage into the Mediterranean. Considering this situation, the area where the current study was carried out is under the influence of Mediterranean surface water currents and winds may be carry macro- and microplastics to the coastline and cause their accumulation (Hengstmann et al., 2018; Dodson et al., 2020). Furthermore, the positive correlation detected between the wind speed data of the winter season and the microplastic accumulations on the beaches showed that the wind has an effect on the transport and accumulation of microplastics (Fig. 6). Similar to this study, Antunes et al. (2018) stated that the abundance of fragment and pellet detected in the autumn/winter season were higher than in the spring season on the Portuguese coasts. De Ruijter et al. (2019) stated in their study that high amounts of fragment are caused by the decomposition of plastic wastes increase in the environment with the intense tourism activities in the summer season, and this result supports the current study. Similarly, in the studies conducted on the Marmara and Mediterranean coasts of Türkiye, it was reported that the most of the plastic litter detected are related to the intense recreational use of the beaches, especially in the summer season (Mutlu et al., 2020; Artüz et al., 2021). In a study conducted on four different beaches in the Southern Aegean coast of Türkiye, Yabanlı et al. (2019) revealed the maximum amount of macro- and microplastic in Aktur Beach (the same beach with the current study) in the summer season (2073.3 ± 648.6 particles kg$^{-1}$ dw for microplastic, 45 ± 16 particles kg$^{-1}$ dw for macroplastic). The amount of macro- and microplastic determined in this study in Aktur Beach was higher than the results of the current study, and this difference may be due to the curfew applied during the pandemic. At the end of the curfew, with the effect of the pandemic, the number of tourists visiting the region decreased by almost four times compared to previous years. Hence, with the decrease in intense anthropogenic activity on the beaches, the amount of plastic litter in the environment may also have decreased. Kaberi et al. (2013), in their study on the Greek island of Kea (Aegean Sea, Eastern Mediterranean), stated that although the island is far from land-based sources, the origin of microplastic pollution is the open sea and in addition, the island is vulnerable to microplastic pollution carried from the Aegean Sea. In another study conducted on the coastline of Northern Crete Island (Greece), Karkanorachaki et al. (2018) stated that the microplastic pollution detected may be originating from marine, since all the sampling stations were not close to any industrial production unit. The flux onto the coastlines is bigger than the flux to the bottom in the Mediterranean. This can lead to significant plastic accumulation in coastal areas (Liubartseva et al., 2018; Gündoğdu and Cevik, 2019).

Studies showed that macro- and microplastic pollution, which differs temporally and spatially, varies depending on the circulation of sea surface water, tidal events, anthropogenic activities (tourism, fishing and agricultural activities), wind conditions, and the management of solid wastes (Karkanorachaki et al., 2018; Tunçer et al., 2018; Tiwari et al., 2019; Zhang et al., 2019; Vidyasakar et al., 2020). In addition, plastic litter concentration in coastal areas is also associated with coastal cleanup efforts and techniques (Loizidou et al., 2018; Zielinski et al., 2019). Beach cleaning activities in Türkiye are mainly carried out by local administrations and in minimal part by volunteers. In addition, cleaning works are usually carried out in the summer season and mostly at the touristic beaches. This could determine a difference in the

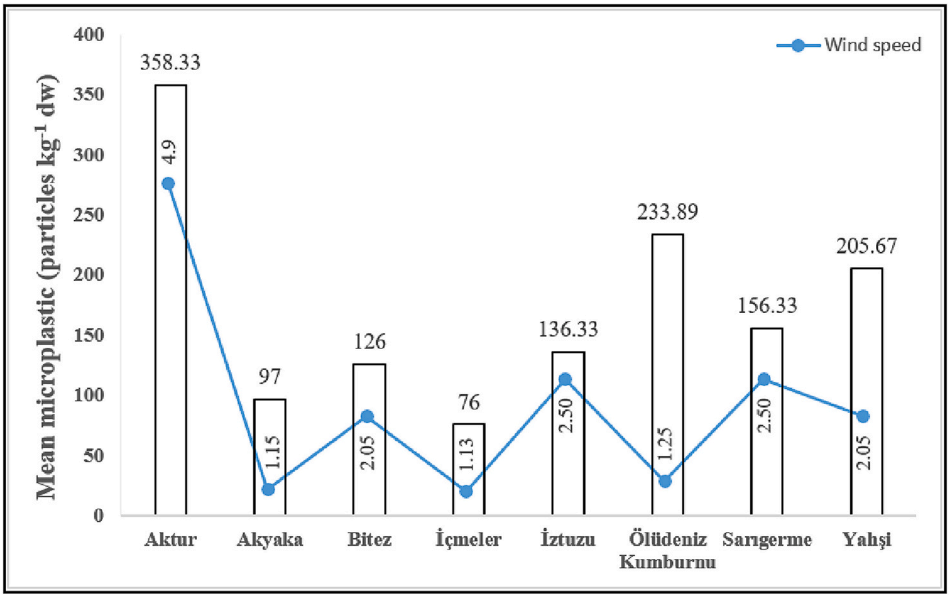

**Fig. 6.** Mean wind speed (m s$^{-2}$) and microplastic amounts detected in winter season.

accumulation rate of plastics (Fauziah et al., 2015; Gündoğdu and Cevik, 2019; Zielinski et al., 2019) and may be the reason for the differences, encountered even on the same beach in different seasons. However, the results of the current study show that periodically cleaning the beaches is not enough to prevent plastic pollution.

The high amount of fibers found in this study may be due to the fibers that release from tourists' clothes, fragmentation of fishing ropes and net, discharge of wastewater treatment plant and the river/rivers flowing into the sea at these points (Zhao et al., 2015; Lots et al., 2017; Urban-Malinga et al., 2020; Aslam et al., 2020; Bissen and Chawchai, 2020; Hossain et al., 2021). In studies on microplastics in marine environments, discharges from rivers (Gündoğdu et al., 2022) and wastewater treatment systems (Browne et al., 2011) were found to be important sources. Several studies showed that millions of microplastics are released into the aquatic ecosystems every day, in particular from the discharge waters of wastewater treatment plants, and approximately 70 % of these microplastics are represented by fibers (Talvitie et al., 2017; Acarer, 2023). Scopetani et al. (2021), reported that the rivers flowing through densely populated and industrialized cities, collecting wastewater from treatment plants and pouring into the sea can be a source of fibers. Laglbauer et al. (2014) reported that 75 % of the microplastics detected on the coast of Slovenia were fiber shaped. Piperagkas et al. (2019), in their study on the Crete Island (Greece), found that fiber pollution in beach sand was more dominant than other microplastic forms in both summer and winter seasons.

The high amount of blue and white colored macro- and microplastics in the current study could be from fishing nets, boat ropes and fibers released from clothes, packaging and kitchenware (Amrutha and Warrier, 2020; Aslam et al., 2020; Fan et al., 2022). In addition, another source of white-colored macro- and microplastics may be that the colored ones lose their color over time due to mechanical abrasion (Bissen and Chawchai, 2020; Vidyasakar et al., 2020). Considering that almost all of the fragments detected in the current study were secondary microplastics, the source of the microplastics in the 1 mm - 5 mm size range, which are detected intensively, may be the fragmentation of larger plastics in the environment and transport by surface currents. Similarly, in a study conducted by Lots et al. (2017) on 23 beaches in 13 different European countries, 54.8 % of the microplastics obtained were between 1 mm - 5 mm, and blue and red colored microplastics were dominant. Likewise, Gül (2023), in his study on the Black Sea coast of Türkiye, stated that the potential source of the fibers with various colors can be the clothes of the beach visitors. In accordance with the findings of the current study, in a study conducted by Hossain et al. (2021) in the Bay of Bengal coast (Bangladesh), microplastics were examined in 3 different size groups and it was reported that particles in the 1–5 mm size range were dominant. Unlike this study, Zhang et al. (2019) found that particles with a size of <1 mm were more dominant in their study on four different islands in the South China Sea. UV rays, oxidation, bacteriological factors, polymer structures, additives used during production, transport time via surface waters to coastline are important factors in the degradation of plastics, and these can vary regionally (Duwez and Nysten, 2001; Klein et al., 2018; De Ruijter et al., 2019). All these factors may be the reason why microplastics in the range of 1 mm - 5 mm were determined more intensely in the current study.

As a result of ATR-FTIR analysis, LDPE and aPP polymer types were dominant in both seasons. While PP and its subtypes are extensively used in the production of automotive parts, food packaging, carpets, water and gas pipes, fishing nets, ropes and bottle caps, LDPE is preferred in for the production of food packaging film, agricultural film, plastic bags (de Wit et al., 2019; PlasticsEurope, 2020). According to the report published by PlasticsEurope (2020), PP and LDPE polymer types are produced most in European countries, and considering these production amounts, the intense determination of LDPE and aPP polymer types in the current study is consistent. Similar to this study, Yabanlı et al. (2019) stated that DYPE and aPP were dominant in their study on the Datça Peninsula (Southern Aegean coast of Türkiye). In a study conducted on the Mediterranean coasts of Türkiye, PE and PP types were for found to be dominant both in sea water and in bottom sediment (Gedik et al., 2022). In another study, PE and PP types detected on the Portuguese coast were denser at ATR-FTIR analyzes (Chouchene et al., 2021).

## 5. Conclusion

The area where the current study is carried out is an important tourism destination remote from high population cities, industrial areas and large commercial ports. In this regard, it can be concluded that one of the factors that may cause macro- and microplastic pollution in the region may be the tourism activities in the summer period. Moreover, the indented coastline, the presence of many large and small islands, the characteristically different Aegean and Mediterranean waters mixing into each other in this region are the factors may increase the macro- and microplastics accumulation in the sampling area. The possible reasons for the detection of high amount of plastic litter in the region, which is at the intersection of the Mediterranean and Aegean Seas, may be the effect of the transport of macro- and microplastics to the coastline via Mediterranean surface water current and the winds. The possible effects of climatic factors such as current direction and intensity, wind speed and precipitation amount on macro- and microplastic pollution in the marine ecosystem are not investigated in detail. In this respect, the present study will be an important guideline for future research.

## CRediT authorship contribution statement

**İdris Şener:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Murat Yabanlı:** Conceptualization, Formal analysis, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

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