Universidad de La Laguna

Facultad de Ciencias
Universidad de La Laguna

Floating microplastics in the nearshore of Vilanova i la Geltrú (western Mediterranean Sea)

Microplásticos flotantes en la costa de Vilanova i la Geltrú (Mar Mediterráneo occidental)

Máster de Biología Marina: Biodiversidad y Conservación

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Universidad
de La Laguna

AUTORIZACIÓN DEL TUTOR/ES

La **Dra. Covadonga Rodríguez González**, Profesora Titular del Departamento de Biología Animal, Edafología y Geología de la Universidad de La Laguna, y la **Dra. Anna Sánchez Vidal** (Universitat de Barcelona), como Tutora Académica y Tutora Externa, respectivamente,

DECLARAN:

Que la memoria presentada por **Eva Díaz Zapata** titulada **"**Floating microplastics in the nearshore of Vilanova i la Geltrú (western Mediterranean Sea)"; "Microplásticos flotantes en la costa de Vilanova i la Geltrú (Mar Mediterráneo occidental)**",** ha sido realizada bajo su dirección y consideran que reúne todas las condiciones de calidad y rigor científico requeridas para optar a su presentación como Trabajo de Fin de Máster, en el Máster Oficial de Postgrado de Biología Marina: Biodiversidad y Conservación de la Universidad de La Laguna, curso académico 2021-2022.

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INDEX

RESUMEN

La contaminación por plásticos es ampliamente conocida como un problema en todos los ecosistemas marinos. Los microplásticos flotantes están aumentando debido a las grandes cantidades de plástico que llegan al océano y a la fragmentación de éstos en porciones de tamaño menor a 5mm. Su distribución en aguas cercanas a la costa es aún poco conocida, aun siendo el lugar donde se supone que se produce la entrada de plásticos al medio marino. Este estudio se ha realizado dentro del proyecto de ciencia ciudadana Surfing For Science, que pretende conocer la magnitud de la contaminación por microplásticos en la costa, mediante arrastre de red en embarcaciones sin motor, en diferentes puntos de la costa catalana. Este es el primer estudio realizado en la zona costera de Vilanova i la Geltrú (Barcelona), un municipio al sur de Barcelona con mucho turismo y una importante actividad pesquera. Desde septiembre de 2021 hasta abril de 2022, se realizaron 14 transectos de aproximadamente 1 milla. Se recogieron un total de 3344 partículas de plástico, representando una abundancia media de 0,44±0,67 ítems·m^{-2}. Estos valores se encuentran en la parte baja de los rangos de abundancias registrados en otras zonas costeras en el Mediterráneo occidental. La serie temporal muestra una tendencia negativa significativa, disminuyendo las concentraciones durante el tiempo del muestreo, debido a la variabilidad estacional. La gran mayoría de los ítems de plástico flotando eran microplásticos con un tamaño medio de 3,44±6,69 mm. La categoría predominante es el plástico de tipo film o lámina, de color transparente/translúcido. El polietileno es el principal polímero que compone los microplásticos muestreados. No se encontró ninguna correlación estadísticamente significativa entre la abundancia de plásticos y las variables ambientales estudiadas (oceanográficas y atmosféricas). Este estudio demuestra la elevada variabilidad espacial y temporal en las abundancias de microplásticos flotando en zonas cerca de la costa, y la importancia de iniciativas de ciencia ciudadana como esta que permiten obtener datos con elevada resolución, estimar su impacto y proponer medidas correctoras, en su caso.

Palabras clave: Mar Mediterráneo, microplásticos flotantes, aguas costeras.

ABSTRACT

Nowadays plastic pollution is a widely known problem in all marine ecosystems. The abundances of floating microplastics are increasing due to the large amounts of plastic that reach the ocean and its subsequent fragmentation into fragments smaller than 5 mm. Their distribution in nearshore waters is still poorly known, that is the place where high emissions may occur. This study is framed within the citizen science project Surfing For Science, that aims to determine the magnitude of plastic pollution in the nearshore by towing a trawl from rowing boats in different locations of the Catalan coast. This is the first study made in Vilanova i la Geltrú (Barcelona), a city south of Barcelona with a lot of tourism and an important fishing activity. From September 2021 to April 2022, 14 transects of approximately 1 mile were carried out. A total of 3344 plastic items were collected, with a mean abundance of 0.44±0,67 items·m^{-2}. This is in the lower range of floating microplastics reported for the nearshore of the western Mediterranean. The time series show a significant negative trend, decreasing concentrations in time, due to seasonal variability. The vast majority of the items were microplastics with a medium size of 3,44±6,69 mm. The predominant category was film/sheets type plastic, transparent/translucent in colour. Polyethylene was the main polymer in sampled microplastics. No statistically significant correlation was found between plastic abundance and the environmental variables studied (oceanographic and atmospheric conditions). This study demonstrates the high temporal and spatial variability of the abundances of floating microplastics in the nearshore, and the importance of initiatives of citizen science that allow to increase sampling resolution, estimate its impact and implement good management, where appropriate.

Key words: Mediterranean Sea, floating microplastics, nearshore

1. INTRODUCTION

Plastic is widely used from 1950 due to its unique properties as inexpensive, lightweight, corrosion resistance, durability, and electrical insulation, among others (Thompson et al., 2009). Carpenter and Smith (1972) began to study plastic pollution in the open ocean and it was the first observation of plastic debris, on the Sargasso Sea. In the 90's, large amounts of floating plastic debris were found in the North Pacific Subtropical Gyre (Moore et al., 2001) and the North Atlantic Subtropical Gyre (Law et al., 2010).

Nowadays plastics debris are present in all marine environments. Plastic has been found floating in surface and subsurface waters (Cózar et al., 2014; Eriksen et al., 2014). Some plastic polymers are less dense than seawater and positively buoyant and are transported long distances by sea surface currents. It has been estimated that 5.25 trillion particles are floating at sea (Eriksen et al., 2014). These floating plastics can lose buoyancy and eventually sink, with the deep sea being a very important sink, where microfibers are the predominant form of plastics in seafloor (Woodall et al., 2014). In the deep sea thermohaline-driven currents can control the distribution of microplastics and create hotspots of up to 1.9 million pieces m^{-2}. Plastic is also found in shoreline, captured by coastlines (Kako et al., 2014; Lavers & Bond, 2017), areas that deserves special attention for plastic removal because of its capacity to retain them (Ho & Not, 2019). It has been found that coastal margins and backshores represent a major sink for marine debris correlated with oceanic, atmospheric processes and coastal usage for recreational activities (Olivelli et al., 2020). All this plastic debris also can be transported offshore and entering in the oceanic gyres (Eriksen et al., 2017) and ending up in the most remote and pristine places on the planet (Allen et al., 2019; Lavers & Bond, 2017; Materić et al., 2022).

Plastic debris have many harmful implications. The most known is the direct and visible impact on biota. Entanglement and ingestion described by Laist (1997) are most important. Entanglement is when a marine life entraps or entangles with anthropogenic debris with subsequent mortality of them. Some studies described a Species Sensitivity Distribution for estimating an indicator for this impact (Høiberg et al., 2022). The other major impact is ingestion, which, together with entanglement, is considered to be one of the most harmful. Plastic in both cases is the most commonly reported material representing de 92%. Subdividing types of plastics, plastic ropes and netting are the 71%

of the encounters in entanglement, and plastic fragments are the majority in ingestion incidents (37%) (Andrades et al., 2019; Gall & Thompson, 2015). In addition, plastic have facility to spread non-indigenous species due to its lightweight (Barnes, 2002), the absorbed persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs) or metals on their surface and are likely to contain plastic additives that add to their toxicity (Meaza et al., 2021). And finally, all these harmful chemicals can be transferred to organisms (Mato et al., 2001).

Little is known about the transformations of plastic in seawater, the stages of weathering or the timescales of degradations, fragmentation, transport, and its ultimate sinks (van Sebille et al., 2015). All these characteristics are different depending on the different polymer types that exists and forms plastic. They provide different properties giving them wide variety of applications. The most popular plastic materials are polypropylene (PP), polyethylene (PE), polyurethane (PU), polyvinyl chloride (PVC), and polystyrene (PS), between others (Crawford & Quinn, 2017a).

In the ocean plastic items are fragmenting as a consequence of prolonged exposure to UV light, and suffer chemical degradation, wave mechanics (physical abrasion) and are grazed by marine life (Barnes et al., 2009; Thompson et al., 2004), breaking them down into smaller and smaller pieces, which reach even the most remote areas (Zhang, 2017). Moreover, not only the size changes during the life of plastic, but also their colour changes, suffering discoloration and shifting their tonality (Martí et al., 2020). It seems inevitable that abundance of plastic fragments will continue to increase in the future.

This fragmentation results in a range of debris size, divided into macroplastics (>25 mm diameter), mesoplastics (5-25 mm), microplastics (<5 mm) and nanoplastics (<100nm) (Jambeck et al., 2015).

Microplastics were observed since 1971 in the North Sea (Buchanan, 1971), and now the highest concentrations are in the Mediterranean and North Pacific waters (van Sebille et al., 2015). Since then, there have been numerous studies on microplastics but almost all of them, sample at offshore waters (>4km from the coast) (Baini et al., 2018; Collignon et al., 2012; de Haan et al., 2019; Schmidt et al., 2018; Xiong et al., 2019). This is due to the fact that these scientific research normally use neuston nets or a manta trawl which are towed by a ship, making difficult to collect data in bathing areas, and increasing the cost of the samplings. Camins et al. (2020) designed an instrument called paddle trawl to fill this gap of information, and with the aim of building a tool that is easy to tow, cheap and scientifically feasible.

There is a low environmental consciousness inducing to an inappropriate waste management, causing vast quantities of plastic to enter the oceans by winds, runoff, rivers, sewage, beach littering and tides (Allen et al., 2019; Browne et al., 2011; Jambeck et al., 2015). Many monitoring efforts have failed to demonstrate consistent real temporal trends, so several modelling studies to see future trends have been done (Borrelle et al., 2020; Galgani et al., 2021; Isobe et al., 2019). These models confirm that these large amounts of plastics are increasing in time, predicting an increase in plastic inputs to the ocean, estimating emissions of 53 million metric tons per year by 2030, and supporting that further research is needed.

The study of the presence, abundance, distribution, fate, evolution, and mechanisms of temporal variance of plastics in the coastal zone are key to implementing good management in these systems. It will help too to understand their influence and the severity of its harm to marine life by large-scale and long-term monitoring, to apply an accurate assessment and correct management.

Surfing for Science is a project initiated by Marine Geosciences research group - University of Barcelona (UB) and The Spanish delegation of Surfrider Foundation Europe that aims to assess the level of microplastic pollution in shoreline waters. Citizens participate in the project by collecting scientific samples whilst paddle surfing. This project share assumptions of citizen science involving citizenship. The engagement of the population and beach users implies an environmental awareness of the problem of microplastics on our beaches. With this project de Haan et al. (2022) assured the quality and consistency of the methodology used during all the process, demonstrating that the acquisition of samples with citizen science is a reliable and powerful tool that can provide invaluable scientific data.

During 8 months, starting from September 2021, in this work not only the author of this manuscript, but also some volunteers helped to acquire scientific samples of plastic in the nearshore of Vilanova i la Geltrú (Barcelona), allowing to fill the gap in knowledge of this transition coastal area.

2. OBJETIVES

The main aim of this study is to investigate the incidence of floating microplastics in the nearshore of the city of Vilanova i la Geltrú, in the western Mediterranean, a highly touristic city and with many fishery activities located south of Barcelona city. The specific objectives of this work are:

- Determine the abundance of floating microplastics in the nearshore, and its temporal variability linked to environmental conditions (oceanographic and atmospheric conditions).
- Investigate the main characteristics (size, colour, shape, type and composition) of the plastics found in order to determine their potential origin and transport processes.
- Raise public awareness of the magnitude of plastic pollution through participation of citizens in the sampling for a scientific project.

3. MATERIAL AND METHODS

3.1. Study area

The samples were collected in nearshore area of Vilanova i la Geltrú (Barcelona), in the Ribes-Roges Beach (Figure 1), in the western basin of the Mediterranean Sea, E-W oriented.

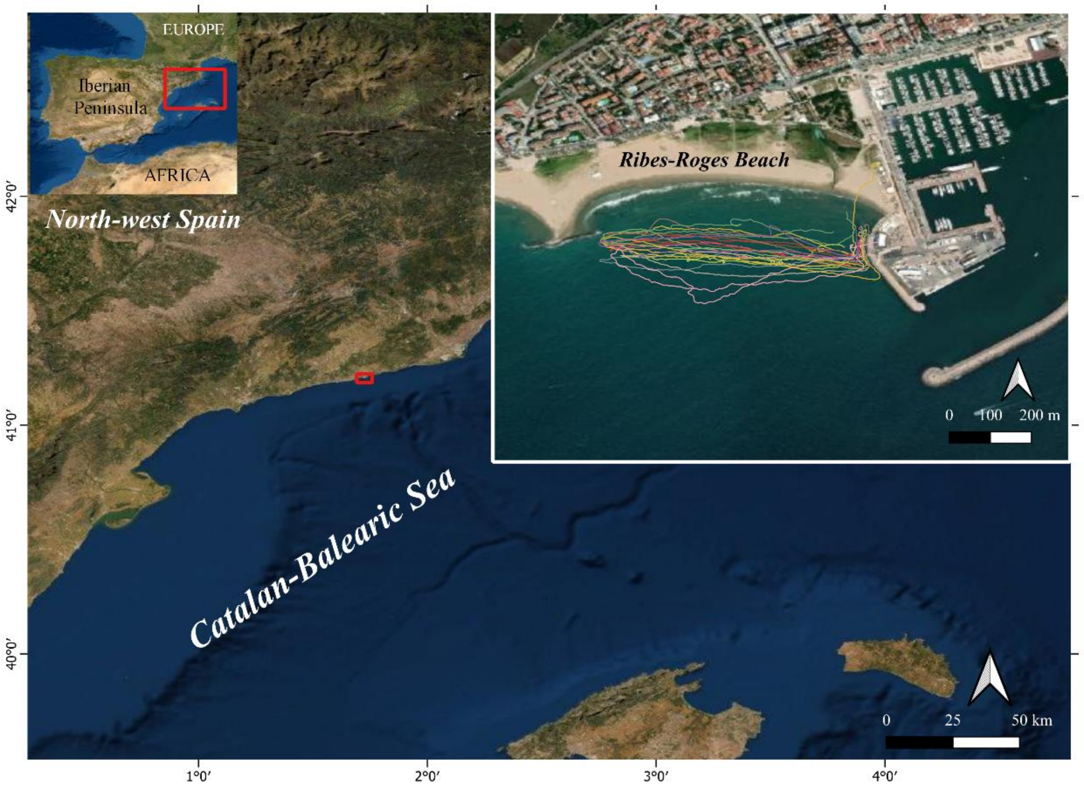


Figure 1. The study area, showing the Catalan-Balearic Sea in the north-western Mediterranean. (A), a zoom-in on the beach where samples were obtained in Vilanova i la Geltrú city. Coloured lines show the 14 transects performed towing a trawl to acquire samples.

It is an urban beach of fine sand, 170 meters wide and 1,200 meters long, located in the middle of the coastal strip of the city. Two torrents flow into the beach, which release all kinds of substances and materials during torrential rains. It is also located at the exit of the fishing and nautical harbour of the city.

3.2. Sample acquisition

Sample collection took place between September 2021 and April 2022, twice a month (except in September and December due to bad sea conditions). The samples were collected using an adaptation of the traditional manta-trawl used to collect floating microplastic samples from oceanographic vessels, called the Paddle-trawl (Figure 2) (Camins et al., 2020). The paddle trawl is made of wood, and includes a net with a mesh size of 335 µm and a final collector bag made by the same mesh. The structure can be attached to any boat designed for sailing, by means of 3m long rope, to avoid turbulence between the table and the net.

Figure 2. Paddle-trawl used for samplings, with de 335 µm net, the collector bag and the 3 m rope.

A recreational paddle surf was equipped with the paddle trawl attached to its rear D-ring. The Wikiloc Outdoor, S.L. free App (Wikiloc, 2019) installed in a smartphone was used to get the geolocation (latitude, longitude, time, and distance) while trawling. The surfer started paddling (Figure 3) with the paddle trawl on the surfboard until it is reached 5-8 m from the shoreline. Once there, the trawl was attached to the board, placed in the water and the geolocation activated.

Figure 3. The Paddle-trawl being trawled by a volunteer during the sampling in Ribes-Roges beach.

The transect lasted approximately 1 hour (1 mile approximately) and followed the best possible coast-parallel transect. All transects are shown in Figure 1. Before reaching the beach, after each trawl, the paddle-trawl was carried onboard, and GPS was turned off. Once in the beach, the net was rinsed thoroughly with freshwater to ensure that all plastic debris go into the collector bag. The sample was stored at 5 ºC until laboratory work.

3.3. Microplastic extraction

Once in the laboratory, the collector bag was inverted and cleaned using distilled water with pressure, spilling the content in a 315 µm sieve, checking no plastic is still in the bag. All the elements bigger than 315 µm were trapped at the sieve (Figure 4). Mesoplastics and macroplastics were removed using tweezers.

Figure 4. The first step in the laboratory work. It can be seen the collector bag inverted, distilled water and the 315 µm sieve.

All the sample in the sieve is spilled in a Petri dish using again distilled water with pressure. If it is necessary, we dissolve the organic matter adding hydrogen peroxide 30%, making easier the extraction of plastics.

Then, with the sample in the Petri dish, this was taken to a stereo-microscope (10X to 50X) in a clean laboratory. All the microplastics were extracted carefully one by one with stainless-steel tweezers, placing them separately on 90 mm glass Petri dish, where plastics were dried at room temperature (Figure 5). Macroplastics (i.e. >25000 µm), were manually extracted and carefully washed to assure that no smaller plastics reminded attached to its surface. Fibres have not been included in this study, as fibres could pass through the 0.3 mm net, and contamination by textiles was not prevented.

Figure 5. The stereo-microscope used in the third step in the laboratory work. Petri dishes with non processed plastics, the new dry Petri dish and the stainless-steel tweezers used.

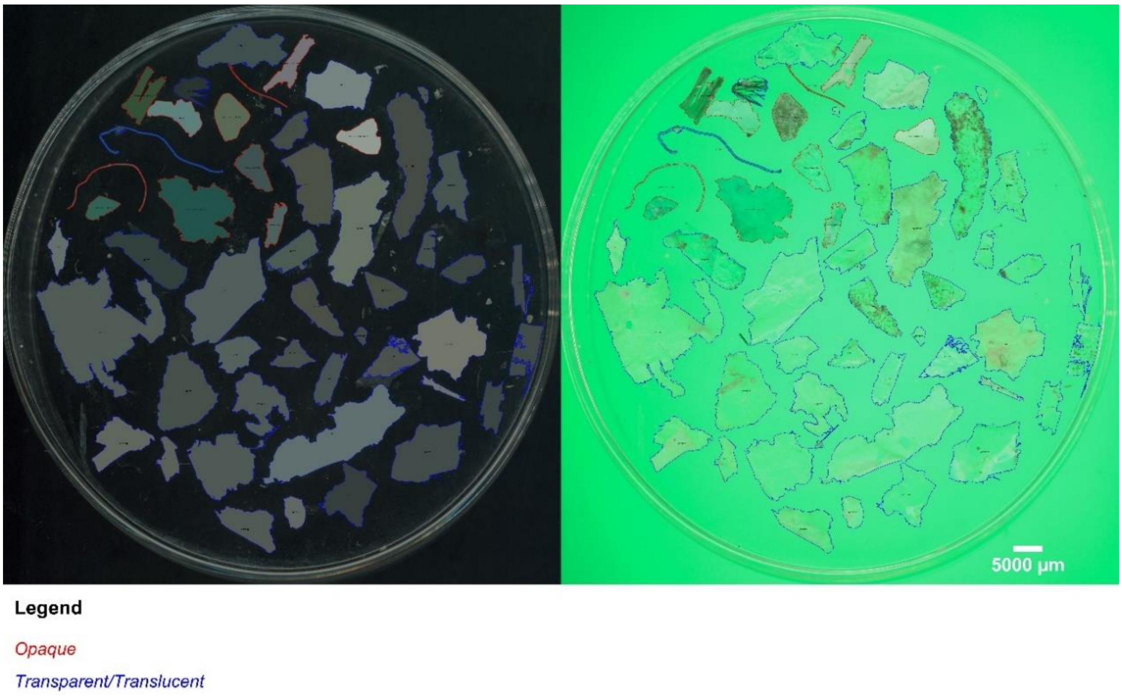


Figure 6. Images obtained with the scanner with black and green background, processed with ImageJ v1.53c program and the script created by Haan, W. The mesoplastics can be seen and their categorisation according to whether they are opaque (red) or transparent (blue).

3.4. Plastic items characterization

The Petri dish with the extracted microplastics was then scanned with black and green background (making them more visible for the subsequent image analysis) (Figure 6), with a modified and colour-calibrated HP G4050 flatbed scanner, with a charge-coupled device sensor at high resolution (1200 dpi; 47.2 pixels' mm^{-1}). The two scans obtained were precisely aligned with custom scan software and processed with ImageJ v1.53 software (Schneider et al., 2012).

ImageJ allows to count all the plastics extracted. Maximum and minimum length, surface areas and perimeter are also registered. Martí et al. (2020) provided a systematic method for colour measurements of plastics, which is used in this study to measure and automatically assign a colour to each particle. Each plastic is also manually categorized according to their nature and shape in rigid fragments (irregular shaped pieces), flexible/rigid films or sheets (thin sheets or membrane-like pieces of plastic), filaments (a strand or fibre), foam (a piece of sponge, foam, or foam-like plastic material), pellets (a small spherical piece of plastic) and spheroid or granular microbeads (a small spherical piece of plastic less than 1 mm), according to the classification described by Crawford & Quinn (2017b). The script used to process all the images and to obtain all this information has been designed by Haan, W (de Haan et al., 2022).

Finally, at the Scientific and Technological Centres of the University of Barcelona (CCiTUB), a Perkin Elmer Frontier FT-IR Spectrophotometer with a diamond crystal ATR accessory was used to chemically identify a subset of 42 random-selected microplastics (1,25% of the total), extracting 3 particles from each Petri dish. The spectral range analysed was between 4000 and 220 cm^{-1} with a 4 cm^{-1} resolution and 16 accumulations. The most common colours and shapes found were more often selected and analysed. Through this process, the polymer composition of each plastic was identified based on IR absorption bands that represent the presence or absence of specific functional groups in the material.

3.5. Data analysis

Once all the data had been obtained by analysing the images with ImageJ, they have been related to data on significant wave height (Hs) and wind speed (Ws) in the area. These meteorological data come from one of the Puertos del Estado buoys (Puertos del Estado, 2021), specifically of SIMAR point 2105134 in front of Ribes-Roges beach.

The GPS data obtained during the transects were mapped and spatially analysed using Quantum GIS v3.20 software. Data points onshore or far from the trawl path, were manually corrected and unrealistic features (small deviations in the track) were smoothed with the QGIS built-in algorithms.

R v4.0.5 software (R Core Team 2021) was used to manage and analyse all the data using packages dplyr, stringr, ggplot2, ggpubr, lubridate, purr, reshape2, trend and table1.

Moreover, the spectra collected in the FT-IR spectroscopy were analysed with Open Specy v0.9.3 software (Cowger et al., 2021), to identify the compounds by comparing them to spectra references in library databases. Microparticles were considered as plastics when the match confidence was >65%. Matches between 60 and 70% were manually examined and only identified when clear evidence of peaks corresponding to known synthetic polymers were found.

The concentrations of plastic debris (items m^{-2}) were calculated by multiplying the paddle trawl mouth length by the transect length.

The temporal trends were formally tested using a non-parametric Mann-Kendall’s trend test.

For the meteorological data, a linear regression was performed with the abundance data and the Hs and Ws data for the 5 days prior to the day of sampling.

Using the data of de Haan et al. (2022), plastic abundance of all locations sampled in the Surfing For Science project with the new Vilanova point were compared. All the values were log-transformed and compared using one-way ANOVA’s followed by Tukey’s HSD post-hoc pairwise comparisons test on the means, for significant responses. The normality and homogeneity of the data was checked using Shapiro-Wilk’s test and Levene’s test respectively.

4. RESULTS

4.1. Microplastics abundances and temporal evolution

A total of 3344 plastic items have been collected in the 14 transects made during 8 months from September 2021 to April 2022 in Ribes-Roges beach (Table 1). The total abundance of floating plastic items ranges from 0.048 items·m^{-2} to 2.65 items·m^{-2} with a mean of 0.44±0.07 items·m^{-2}. Sorting by the size, the abundance of floating microplastics (< 5mm) ranged from 0.046 items·m^{-2} to 2.022 items·m^{-2} with a mean of 0.37±0.52 items·m^{-2}, the abundance of mesoplastics (5-25 mm) ranged from 0.0017 items·m^{-2} to 0.59 items·m^{-2}, with a mean of 0.063±0.016 items·m^{-2} and with macroplastics (> 25 mm) ranging from 0 items·m^{-2} to 0.03 items·m^{-2} , with a mean of 0.004±0.008 items·m^{-2}.

Table 1. Abundance of microplastics, mesoplastics, macroplastics and total plastic items per sampling day, expressed in items per square meter.

Abundance (items/m^2)	**2021 09-14**	**2021 10-07**	**2021 10-18**	**2021 11-05**	**2021 11-22**	**2021 12-13**	**2022 01-12**	**2022 01-18**	**2022 01-31**	**2022 02-17**	**2022 03-08**	**2022 03-31**	**2022 04-11**	**2022 04-27**	**Total (Mean**±SD)
Total	2.65	0.674	0.764	0.506	0.362	0.154	0.158	0.130	0.106	0.126	0.113	0.297	0.063	0.048	0.440±0.677
Microplastics	2.02	0.596	0.689	0.488	0.337	0.147	0.124	0.121	0.088	0.102	0.099	0.286	0.060	0.047	0.372±0.519
Mesoplastics	0.600	0.069	0.067	0.015	0.025	0.007	0.023	0.007	0.018	0.022	0.010	0.011	0.003	0.002	0.063±0.156
Macroplastics	0.031	0.008	0.008	0.004	0	0	0.011	0.002	0	0.002	0.003	0	0	0	0.005±0.008

Figure 7 shows the time series of plastic abundance. The highest concentrations were found in September (2.65 items·m^{-2}) and the lowest in April (0.048 items·m^{-2}). A trend with decreasing concentrations of plastics towards September to April could be observed (Man-Kendall's trend test $p<0.05$).

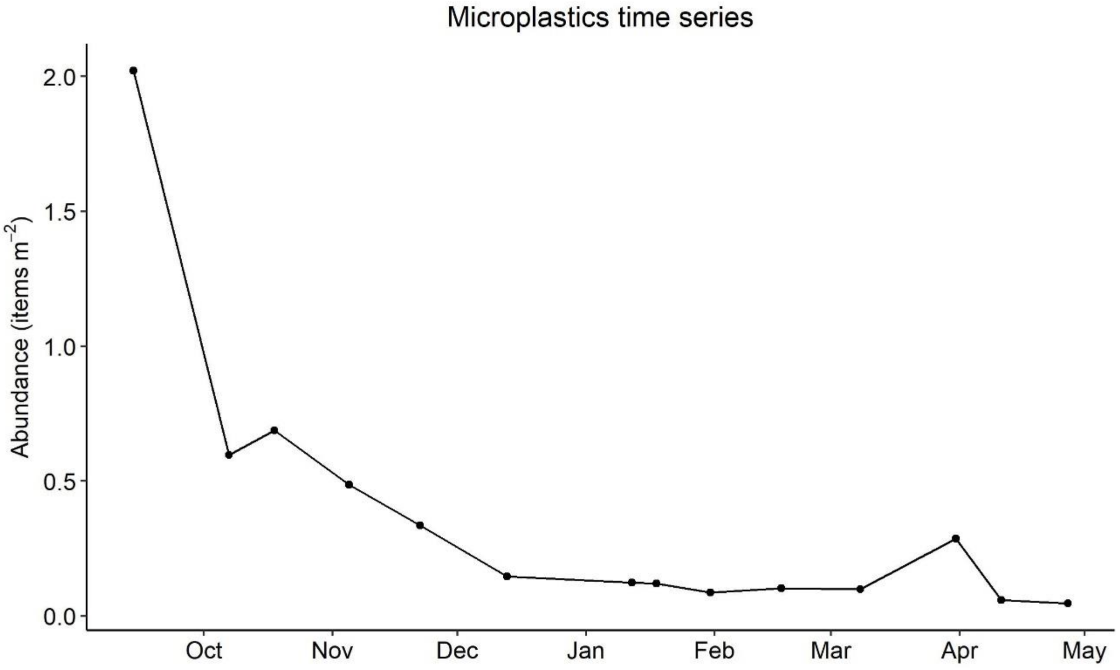


Figure 7. Time series of total abundances of floating microplastic items per square meter on Ribes-Roges beach between September 14, 2021 to April 27, 2021.

4.2. Characterization of plastics

The obtained results show a predominance of microplastics (84.9%), followed by mesoplastics (14%) and the lowest value found for macroplastics (1.1%) (Figure 8).

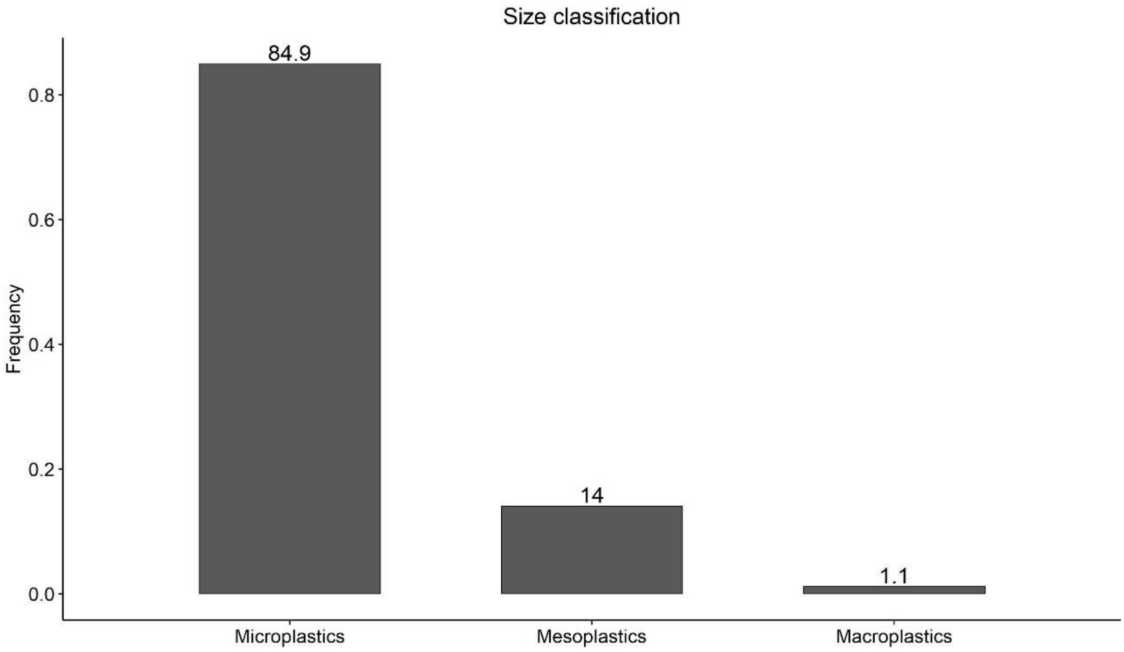


Figure 1.Groups of plastic items according to their size. Macroplastics (>25 mm), mesoplastics (5-25 mm) and microplastics (<5 mm).

The 62.5% of the plastics were within the range of 1-5 mm, and the 22.4% were smaller than 1 mm (both classifications within microplastic size). A 9.1% of the plastics fund were within the range of 5-10 mm and 4.9% between 10-25mm (mesoplastics size). And finally, 1.1% of the plastics found were macroplastics (>25mm) (Figure 9). The mean size of all the plastics found was 3.44±6.69mm.

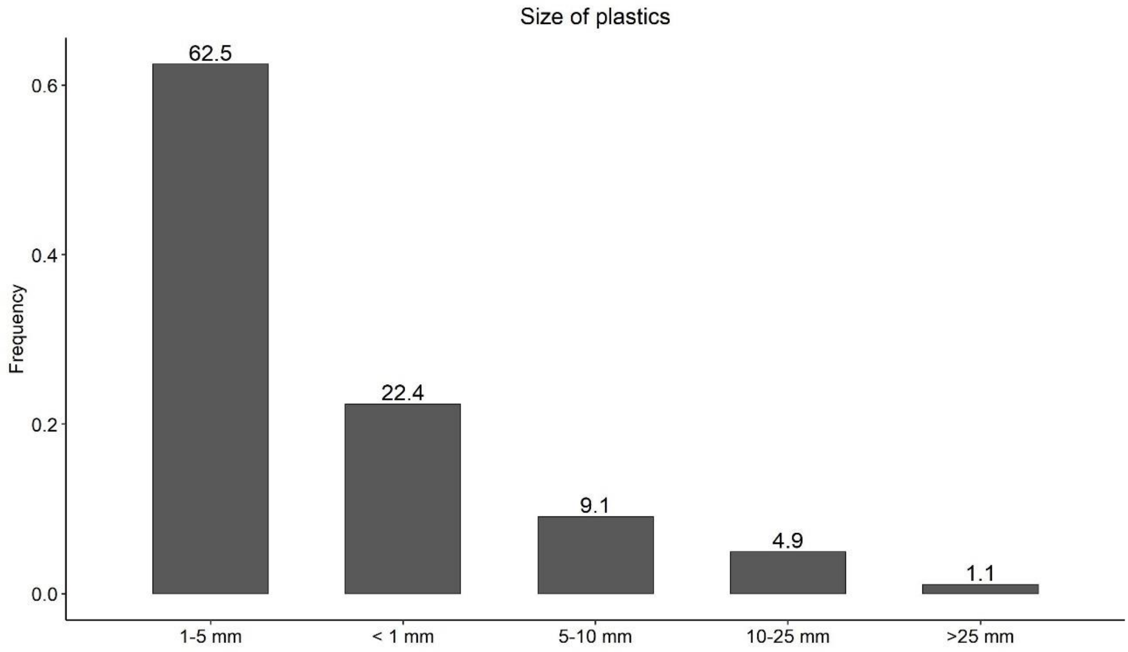


Figure 9. Classification by size of all sampled the items.

Classifying each plastic by their nature and shape, the most common category found is flexible/rigid films which represent 67.6% of the total, subsequently with a 17.2% of rigid fragments, and then filaments with a 10.3% of the total. Foams represent a 3.6% and finally 1.3% corresponding to artificial turf, as shown in Figure 10.

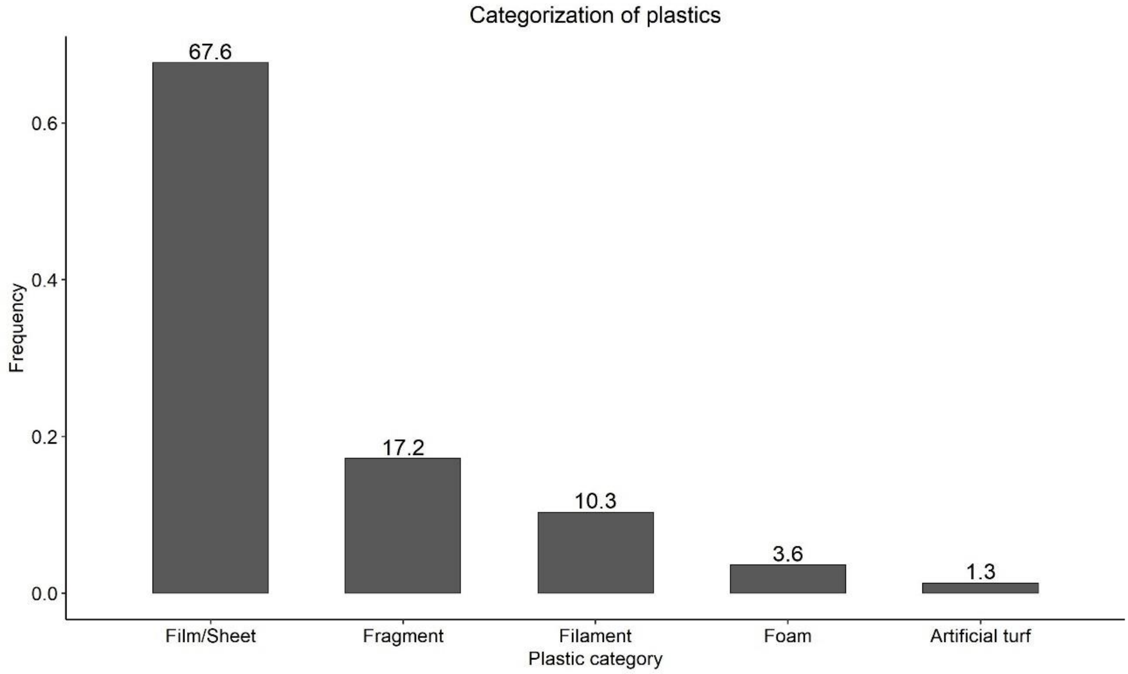


Figure 10. Categorization of plastics according to their nature and shape.

Finally, another characteristic analysed is colour. As can be observed in Figure 11, transparent and translucent plastics (TT) were most frequently found being the 68.9% of the total, followed by greyish colours (i.e., grey, black and white) (18.2%). Other colours, grouped into blueish-greenish (i.e. sky, blue, cyan, turquoise and green), yellowish (i.e. yellow, brown and orange), and reddish (i.e. red, pink, violet and magenta) were less frequent, accounting 9.4%, 1.9% and 1.7% of colours, respectively.

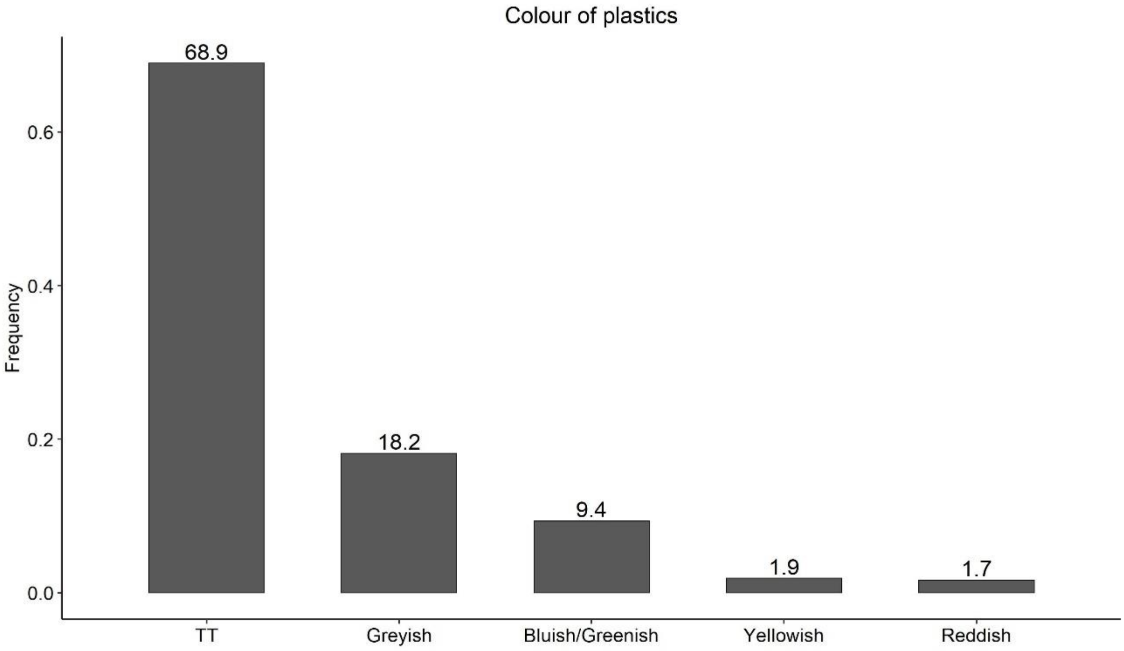


Figure 11. Classification by groups of colours of all the plastics sampled.

4.3. Polymer composition of microplastics

Of the 42 microplastics analysed by the FT-IR Spectrophotometer, 5 polymers have been identified including PE, PP, PA, PS and PU. Low and high density PE was the most common polymer found in all microplastics samples, representing the 63% of the total plastics analysed, followed by polypropylene PP with a 22%, and finally PA, PS and PU, in the same proportions, with a 4.9% each (Figure 12).

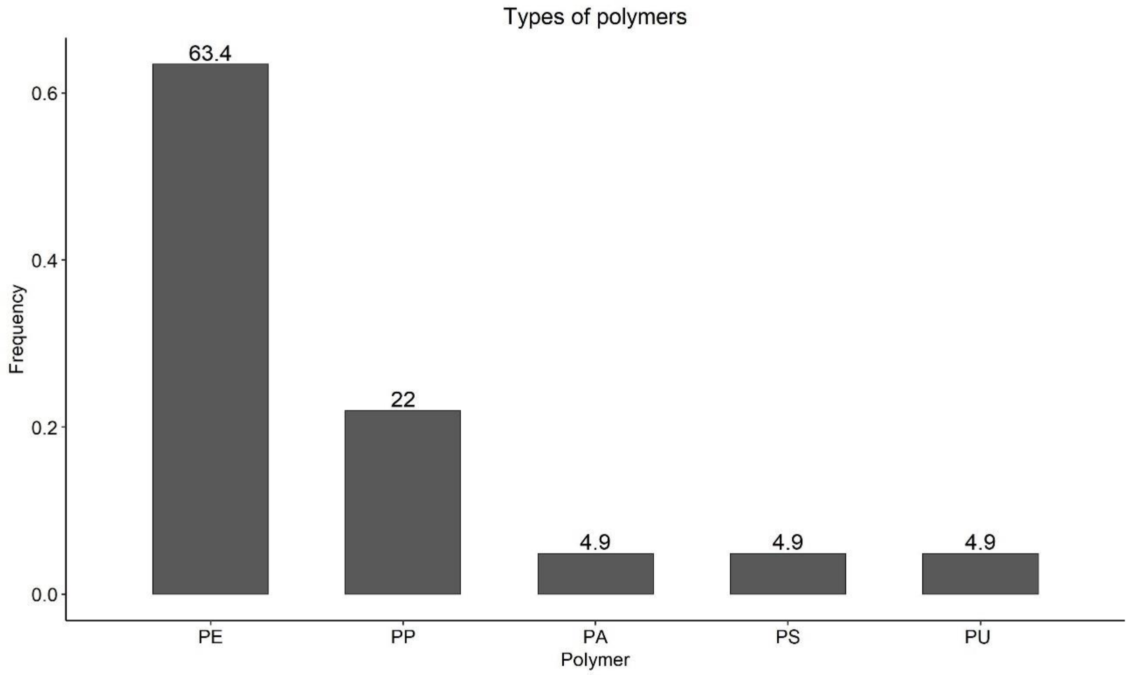


Figure 12. Types of polymers forming the microplastics in a sub-sample of 42 items. Results obtained by FT-IR Spectrophotometer.

4.4. Significant wave height and wind speed

Plotting the abundances (items·m^{-2}) of plastics against significant wave height (Hs) and wind speed (Ws) using linear regression, have been obtained (Figures 13 and 14). In these figures, the Hs and Ws data of the 5 days before each sampling day can be seen compared to the abundance of plastics, R value and p-value also obtained.

In none of the 5 days prior to sampling there is an observed relationship between abundances and Hs or Ws ($p>0.05$). The data were also compared with the 10 days prior to sampling, and the same results were obtained.

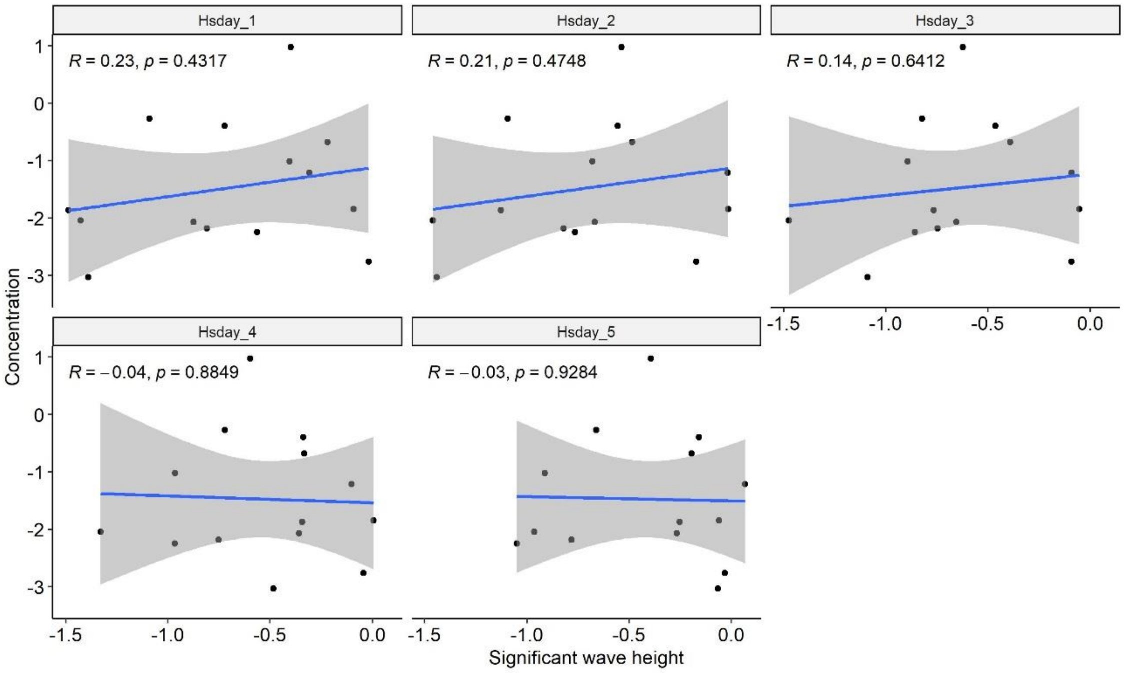


Figure 13. Correlation between significant wave height (Hs) and concentration of plastics (items·m^{-2}) about the 5 days before the samplings.

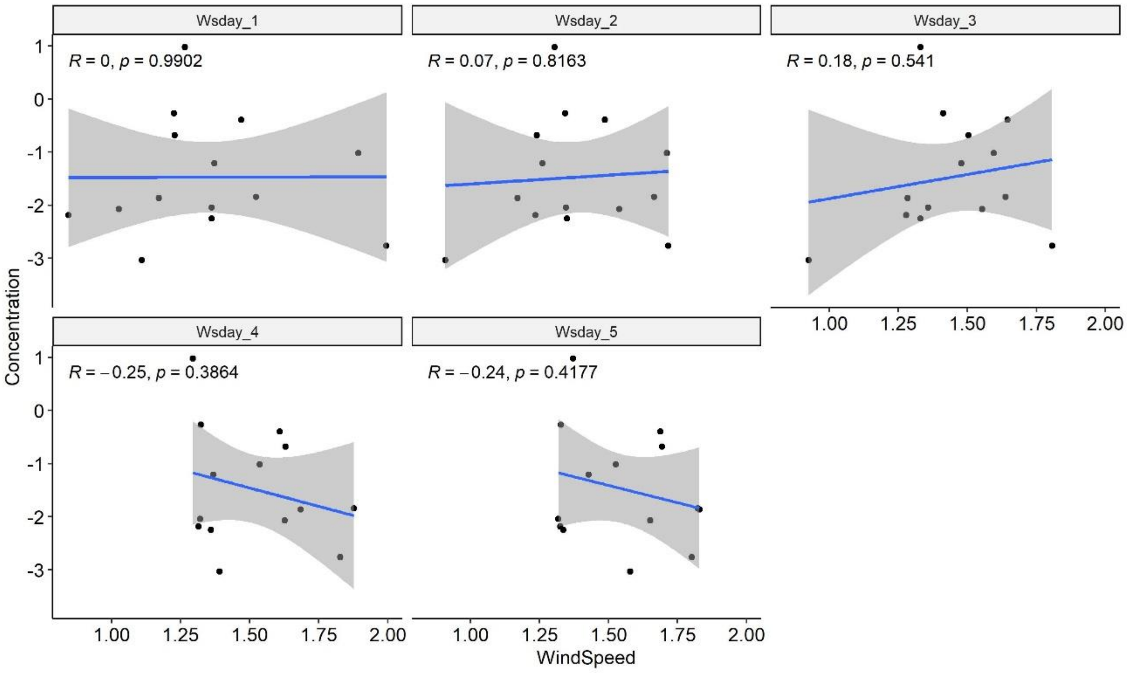


Figure 14. Correlation between wind speed (Ws) and concentration of plastics (items·m^{-2}) about the 5 days before the samplings.

5. DISCUSSION

5.1. Plastic debris characterization

Most of the plastic debris sampled (84.9%) are microplastics (<5mm). The progressive breakdown of large plastic objects results into more and smaller pieces (Barnes et al., 2009; Jambeck et al., 2015), what should lead to a gradual increase of fragments toward small sizes (Cózar et al., 2014). Eriksen et al. (2014) observed the same in all regions globally except in the S. Pacific where large and small microplastic counts were nearly equal. The longevity of this plastics depends on their properties, and estimates to take hundreds to thousands of years, but environmental weathering still causes this fragmentation. Breakdown is caused by different factors as light, temperature, air, water, biodegradation, and mechanical forces. Photodegradation is the most important process that begins plastic degradation (Lestari et al., 2022; Zhang et al., 2021).

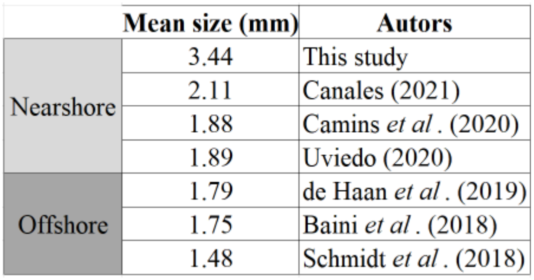
Therefore, larger microplastics were expected to be more abundant than smaller microplastics in nearshore waters, due to the retention and degradation that they suffer in the beaches, by contrast results show a predominance (62.5%) of particles between 1 to 5 mm (Figure 9), and in second place particles <1 mm being a 22.4% of the total.

This predominance in 1 to 5 mm was observed in other studies too (Cózar et al., 2014; de Haan et al., 2022; Eriksen et al., 2014). Cózar et al. (2015), also found in the Mediterranean basin an increase abundance in microplastics with a gap below 1 mm, suggesting removal of plastic items below 1 mm in size from the surface, which fits with our results. The removal of these 1 mm plastics was suggested for the open ocean too (Cózar et al., 2014).

Pedrotti et al. (2016) and Zeri et al. (2018) found higher concentrations of microplastics closer to the coast (<1 km and ≤4 km, respectively) than in offshore waters. In both studies, higher concentration in microplastics nearshore were related to effective fragmentation in this zone (due to long residence times), land sources, and loss of buoyancy offshore. But, in contrast, Baini et al. (2018) observed lower concentration of microplastics in nearshore waters than offshore, relating this with local hydrodynamic, wind conditions and land sources.

The mean plastic size in Vilanova i la Geltrú was 3.44 mm. In table 2, it can be seen the difference in mean size, being our results de highest found in nearshore and offshore waters. Nearshore studies like those of Canales (2021), Camins et al. (2020) and Uviedo (2020) found smaller sizes and similar to those found in offshore waters (Baini et al., 2018; de Haan et al., 2019; Schmidt et al., 2018). This is consistent with the statement of Morales-Caselles et al. (2021), who observed more smaller plastics in open waters. These results may suggest that there is a degradation of plastics from coastal waters to the high seas.

Table 2. Mean size of plastic items in some studies nearshore and offshore waters.



	Mean size (mm)	Autors
Nearshore	3.44	This study
	2.11	Canales (2021)
	1.88	Camins *et al*. (2020)
	1.89	Uviedo (2020)
Offshore	1.79	de Haan *et al*. (2019)
	1.75	Baini *et al*. (2018)
	1.48	Schmidt *et al*. (2018)

Taking in account the mean size, Pedrotti et al. (2016), as opposed, found an increase in size of fragments with the distance to the coast (1.85, 2.76 and 3.86 mm respectively at < 1 km, 1–10 km, >10–46 km), although no samples were collected at <100 m from the coast. Our results suggest that microplastics found have been a relatively short time in the environment and are thus less fragmented and of higher size. This could be explained by the proximity of lad-based sources.

As shown in Figure 10, the vast majority category of plastic sampled is film/sheet items, followed by fragments, which potentially come from the fragmentation of larger plastic pieces, not matching with the high concentrations of fragments in offshore areas (Martí et al., 2020; Suaria et al., 2016).

In other studies, films always appear in the second place, after fragments, both in nearshore and offshore waters (Camins et al., 2020; Compa et al., 2020; Cózar et al., 2015; de Haan et al., 2022; Gündoğdu, 2017; Martí et al., 2020; Pedrotti et al., 2016; Suaria et al., 2016; Zeri et al., 2018). Although films are detected in all areas, we found them in higher percentages in coastal areas than offshore (de Haan et al., 2022; Ho & Not, 2019; Suaria et al., 2016). Our results could be explained on the large amounts and frequent dumping of wrappers (39%), bags (22%) and beverage containers (11%) taking place in coastal waters in conjunction with their retention and sinking close to shore (Morales-Caselles et al., 2021). In addition, these films have also been found on human faces, turtles (*Chelonia mydas*), True's beaked whale (*Mesoplodon mirus*), grey seals (*Halichoerus grypus*), seabirds, among others (Codina-García et al., 2013; Meaza et al., 2021), and in atmospheric samples (Allen et al., 2019).

We found a prevalence in colour of transparent/translucent, greyish, blue-like, yellowish, and reddish colours as in the study of de Haan et al. (2022), and similar to findings of Martí et al. (2020). These results make sense as the film/sheet category is the most common sampled, and this category is related to transparent/translucent items, while filaments (e.g. fishing lines) were highly related to blue, turquoise and green colours, being the least frequent in this study.Colour characterisation is important because colour changes (whitening, yellowing, and tanning) may be related to degradation by UV light (Martí et al., 2020). In addition, it is known that different species of seabirds may be ingesting different plastic colours (Codina-García et al., 2013). Plastics in seabirds of the Mediterranean Sea had a high proportion of laminar sheet and filaments, and light coloured plastics dominated together with dark ones, which fits with all high percentages of films and sheets and TT colour in our results and other studies already mentioned.

Focusing on the composition of the microplastics found, the predominant polymer is PE, followed by PP. This data fits well with the fact that PE and PP are the most abundant plastics in worldwide to make disposable plastic products with a 36% and 21%, respectively (Geyer et al., 2017). PP, PE and PS always can be found at beaches in the form of plastic bottles, bottle rings, caps straws, and cups, PS fishing boxes or wrappers (Plastics Europe, 2016). Moreover, PP, PE, and PA are positive buoyant in seawater ($\rho<1.02\ g\cdot cm^{-3}$), therefore are common in microplastic of waters (Compa et al., 2020; Crawford & Quinn, 2017b), and they are easily transported in surface seawaters. In all environmental compartments in the Mediterranean Sea all studies show same results, with PE as the main polymer followed by PP (Camins et al., 2020; de Haan et al., 2019; Digka et al., 2018; Hidalgo-Ruz et al., 2012; Pedrotti et al., 2016; Vianello et al., 2018; Zayen et al., 2020; Zeri et al., 2018). And the same results being found out of the Mediterranean Sea (Kara Lavender Law et al., 2010; Lebreton et al., 2018).

5.2. Seasonal variability and environmental factors

The time series of floating plastic debris show a negative trend, with decreasing concentrations in time in Ribes-Roges beach (Kendall's tau: -0.78, p<0.0001). Higher concentrations were found after summer months (Fig.7). Vilanova i la Geltrú, because of its long and big sand beaches, receives lot of tourism in summer, so it maybe one of the causing factors of this variability. Grelaud & Ziveri (2020) observed a seasonal pattern, increasing during summer according to the increase of waste generation due to the seasonal influx of visitors in the Mediterranean coasts, so this assumption could be supported. Hann et al. (2022), observed increase in loads of plastics before and after summer months, which fits with this seasonal population increase, and with seasonal variation in hydrodynamics (higher wind and current speeds in winter). It would be necessary to continue sampling in Vilanova i la Geltrú to see if these concentrations rise exponentially again until after the summer months.

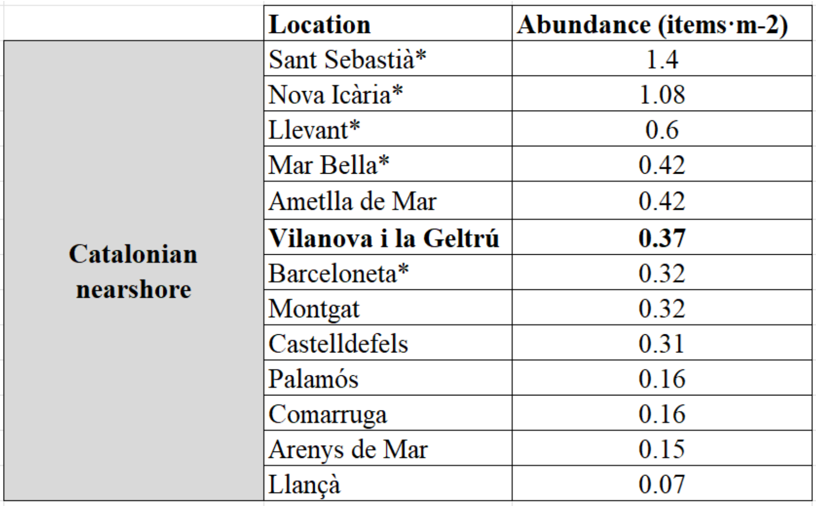
No statistically significant correlation was found between plastic abundance and the environmental variables studied (Hs and Ws). As can be seen in results, not all days following the highest periods of significant wave height and wind speed translate into the highest abundances of plastic collected. On the other hand, the highest plastic abundances were expected during the days following the periods of highest Hs and Ws, as they are strongly related to rainfall events. This non-correlation could be explained by the insignificance that these data may have, since meteorological variables come from SIMAR node 2105134 which is the closest to the study area. SIMAR data come from numerical modelling (they are synthetic data that do not come from direct measurements in nature), which leads to underestimation of wave heights and wind speed in situations of very extreme storms, affecting the quality of the study, in addition to the fact that the dynamics inside the beaches surrounded by breakwaters could be modified.

5.3. Floating plastic abundances in the nearshore of Vilanova i la Geltrú and comparison with other locations

It has been generally accepted that plastics are ubiquitous in the marine system (Browne et al., 2015; Eriksen et al., 2014; Schwarz et al., 2019; van Sebille et al., 2015). Nevertheless, little is known about the concentrations and composition nearshore, where a high proportion of plastic enters the marine system, and may get trapped or beached or resuspended during stormy conditions (Lebreton et al., 2019; Morales-Caselles et al., 2021; Onink et al., 2021). Our study increases the knowledge about these plastic abundances, temporal evolution, and their characteristics in this transitional key area of the marine environment.

We have found that on average there are 0.44 plastic items·m^{-2} (0.37 microplastics items·m^{-2}) in the nearshore of Vilanova i la Geltrú. Comparing the total mean abundance of microplastics in this study with the other locations in Surfing For Science Project, being all the points nearshore, we observe that there is a big variability in abundance between them, from 0.07 to 1.4 items·m^{-2} (Table 3). Of de 13 locations sampled, the average abundance on Ribes-Roges beach had similar values to Ametlla de Mar, Montgat and two Barcelona beaches (Mar Bella and Barceloneta). Ametlla and Montgat have a much smaller number of inhabitants than Vilanova (hosting >7 thousand; >12.2 thousand; > 67.4 thousand inhabitants respectively), so this will not be a remarkable factor in the similarity of abundance between these 3 beaches. The rest of the beaches that are above the abundance values of this study are beaches in Barcelona, the city with the most inhabitants in the project (IDESCAT 2016).

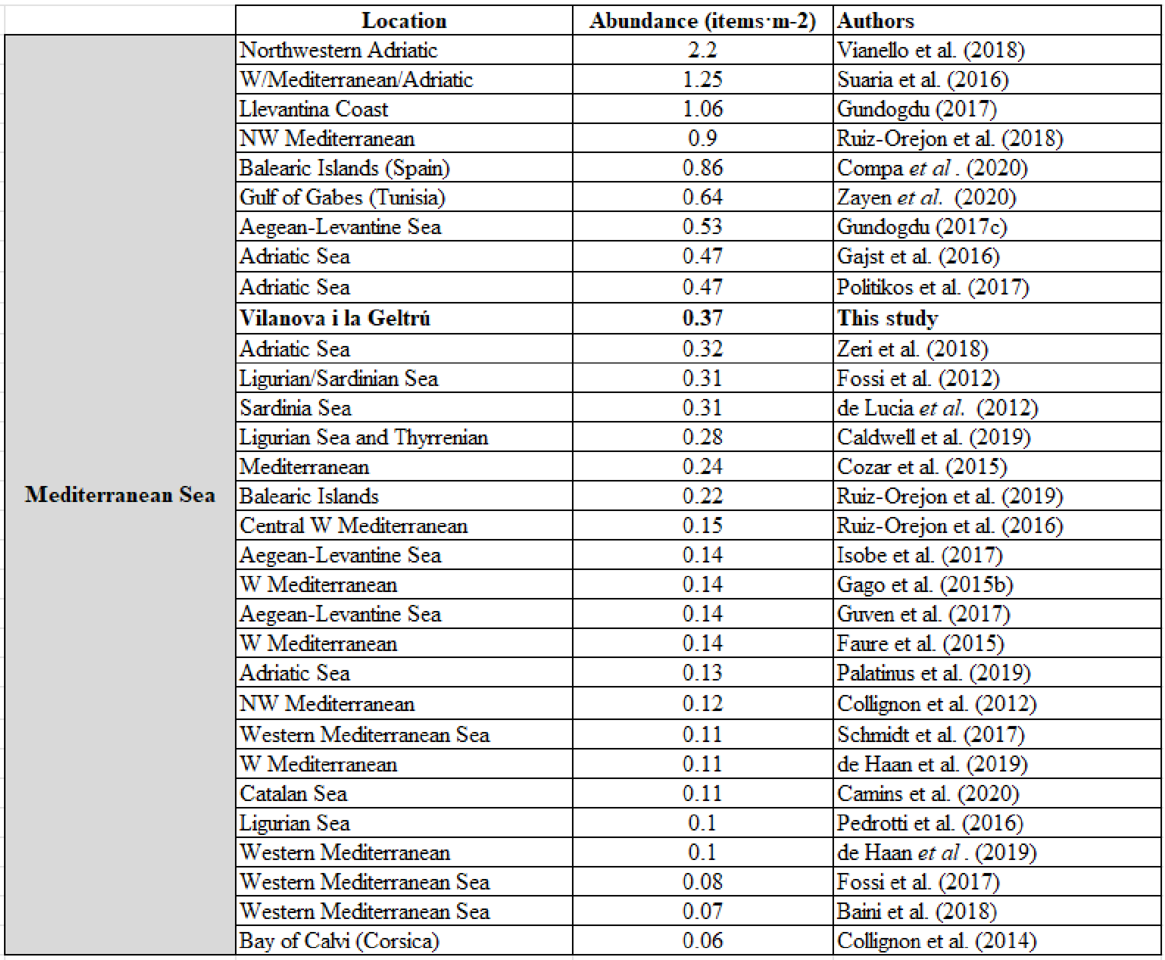
Table 3. Abundance of microplastics in nearshore waters of Catalonia (Western Mediterranean Sea). All data from de Haan et al. (2022) of Surfing For Science Project (*Barcelona City beaches).



	Location	**Abundance (items·m-2)**
Catalonian nearshore	Sant Sebastià*	1.4
	Nova Icària*	1.08
	Llevant*	0.6
	Mar Bella*	0.42
	Ametlla de Mar	0.42
	Vilanova i la Geltrú	**0.37**
	Barceloneta*	0.32
	Montgat	0.32
	Castelldefels	0.31
	Palamós	0.16
	Comarruga	0.16
	Arenys de Mar	0.15
	Llançà	0.07

On the other hand, looking at microplastics concentration values found in other regions of the Mediterranean Sea (Table 4), Vilanova i la Geltrú, still has the highest values of the 31 studies that have been reviewed. We have very similar values to the most recent studies of the Adriatic Sea. Moreover, Ribes-Roges beach stands out for its high concentrations of microplastics compared to the other studies in the Western Mediterranean Sea (Baini et al., 2018; Fossi et al., 2017; de Haan et al., 2019).

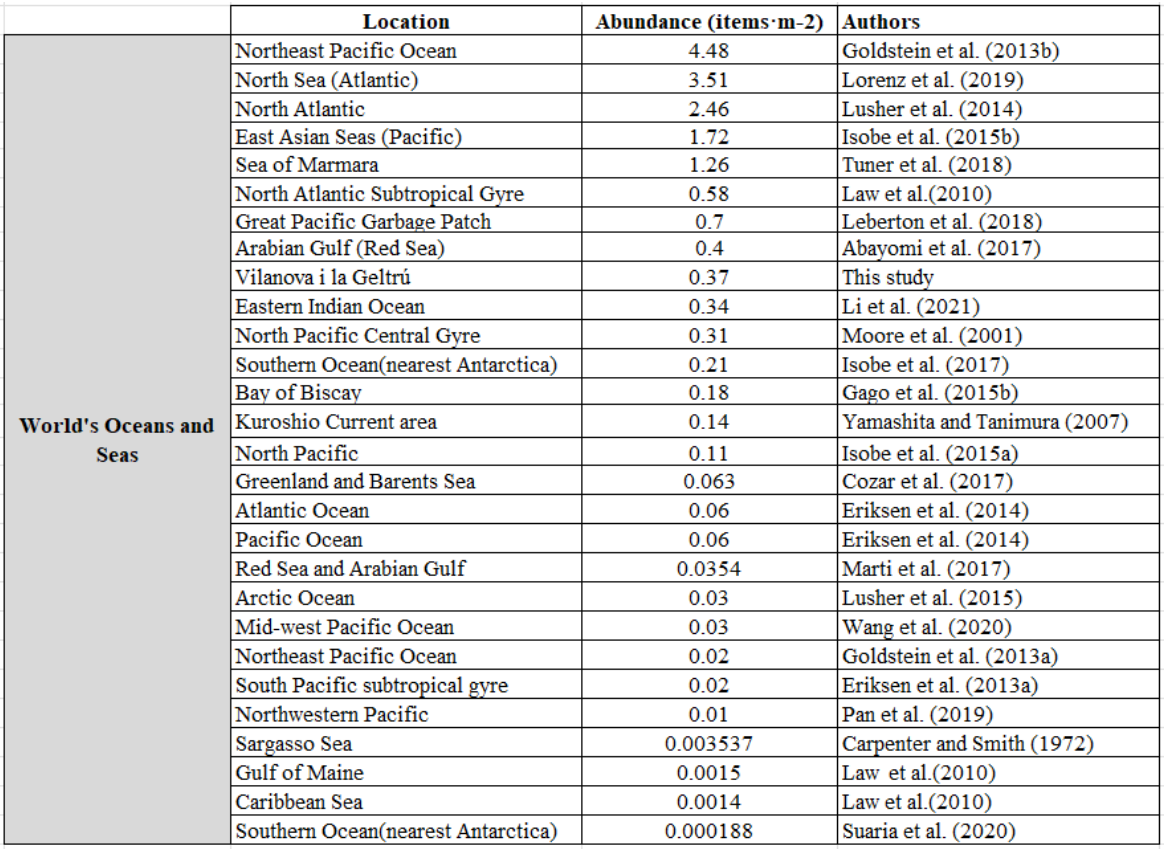
Table 4. Abundance of microplastics in Mediterranean Sea.



	Location	Abundance (items·m-2)	Authors
Mediterranean Sea	Northwestern Adriatic	2.2	Vianello et al. (2018)
	W/Mediterranean/Adriatic	1.25	Suaria et al. (2016)
	Llevantina Coast	1.06	Gundogdu (2017)
	NW Mediterranean	0.9	Ruiz-Orejon et al. (2018)
	Balearic Islands (Spain)	0.86	Compa *et al* . (2020)
	Gulf of Gabes (Tunisia)	0.64	Zayen *et al.* (2020)
	Aegean-Levantine Sea	0.53	Gundogdu (2017c)
	Adriatic Sea	0.47	Gajst et al. (2016)
	Adriatic Sea	0.47	Politikos et al. (2017)
	Vilanova i la Geltrú	**0.37**	**This study**
	Adriatic Sea	0.32	Zeri et al. (2018)
	Ligurian/Sardinian Sea	0.31	Fossi et al. (2012)
	Sardinia Sea	0.31	de Lucia *et al.* (2012)
	Ligurian Sea and Thyrrenian	0.28	Caldwell et al. (2019)
	Mediterranean	0.24	Cozar et al. (2015)
	Balearic Islands	0.22	Ruiz-Orejon et al. (2019)
	Central W Mediterranean	0.15	Ruiz-Orejon et al. (2016)
	Aegean-Levantine Sea	0.14	Isobe et al. (2017)
	W Mediterranean	0.14	Gago et al. (2015b)
	Aegean-Levantine Sea	0.14	Guven et al. (2017)
	W Mediterranean	0.14	Faure et al. (2015)
	Adriatic Sea	0.13	Palatinus et al. (2019)
	NW Mediterranean	0.12	Collignon et al. (2012)
	Western Mediterranean Sea	0.11	Schmidt et al. (2017)
	W Mediterranean	0.11	de Haan et al. (2019)
	Catalan Sea	0.11	Camins et al. (2020)
	Ligurian Sea	0.1	Pedrotti et al. (2016)
	Western Mediterranean	0.1	de Haan *et al* . (2019)
	Western Mediterranean Sea	0.08	Fossi et al. (2017)
	Western Mediterranean Sea	0.07	Baini et al. (2018)
	Bay of Calvi (Corsica)	0.06	Collignon et al. (2014)

Finally, comparing the values of the nearshore waters of Vilanova with concentrations anywhere in the world, we can see that out of 26 studies reviewed (Table 5), the values of this study are among the first. Our values are very similar to those found in the Red Sea, Eastern Indian Ocean and North Pacific Central Gyre.

Table 5. Abundance of microplastics in world's Oceans and Seas.



	Location	Abundance (items·m-2)	Authors
World's Oceans and Seas	Northeast Pacific Ocean	4.48	Goldstein et al. (2013b)
	North Sea (Atlantic)	3.51	Lorenz et al. (2019)
	North Atlantic	2.46	Lusher et al. (2014)
	East Asian Seas (Pacific)	1.72	Isobe et al. (2015b)
	Sea of Marmara	1.26	Tuner et al. (2018)
	North Atlantic Subtropical Gyre	0.58	Law et al.(2010)
	Great Pacific Garbage Patch	0.7	Leberton et al. (2018)
	Arabian Gulf (Red Sea)	0.4	Abayomi et al. (2017)
	Vilanova i la Geltrú	0.37	This study
	Eastern Indian Ocean	0.34	Li et al. (2021)
	North Pacific Central Gyre	0.31	Moore et al. (2001)
	Southern Ocean(nearest Antarctica)	0.21	Isobe et al. (2017)
	Bay of Biscay	0.18	Gago et al. (2015b)
	Kuroshio Current area	0.14	Yamashita and Tanimura (2007)
	North Pacific	0.11	Isobe et al. (2015a)
	Greenland and Barents Sea	0.063	Cozar et al. (2017)
	Atlantic Ocean	0.06	Eriksen et al. (2014)
	Pacific Ocean	0.06	Eriksen et al. (2014)
	Red Sea and Arabian Gulf	0.0354	Marti et al. (2017)
	Arctic Ocean	0.03	Lusher et al. (2015)
	Mid-west Pacific Ocean	0.03	Wang et al. (2020)
	Northeast Pacific Ocean	0.02	Goldstein et al. (2013a)
	South Pacific subtropical gyre	0.02	Eriksen et al. (2013a)
	Northwestern Pacific	0.01	Pan et al. (2019)
	Sargasso Sea	0.003537	Carpenter and Smith (1972)
	Gulf of Maine	0.0015	Law et al.(2010)
	Caribbean Sea	0.0014	Law et al.(2010)
	Southern Ocean(nearest Antarctica)	0.000188	Suaria et al. (2020)

It can also be seen that high values can be found at nearshore waters like San Sebastià beach, Balearic Islands, Gulf of Gabes or Vilanova i la Geltrú (Table 4), not being open ocean abundances the highest, like Sardinia Sea, Central and Western Mediterranean, Southern Ocean, Gulf of Maine and Caribbean Sea (Table 4 and 5). This observation suggests that the accumulation of large amounts of floating plastic are not exclusive of open ocean areas, as suggested by some studies (Cózar et al., 2014; Suaria et al., 2016), and supports previous observations that nearshore Mediterranean areas may be significant areas of accumulation of plastic debris (Lebreton et al., 2019; Onink et al., 2021, de Haan et al., 2022). The main factor that explains the plastic loads in this zone may be coastal population (60%), followed by rivers (32%) and fisheries (6%) (Kaandorp et al., 2020). It appears that coastal areas may be harbouring the amount of floating plastic that is lacking in other areas of the world (Thompson et al., 2004), as in the seabed, the water column, beaches, or animals (van Sebille et al., 2020). Other factor that can explain these accumulations nearshore, is the possible barrier effect that create breakwaters, not letting particles go out, as suggests Camins et al. (2020) and de Haan et al. (2022).

After reviewing the literature and observing the great variability in the concentrations of microplastics in different regions of the planet including coastal areas, offshore, in the deep sea or on the surface, we can say that no pattern is followed and that these abundances will depend on many factors at once. Among them: hydrodynamic conditions, population size, river discharges, seasonal changes, and coastal shape (de Haan et al., 2022).

Being Vilanova i la Geltrú a new point in the Surfing For Science project, data acquired can be helpful to have a new information along Catalonian coast, together with the data of Haan et al (2022). In the Figure 15, it can be observed that Vilanova i la Geltrú point (in red) follows the bell-curved trend observed by de Haan et al. (2022). Statistical differences were found across the points sampled in Surfing For Science regarding abundances (ANOVA, F-value= 3.46 , $p < 0.01$), but significant differences were only in plastic abundances of Llançà (with all Barcelona City beaches and Vilanova i la Geltrú). This difference in abundance of microplastics may be due to the fact that the population density of Llançà (hosting >4.7 thousand inhabitants) is far less than Barcelona City (hosting >1.6 milion inhabitants) or Vilanova i la Geltrú (hosting <67.4 thousand inhabitants) (IDESCAT 2016).

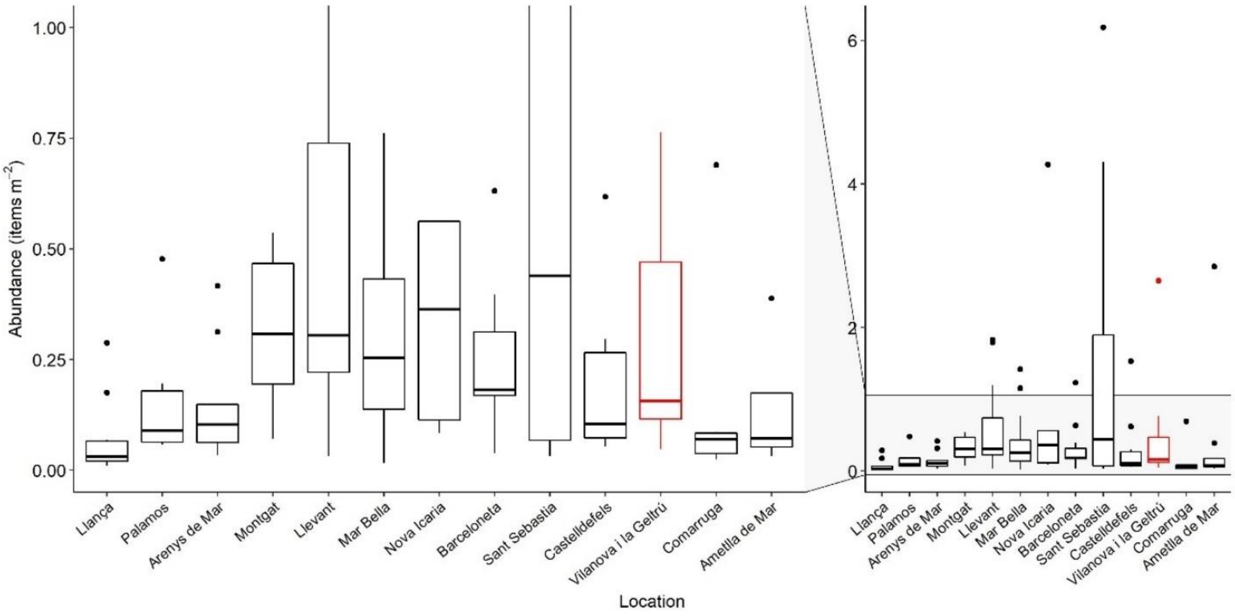


Figure 15. All de data of plastics in items·m^{-2} of the sampled beaches in Surfing For Science Project.

6. CONCLUSIONS

- With this study we can validate the plastic collection with the Paddle-trawl as a viable method for the study of microplastics in an area close to the coast and inaccessible to oceanographic vessels.

- The concentrations found are lower than those found in large cities, but similar to some of those found in the open sea.

- Microplastic concentrations are conditioned by lots of factors at the same time. For this reason, temporal variability is an important key to understand its behaviour (occurrence, distribution, and dynamics).

- It would be necessary to continue sampling in order to obtain more consistent data over a longer period of time, due to the high spatial and temporal variability of microplastics.

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