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Are the seafloors of marine protected areas sinks for marine litter? Composition and spatial distribution in Cabrera National Park

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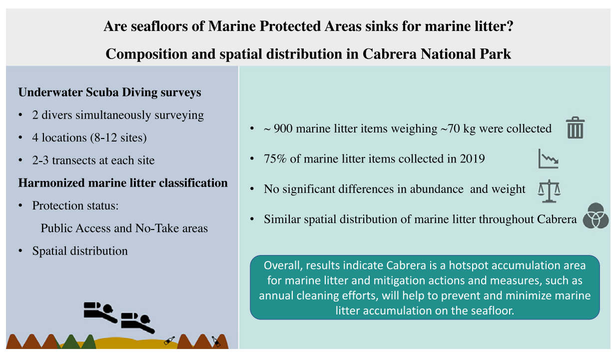
HIGHLIGHTS

- Low accumulation rate:75% less seafloor marine litter during the second survey
- Glass and artificial polymers were the most common items identified.
- Marine litter accumulation was higher in sand patches within seagrass meadows and in rocky areas.
- No significant differences were identified in the spatial distribution marine litter.

GRAPHICAL ABSTRACT



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ABSTRACT

The seafloors of oceans and seas are becoming major sinks for marine litter (ML) at a global scale and especially within the Mediterranean Sea. Within global oceans and seas, Marine Protected Areas (MPAs) have been established to protect and conserve marine habitats and increase marine biodiversity. In this study, extensive coastal shallow scuba diving surveys were conducted in 2019 and 2020 to identify the distribution of ML in the MPA of Cabrera Marine-Terrestrial National Park (Cabrera MPA) in the Balearic Islands. Approximately 900 items weighing 70.1 kg were collected throughout the MPA during the underwater surveys. Glass bottles, including pieces (25–30%) and glass or ceramic fragments >2.5 cm (8–19%) were the most common identified items followed by plastic food containers and plastic bags (~8%). Overall, 75% of the abundance of collected ML was observed during the first year. In terms of the protection status of the different locations, similar abundances of ML were found in public access areas and no-take areas. Additionally, no significant differences were identified according to location indicating that ML on the seafloor was homogeneous within the studied shallow coastal areas. Overall, the results indicate that Cabrera MPA is a hotspot for ML and mitigation actions and measures, such as annual cleaning efforts, can help to prevent and minimize ML accumulation on the seafloor.

1. Introduction

Human activities and cumulative pressures on the marine environment have been increasing over the last several decades (Halpern et al., 2015). Among these pressures, marine litter (ML), specifically plastic pollution, has a growing role in its impact on the marine environment (Andrady, 2011; Jeftic et al., 2009). For the purpose of this study, we consider the definition of ML of the United Nation Environment Programme consisting of items that have been made or used by people and are deliberately discarded in the sea or rivers or on beaches; brought indirectly to the sea with rivers, sewage, storm water or winds; accidentally lost, including material lost at sea in bad weather (fishing gear, cargo); or deliberately left by people on

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beaches and shores (UNEP, 2009). Once ML enters the environment, the most common fates are either floating on the sea surface, beach along the coastline and submerged settling on the seafloor (Alomar et al., 2020a; Cavalcante et al., 2020; Suaria et al., 2014; Vlachogianni et al., 2018). Of these items, an estimated 4.8 to 12.7 million metric tons of plastic waste enters annually into the marine environment (Jambeck et al., 2015). Of the waste that enters the marine environment, in the Mediterranean Sea there are approximately 70 kg km^{-2} of marine litter and it is estimated that globally 94% of all ML items settle onto the seafloor (Eunomia, 2016; Pham et al., 2014). Modeling studies have highlighted the effect of particle density on the distribution of plastics in the seas, with negatively buoyant particles ending up accumulating on the seafloor (Soto-Navarro et al., 2020) with the seafloor being the ultimate sink (Fortibuoni et al., 2019; Woodall et al., 2014).

The abundance of ML on the seafloor has been identified quantitatively and qualitatively over the past several years through various sampling methods which target marine litter directly and indirectly. In this sense, depending on habitat type and sampling depth, ML on the seafloor can be studied indirectly and simultaneously during fisheries bottom trawls in fisheries stock assessments (Alomar et al., 2020a,2020b; García-Rivera et al., 2017; Mifsud et al., 2013; Strafella et al., 2015). Additional methods include optically through Remotely Operated Vehicles (ROVs) or underwater hyperspectral imaging (Angiolillo et al., 2015; Bo et al., 2014; Costanzo et al., 2020; Foglini et al., 2019; Gerigny et al., 2019; Ioakeimidis et al., 2015; Madricardo et al., 2020) and in coastal areas through scuba diving surveys (Fortibuoni et al., 2019; Lucrezi et al., 2018). Scuba diving surveys applied as techniques for marine litter sampling have largely been dependent on marine citizen science surveys performed by either individual scuba divers or diving clubs/schools (Lucrezi et al., 2018). Moreover, these sampling techniques have been identified as the most advantageous in shallow coastal areas as there is minimal impact on habitats and species, have a very low economic cost compared to ROVs and trawls in addition to the ability for the observer to collect and weigh identified items providing a detailed description and quantification of seafloor marine litter either by weight and number of items (Consoli et al., 2020).

Across the Mediterranean region, and especially in the Balearic Islands, marine diversity in coastal areas is at much higher risk of encountering plastic marine litter in addition to the overall cumulative effects of anthropogenic pressures within these ecosystems (Coll et al., 2012; Compa et al., 2019). The interactions and effects of seafloor litter on benthic habitats and species are of growing concern. Impacts have been reported on seagrass, coralligenous and sponge communities (Foglini et al., 2019; Sanchez-Vidal et al., 2021). While ingestion, entanglement or overlaying of substrates has been reported to effect benthic and demersal fish, elasmobranchs, crustaceans and cephalopod communities (Alomar et al., 2020b).

According to the IUCN, Marine Protected Areas (MPAs) area a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Laffoley, 2008). Consequently, MPAs have become the primary tool for in situ habitat and biodiversity conservation reducing anthropogenic impacts, maintaining and improving biodiversity and building ecosystem resilience (Coll et al., 2012). Nowadays, there is a growing increase in establishing MPAs, especially with the new European Strategy for Biodiversity, which aims to protect 30% of European seas and oceans by 2030 (European Commission, 2020). Despite this progress, quantifying the effectiveness on ML reduction is difficult due to the ubiquity of this type of pollution and the vital role that currents and winds play in the transport of litter from source areas to distant regions. Many authors have highlighted that MPAs are not free from ML, since higher quantities of ML have been identified in protected areas rather than in areas heavily affected by human pressures. Examples of this are the recordings of marine litter with a strong dominance of fishing and aquaculture-related origin in rocky bottoms of a Site of Community Interest (Melli et al., 2017) or the presence of floating plastic litter in all samples and throughout all years in the recently approved Menorca Channel MPA (Ruiz-Orejón et al., 2019). Moreover, higher levels of microplastics in sediments were observed in Croatian Nature Parks, marine ecosystems of great ecological interest, and MPAs in the northern Adriatic Sea (Blašković et al., 2017) compared to other unprotected areas in different Mediterranean sub-regions giving further evidence that the delimitation of MPAs does not represent an effective barrier to avoid plastic contamination (Ruiz-Orejón et al., 2019). In line with this, the Plastic Busters MPAs Project, aims at maintaining and preserving natural ecosystems from marine litter along pelagic and coastal MPAs across the Mediterranean Sea. In the western Mediterranean Sea, the Cabrera Archipelago Marine-Terrestrial National Park was the first national marine-terrestrial park to be established. Since then, it has played an important role in the conservation of the ecology and biology of coastal waters in the Balearic Sea and a reference for marine conservation nationally. However, despite its conservation status, this coastal MPA is not free from plastic pollution and mean values of up to 0.90 ± 0.10 microplastics/g of dry sediment have been previously quantified, indicating that seafloor areas could be a sink of transferred micro and macrolitter (Alomar et al., 2016).

Consequently, this study aims to: i) identify abundance and weight of macro litter (items >2.5 cm) on coastal shallow seafloor areas of a MPA; ii) categorize the items identified on the seafloor according to harmonized protocols; iii) identify which factors influence the spatial distribution of ML by abundance and weight.

2. Materials and methods

2.1. Study area

The seafloor marine litter surveys were carried out within the coastal shallow waters of the Cabrera Marine-Terrestrial National Park (Cabrera MPA) located of the south-eastern coast of the island of Mallorca in the Balearic Island Archipelago (Fig. 1). Cabrera MPA is the largest marine national park in Spain with over 895 km^2 of protected sea area. Cabrera MPA hosts a variety of terrestrial and marine endemic species and has several protection statutes including a Special Protection Area (SPA) for birds, a Site of Community Importance (SIC) and a Specially Protected Areas of Mediterranean Importance (SPAMI).

A total of 58 scientific underwater scuba diving transects were performed at Cabrera MPA for the quantification of marine litter. Two sampling surveys were conducted, the first one during the last week of July and the first week of August 2019 and the second survey during the first two weeks of July 2020. Four locations were surveyed: Es Port, Santa Maria, Estells and Es Burrí, including twelve sites (Fig. 1). Within the harbour area of Cabrera, Es Port (Fig 1 A), located in an enclosed bay, four sites were surveyed. This is a public access area that contains several moored buoys, which can be used by visiting boats during the day and overnight. Furthermore, this is the only area of the Cabrera MPA with a residential zone for employees of the park, a visitor centre, a small shelter (12 places) and a small canteen. Also in the north of the island, lies Santa Maria (Fig 1 B), which is a restricted no-take area with no public access where two sites were sampled. Along the eastern coast of Cabrera, lies Es Burrí (Fig 1 C), where all activities are strictly prohibited and where three sites were sampled. Finally, three sites in Estells (Fig 1 D), situated at the southern region, were also sampled. Similar to Santa Maria and Es Burrí, this is a no-take area and all human activities are prohibited in Estells.

2.2. Seafloor marine litter surveys

Seafloor surveys were conducted at 12 sites in 2019 and at 8 sites in 2020 (Fig. 1). Three survey transects were performed at each site at a depth range of 1 to 10 m, depending on the sampling site and the topology and habitat of the seafloor. For each underwater transect, two scuba divers surveyed for an average of 15 min, searching for marine litter across a maximum transect width of four meters; two meters per diver. At most sites, fixed line transects were not feasible due to the topography of the sampling area, GPS locations were taken at the beginning and end of each transect and the survey area was defined by the length and survey width (m^2).

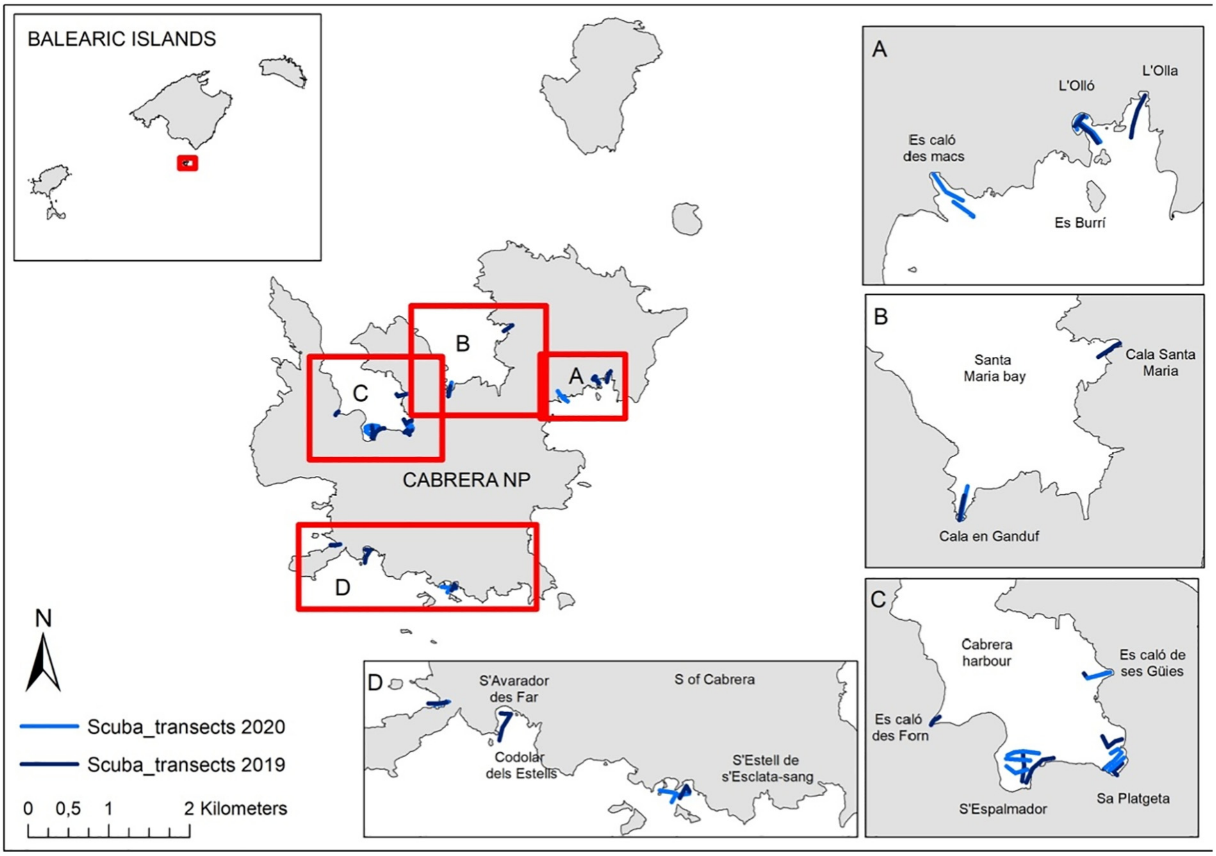

Fig. 1. Study area for the underwater scuba diving survey transects and the sampling locations for 2019 and 2020 in the Cabrera Marine-Terrestrial National Park located in the Balearic Island Archipelago. Dark blue lines indicate transects performed in 2019 and light blue lines indicate transects conducted in 2020.

Every time divers observed a litter item, the depth and characteristics of the surrounding habitat were also recorded, as well as the litter type. All observed marine litter on the seafloor was collected for posterior classification on land according to standardized and harmonized methodologies (Fossi et al., 2019; Vlachogianni et al., 2013).

2.3. Beach litter surveys

There were five locations of the scuba diving surveys that coincided with macro-litter beach clean-ups from 2019, three locations within the harbour area of Cabrera, Es Port, and two within Santa Maria Bay. All collected items during the beach clean-ups were transported to the laboratory located in Cabrera MPA and were categorized in situ following the harmonized protocols from the Plastic Busters MPAs project (Fossi et al., 2019). The protocol is adapted from the Technical Group Marine Litter (TSG_ML) for the Marine Strategy Framework Directive (Hanke et al., 2013). All items were classified and assigned the TSG_ML General Code and weighed to the nearest two decimal points (grams). The area of each beach was calculated as the entire length of the beach and width from the shoreline to the backshore and environmental characteristics of the beach were recorded. The marine litter classification was performed accompanied by experts and all visible non-organic items were collected from the sampling site.

2.4. Marine litter classification

Once onshore in the laboratory, all collected marine litter items from both the seafloor (wet) and beach (dry) litter surveys were classified following the Plastic Busters MPAs toolkit for harmonized adapted from the Annex 8.1 Master List of Categories of Litter Items from the Technical Group Marine Litter for the Marine Strategy Framework Directive (Hanke et al., 2013). This classification consists of the main categories: artificial polymers, glass/ceramics, processed/worked wood, cloth/textiles, metal, paper/cardboard, rubber and other. All items were counted, categorized and assigned the TSG_ML General Code, weighed to the nearest two decimal points (grams) and assigned the following size classes: A $= 25$ cm^2, B $= 100$ cm^2, C $= 400$ cm^2, D $= 2500$ cm^2, E ≤ 1 m^2, F > 1 m^2.

2.5. Data analyses

2.5.1. Seafloor macro-litter distribution

To determine whether there were differences between the abundance (items/100m^2) and weight (g/100m^2) of the items considering protection status, a Mann-Whitney test was applied to test differences between no-take and public access areas. Prior to the analyses, a Shapiro-Wilk confirmed that distributions were not normally distributed. Furthermore, to determine the significant effect of the size class of the different types of items, a non-metric dimensional scaling (nMDS) was performed as an unconstrained method of 2-D ordination of the material variables to visualize multivariate patterns of the items found on the seafloor. Significant differences between size class and material types were tested via a non-parametric ANOSIM test with a Bray-Curtis distance matrix run for 9999 permutations. Goodness of fit was based on the following stress categories (<0.05 excellent, <0.1 great, <0.2 good and >0.3 poor representation).

To determine the spatial distribution of marine litter on the seafloor, two models were performed, one for abundance and one for the weight of marine litter items. A generalized linear mixed model was performed considering location (Es Port, Estells, Santa Maria and Es Burrí) as a fixed factor while transects (T1, T2 and T3) were nested within each site as a random effect. Two separate methods were used to determine the best model; full model compared to a base model without the random effect for both the number of items and the weight and the lowest Akaike's Information

Criterion and normality was checked by visually inspecting the model residuals. A post hoc analysis pairwise comparison between each level in each factor and estimated marginal means were calculated and predictions were generated for significant factors.

Additionally, beach surveys were also conducted in 2019 at several locations in the public access area of Es Port (sa Platgeta, es Caló de ses Güies and s'Espalmador) and the no take-area of Santa Maria (Cala Ganduf and Cala Santa Maria) (Fig 1). A Pearson's correlation between the mean abundance (items/m^2) and weight (g/m^2) collected along the beaches versus seafloor marine litter collected through scuba divers was analysed to determine whether differences were found between marine litter deposited along beaches and seafloor areas. All analyses were performed in RStudio version 3.6.2. (R Core Team, 2016).

3. Results

3.1. Marine litter abundance and weight in underwater seafloor scuba diving surveys

A total of 901 items weighting 70.1 kg were quantified in the coastal seafloor areas of Cabrera MPA. In 2019, the total number of items collected was 668 items that weighed a total amount of 51.1 kg, while in 2020 the amount collected was 233 items with a total weight of 19 kg (representing a 75% of the total) (Table 1). Overall, in 2019, approximately 10,000 m^2 of coastal seafloor areas were surveyed with litter densities ranging from an average (± standard deviation SD) of 0.2 (± 0.3) items/100 m^2 to an average (± SD) of 61.9 (± 105.7) items/100 m^2 while in 2020 the litter density ranged from an average (± SD) 0 ± 0 to 10.6 ± 4.2 items/100m^2 with more than 7800 m^2 of seafloor area surveyed. The sampling site of es Caló des Forn located within the Es Port area, where designated moorings are permitted during daytime hours, had the second highest average litter density (40.6 ± 14.9 items/100m^2). The site with the lowest densities of items found was in the southern region of Cabrera in Codolar dels Estells with an average of 0.2 ± 0.3 items/100m^2 where access is restricted and only one item was found in 2019 and no marine litter was observed in 2020.

Overall, the most common habitats assessed in this study where ML items were found were sandy habitats (30%) followed by seagrass with sand (19%) and seagrass with sand patches (18%) (Table 3). In terms of ML found in each of the habitats studied, most of the items were found in rocky habitats (4.9 ± 17.7 ML items/habitat) and in seagrass habitats with sand patches (2.3 ± 3.8 ML items/habitat) (Table 3). In terms of ML regarding weight, seagrass habitats had the highest accumulations of items weighing 350.2 ± 368.5 g/habitat while seagrass habitats with sand patches on average had the second highest ML abundance by weight with an average of 235.8 ± 813.9 g of ML per habitat. Regarding location, in the public access area of Es Port, the primary habitats where marine litter was found were sandy (37%) and seagrass habitats with sand (20%), while in the no-take area of Es Burrí, the majority of the habitats were either sandy and rocky (21%) or seagrass with sand patches (21%). In the no-take area of Santa Maria in the north, the majority of habitats were sandy (24%) and seagrass and sandy (19%), similar to Es Port, while in the southern region, Estells, was composed mostly of rocky habitats (67%) with a mixture of seagrass and sandy habitats (~30%).

3.2. Marine litter classification

In terms of overall abundance by material types, artificial polymers (50%; 450 items) and glass/ceramics (41%; 369 items) were the primary types of items collected in seafloor areas. In comparison, the reverse was found for overall ML abundance by weight with glass/ceramics (48.5%; 34.1 kg) followed by artificial polymers (25%; 17.8 kg) being the most

Table 1
Summary of the underwater seafloor scuba-diving marine litter surveys performed for macrolitter items.

Year	Location	Site	Marine Reserve Protectin Status	N. of transects	Total Transect length (m)	Transect Depth Range (m)	Total Surveyed Area (m^2)	Total Marine Litter Items (n)	Total Marine Litter Weight (g)	Total Artificial Polymer Weight (g)	Average ± Standard Deviation Litter density (n items/100 m^2)	Artificial Polymers (%)
2019	Es Port	Es caló des forn	Public access	3	60.22	2.2–4	240.89	90	17,884.1	8812.3	40.6 ± 14.9	58.59
	Es Port	S'Espalmador	Public access	3	337.58	1.8–6.9	2025.5	26	6284.1	42.5	2.1 ± 3	13.38
	Es Port	Sa Platgeta	Public access	3	142.61	1.0–1.35	855.68	26	291.1	47.2	3 ± 2	23.08
	Es Port	Sa platgeta des pagès	Public access	3	129.26	2.4–4.0	775.59	39	1662.9	196.6	5.3 ± 2.2	51.28
	Es Port	Es caló de ses Güies	Public access	3	126.91	2.4–8.7	761.44	86	10,316.6	797.4	14.9 ± 16	15.12
	Santa Maria	Cala en Ganduf	No-take	3	167.03	2.2–7.35	1002.19	98	4113	1518	8.5 ± 8.1	79.59
	Santa Maria	Cala Santa Maria	No-take	3	127.59	1.7–5.75	885.07	49	2588.5	1506.1	11.5 ± 10.4	89.8
	Es Burrí	L'Olla	No-take	3	130.17	3.5–5.2	520.67	90	2766.98	647.38	18.4 ± 10.7	91.11
	Es Burrí	L'Olló	No-take	3	138.57	2.8–6.7	554.26	37	1100.6	868.9	6.1 ± 4.7	94.59
	Estells	S'Estell de s'Esclata-sang	No-take	3	117.63	3–4.8	705.77	2	302	0.4	5.5 ± 9.4	50
	Estells	Codolar dels Estells	No-take	3	233.97	3–10.4	935.87	1	0.4	75.4	0.2 ± 0.3	100
	Estells	S'Avarador des Far	No-take	3	109.52	1.5–8	781.88	124	3794.58	515.68	61.9 ± 105.7	12.1
2020	Es Port	S'Espalmador	Public access	3	323	2.2–6.8	1292	41	9350.2	69.7	3.2 ± 3	9.76
	Es Port	Sa Platgeta	Public access	3	335	0.5–1.7	1340	30	1318.2	95.4	2.5 ± 1.8	30
	Es Port	Es caló de ses Güies	Public access	2	72	2.9–8.35	288	31	4779	590.6	10.6 ± 4.2	19.35
	Santa Maria	Cala Ganduf	No-take	3	180	2.3–4.7	720	58	1658.89	638.19	9 ± 6.5	84.48
	Es Burrí	L'Olló	No-take	3	206	2.85–5.9	824	24	1034.5	546.5	3.7 ± 3.1	68.18
	Es Burrí	Es caló des Macs	No-take	3	202	1.75–6.1	808	12	345.9	346.9	1.6 ± 1.1	100
	Estells	Codolar dels Estells	No-take	3	354	1.2–4.3	1416	0	0	0	0 ± 0	0
	Estells	S'Avarador des Far	No-take	2	93	1.7–5.8	372	37	521.8	342.4	8.3 ± 10.7	27.03

common marine litter items. Processed/worked wood, cloth/textile and metal items comprised less than 5% (5 items; 12 items; 40 items) of the total abundance. However, in terms of weight, they made up almost 25% (7.8 kg; 6.6 kg; 4.2 kg) of the marine litter composition. Regarding locations, at sites found within the port (i.e. s'Espalmador and sa Platgeta) mainly glass items were observed while in sites within the no-take areas (i.e. l'Olla and Cala Santa Maria), the majority of the items were made of artificial polymers (mainly plastic items from beverage and food containers) (Fig. 2). A shift in the type of materials found in coastal seafloor areas from 2019 to 2020 was evident at all sites, as rubber was absent in 2020 and metal was scarce in 2020 compared to 2019.

The nMDS ordination results indicated a stress type 1, stress = 0.09 (Fig. 3). Material type was significant (ANOSIM, $R = 0.358$, $p < 0.001$), indicating differences between sizes and material types. Artificial polymers, glass and ceramics were presented in almost all the size classes while other items such as processed/worked wood were more similar to either the very large size class (F) or the smallest size class (A), while metal and other objects had a medium size frequency (B) and were not abundant in the other size classes (Fig. 3).

The top ten items have been presented by year (Table 2). In 2019, bottles (including pieces) were the most abundant items collected (30.2%) followed by glass or ceramic fragments >2.5 cm (8.5%). The third most common items were food containers (7%) followed by plastic pieces (6.6%). In 2020, the same categories as 2019 were dominant with glass/ceramic fragments >2.5 cm (18.9%) followed by the third most common ML type which was remnants from plastic bags (8.2%). Overall, similar items were collected both years with differences such as the presence of metal pieces and fishing gear in 2020 in comparison to 2019.

3.3. Spatial distribution

Regarding differences in the abundances of ML collected considering protection status, the mean abundance of items collected in no-take areas was of 13.6 ± 30.9 items/100 m^2 weighing an average of 1111.1 ± 3139.9 g/100 m^2 while in public access areas these densities had a mean value of 5.7 ± 7.3 items/100 m^2 although the mean weight of these items increased substantially to 606 ± 673.4 g/100 m^2 (Fig. 4). In terms of overall abundances, no significant differences were found between the number of items found in no-take areas compared to public access areas (MW, $p > 0.05$ nor in terms of weight (MW, $p > 0.05$).

In terms of the spatial distribution between locations, results from the abundance model indicated that the model only including the fixed effect for location (AIC, 296.5) was the best model although the random effects had a very low intraclass correlation (ICC = 0.14), as the variances were very low and close to zero and no significant differences were found between any of the locations in the analysis (GLMM, $p > 0.05$) (Fig. 5A). For the weight model, the best model included the random effects of transects nested within sites (AIC, 1002.7) with a high ICC of 0.88 (Fig. 5B). Despite this, results indicated that no significant differences were identified between locations (GLMM, $p > 0.05$). For both models, this was further confirmed with the post hoc analyses.

For the correlation between abundance of items on beaches and seafloor areas, a positive correlation was found in terms of abundance although no significant differences were found ($R = 0.27$, $p = 0.33$) (Fig. 6A). In relation to the weight of items, a very slight negative correlation was found although no significant differences were found between marine litter on beach and in shallow coastal seafloor areas ($R = -0.03$, $p = 0.89$) (Fig. 6B).

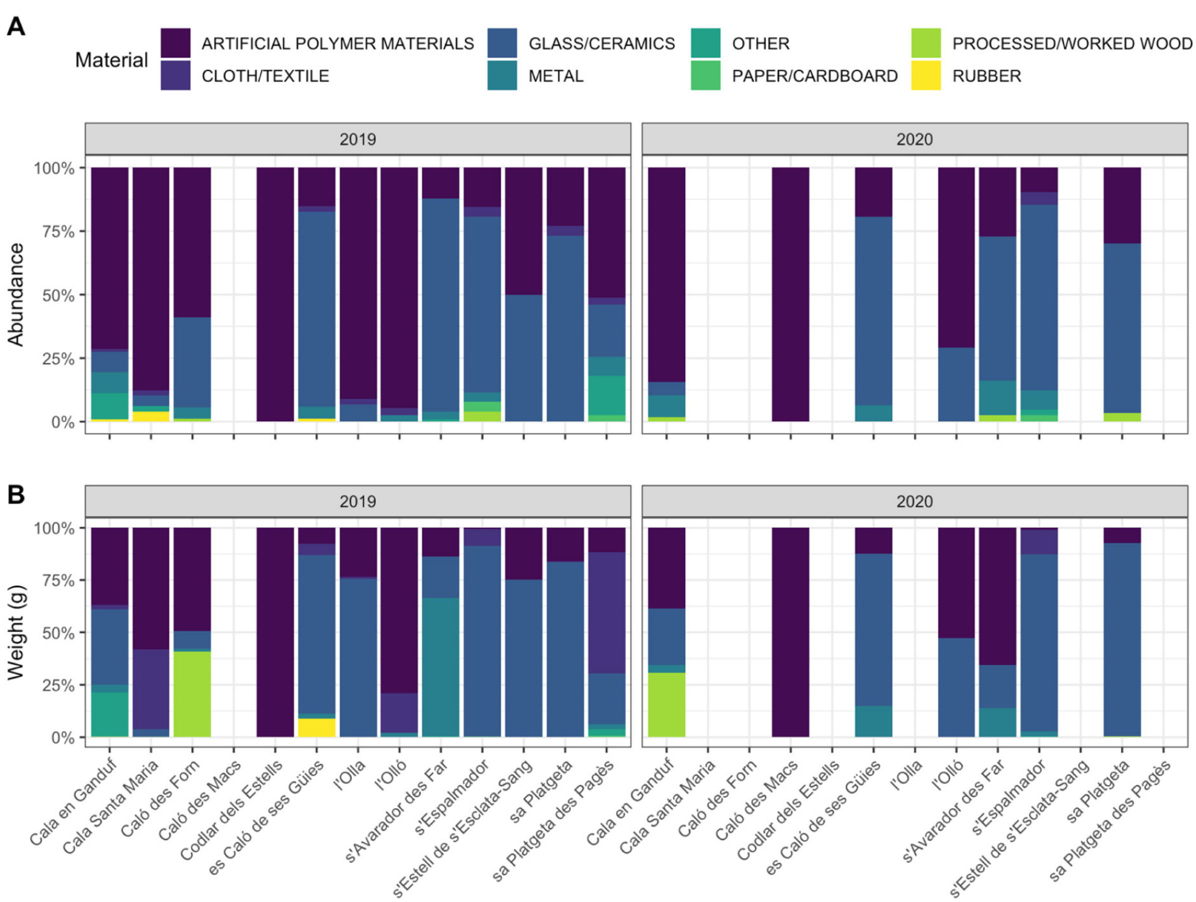

Fig. 2. Summary of the percent abundance of the materials collected at each sampling site by year for abundance (A) and for weight (B). Category classification follows the Plastic Busters MPAs harmonized protocols (Fossi et al., 2019). Empty bars indicate that site was not surveyed during the corresponding year.

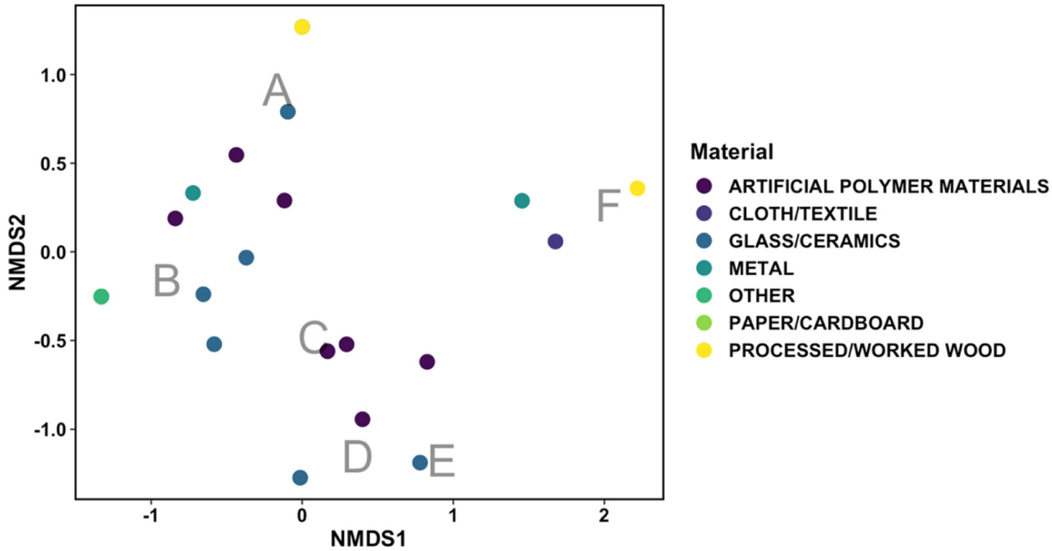

Fig. 3. Visualization of the non-metric multidimensional scaling for the material types found on the seafloor and the size classification of the items. All items were categorized and assigned the TSG_ML General Code, weighted to the nearest two decimal points (grams) and assigned the following size classes: A = 25 cm^2, B = 100 cm^2, C = 400 cm^2, D = 2500 cm^2, E ≤ 1 m^2, F > 1 m^2.

Table 2
Summary of the top ten items from underwater seafloor scuba diving marine litter surveys collected in 2019 and 2020.

Year	Marine Litter category	Sub-category	N	%
2019	GLASS/CERAMICS	Bottles, including pieces	202	30.2
	GLASS/CERAMICS	Glass or ceramic fragments >2.5 cm	57	8.5
	ARTIFICIAL POLYMER MATERIALS	Food containers incl. fast food containers	47	7.0
	ARTIFICIAL POLYMER MATERIALS	Plastic pieces 2.5 cm > < 50 cm	44	6.6
	ARTIFICIAL POLYMER MATERIALS	Bags	37	5.5
	ARTIFICIAL POLYMER MATERIALS	Nets and pieces of net < 50 cm	31	4.6
	ARTIFICIAL POLYMER MATERIALS	Sheets, industrial packaging, plastic sheeting	19	2.8
	OTHER	Other	18	2.7
	ARTIFICIAL POLYMER MATERIALS	Other plastic/polystyrene items (identifiable)	17	2.5
	ARTIFICIAL POLYMER MATERIALS	Drink bottles ≤0.5 l	15	2.2
2020	GLASS/CERAMICS	Bottles, including pieces	57	24.5
	GLASS/CERAMICS	Glass or ceramic fragments >2.5 cm	44	18.9
	ARTIFICIAL POLYMER MATERIALS	Plastic bag collective roll; what remains from rip-off plastic bags	19	8.2
	ARTIFICIAL POLYMER MATERIALS	Plastic pieces 2.5 cm > < 50 cm	19	8.2
	ARTIFICIAL POLYMER MATERIALS	Small plastic bags, e.g. freezer bags, including pieces	11	4.7
	METAL	Other metal pieces <50 cm	9	3.9
	ARTIFICIAL POLYMER MATERIALS	Food containers incl. fast food containers	8	3.4
	ARTIFICIAL POLYMER MATERIALS	Shopping bags, incl. pieces	5	2.1
	ARTIFICIAL POLYMER MATERIALS	String and cord (diameter less than 1 cm)	5	2.1
	ARTIFICIAL POLYMER MATERIALS	Fishing net	4	1.7

4. Discussion

This research highlights the extensive presence of marine litter along the shallow coastal seafloor area of the Cabrera MPA as well as the importance that seafloor marine litter monitoring programs should be conducted in an annual basis and include removal when possible given that an overall average marine litter abundance of 7.59 items/100 m^2 (range 0–37.36 items/100 m^2) weighing over 70 kg was quantified in two years of scientific surveys with 75% of observed marine litter collected from the first to the second year. These high abundances of ML in the coastal regions are in agreement with other regions in the Mediterranean Sea where shallow coastal areas are sinks for marine litter, especially within the first 5 nautical miles of the coastal areas (Alomar et al., 2020a; Katsanevakis and Katsarou, 2004).

Table 3
Summary of the average (± standard deviation) of the abundance and weight if marine litter items collected and their overall percent contribution per habitat during the seafloor visual scuba surveys.

Habitat	ML abundance (n° items)	ML weight (g)	Percent (%)
Rocky	4.9 ± 17.7	204.6 ± 485.3	7.6
Sand patches	1.7 ± 2.7	81.5 ± 135.2	6.6
Sandy	1.9 ± 4.4	156.8 ± 283.5	30.5
Sandy and rocky	1.6 ± 2.5	35.6 ± 57.3	8.7
Seagrass	1.1 ± 0.6	350.2 ± 368.5	2.8
Seagrass and rocky	1.5 ± 1.8	53.6 ± 81.1	5.9
Seagrass and sandy	2.2 ± 2.5	315.5 ± 1101.8	19.4
Seagrass with sand patches	2.3 ± 3.8	235.8 ± 813.9	18.4

The ML concentrations varied in comparison to other seafloor regions in the Mediterranean Sea. In the deep sea, 4.06 ± 1.8 kg of litter/ha was reported south of the Balearic Islands with concentrations ranging from 0.7 and 1.8 kg of litter ha^{-1} throughout sites (Pham et al., 2014). Along the Spanish continental shelf, a mean density of 9.8 kg/km^2 ML (García-Rivera et al., 2018) and on the Balearic shelf a mean value of 1.39 ± 0.13 kg/km^2 ML (Alomar et al., 2020a) was reported. Throughout the Adriatic-Ionian microregion, ML from trawl surveys have indicated the Gulf of Venice in Italy has the highest median density of 983 items/km^2

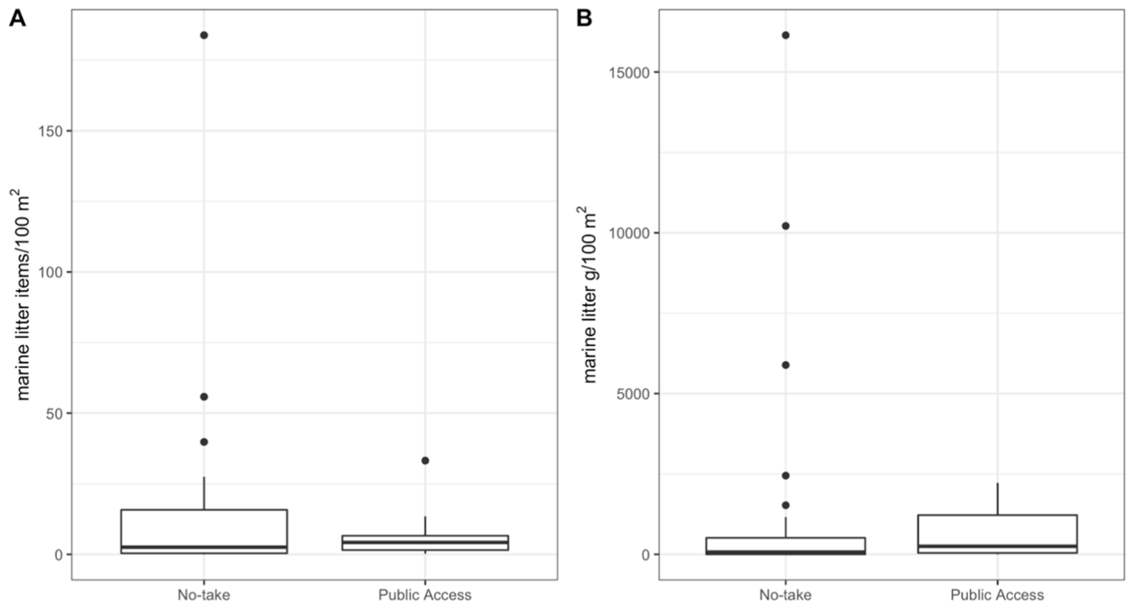

Fig. 4. Summary of the classification of the marine litter collected in the underwater scuba diving survey transects according to protection status, whether the location was a no-take or public access, for the average number of marine litter (items/100 m^2) (A) and for weight of marine litter (g/100 m^2)(B).

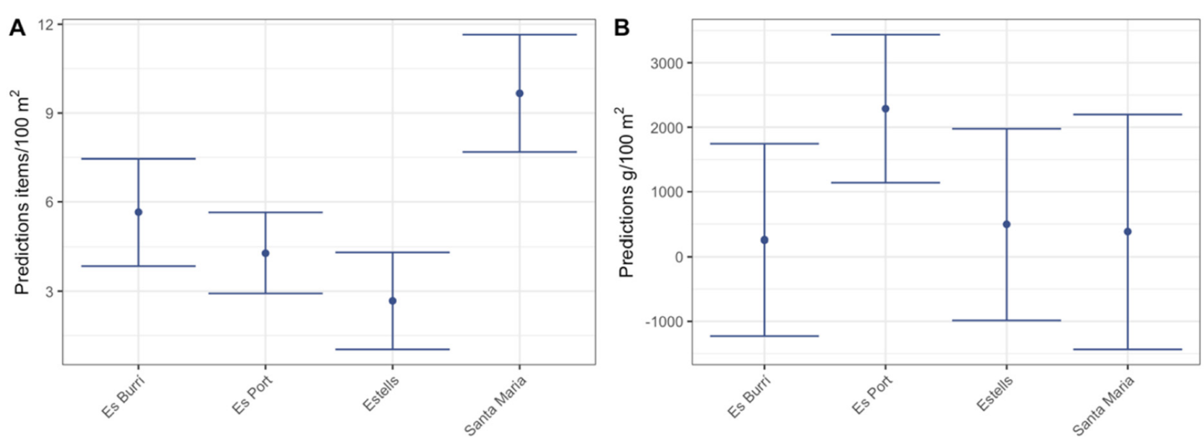

Fig. 5. Results from the generalized linear mixed model analyses to identify the spatial distribution of marine litter between locations for abundance (A) and weight (B). Error bars indicate 95% confidence interval.

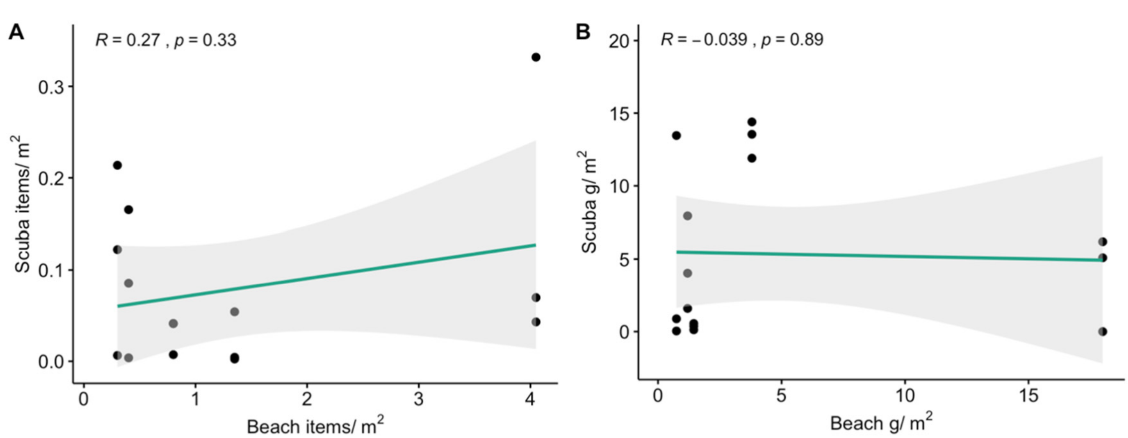

Fig. 6. Pearson's correlation between marine litter collected on beaches (x-axis) and marine litter collected during the underwater scuba diving survey (y-axis) for abundance (A) and weight (B). 95% confidence interval indicated by the grey ribbon.

(Fortibuoni et al., 2019). In the south-east Adriatic, through scuba diving surveys, an average of 2.49 items per 1000 m^2 (Macic et al., 2017) was reported while in the coastal regions of Bosnia and Herzegovin, the scuba visual surveys found a median density of 7 and 4 items/100 m^2 (Fortibuoni et al., 2019). From the scuba diving citizen science survey, 43.55 items/100 m^2 was observed (Consoli et al., 2020) and from ROV transects, of 0.57 ($\pm$0.08) items/100 m^2 (Consoli et al., 2021). Overall ML collection was variable dependent on locations and sampling methodologies, the items collected at Cabrera National Park are inline with ROV and scuba surveys throughout the Mediterranean Sea.

In this study, ML was abundant throughout the MPA and no significant differences were found between the number of items collected within the no-take areas of the MPA compared to the public access areas. This is concerning as this indicates that regardless of the protection status of the area, ML is still accumulating in these coastal areas. In terms of the weight of items, those ML items found within the public access areas of the Cabrera National Park were almost twice as heavy as items identified in the no-take areas of this MPA. All of the public access areas are located within the harbour of Cabrera island, which is exposed to human activities (moorings of boats, residential area for employees, visitors' centre, small shelter, canteen and bathing beaches). ML quantified here consisted mainly of glass bottles, which are heavier than artificial polymer items and consequently are less easily transported across the marine environment through currents. Thus, this could explain the higher amount of ML (in terms of weight) in this area compared to the no-take areas. Although the age of marine litter items is often hard to identify, there was a substantial amount of biofouling on the majority of the glass items which is a possible indication of antiquity. Additionally, when considering the size of ML items, artificial polymer items were the most prominent found in all size classes. It is extensively known that artificial polymer items are found in a wide range of sizes, from a micro-to a macro-scale, throughout the marine environment. Although it is not unexpected that all size classes were observed for plastics in comparison to the other litter types considering that one of the main long-term concerns for artificial polymer items are the fragmentation and weathering of larger objects into smaller items (Andrady, 2015).

Glass bottles and pieces were the primary items collected during both survey seasons although this decreased from 202 items in 2019 to 57 in items in 2020 (~75% decrease). Overall this indicated the successful removal of the items by the scuba divers and highlights a low accumulation rate of ML in the study area. A part from glass/ceramics categories, several items from artificial polymers were abundant during both surveys. Several of the top ten items identified in Cabrera MPA, such as glass bottles including pieces, food containers and plastic pieces with a size classification between 2.5 cm > < 50 cm, were similar and comparable to those found in larger, regional scuba surveys such as in the Adriatic and along the Italian coastline. It is important for these surveys to be performed at a local level in order to identify mitigation measures for that region. In Cabrera MPA, the most abundant items during both survey years were glass bottles (including pieces) and glass or ceramic fragments >2.5 cm (~50%) heavily covered with epibionts. This may give an indication that these items were not recent but rather that they have been accumulating on the seafloor for some time. This is also in agreement with Fortibuoni et al., 2019 where glass bottles and pieces were abundant within the Adriatic, making up ~26% of the sampled ML, although the authors do not mention age nor biofouling of items. Scotti et al., 2021 on the other hand, reported that glass bottles only made up 10% of the items collected along the Italian coastline, which is a much lower occurrence than in Cabrera MPA. Another example of the importance of local surveys is reflected in Fortibuoni et al., 2019, as some of the most common items found were household appliances and car parts/batteries. These larger items were absent from Cabrera MPA as such items are limited to exclusive use with staff housing and the official number of vehicles in Cabrera MPA is less than 10. Moreover, heavy items such as car parts/batteries are less easily transported through currents and winds in comparison to plastic items, which are much lighter and can be easily transported longer distances. In fact, plastics are the most common ML category in the no-take areas of Cabrera MPA, where human access is under severe restrictions. Observations from this study reflect that ML is reaching these areas, possibly due to oceanographic transference from more polluted areas to this pristine zone. In Cabrera MPA, although the abundance of remnants of fishing gear were found in 2020 (<2%) highlighting that despite minimal amounts of fishing material found, it is still sufficient to be a representative material within Cabrera. A possible explanation for this, could be that currently fishing is permitted within the surrounding waters by professional artisanal fishermen or derived from recreational or professional fishing activities in the nearby waters of the Balearic Sea. When comparing abundances between other regions, in the deep sea, Macic et al. (2017) observed that 47–79% of marine litter was of plastic origin. Katsanevakis and Katsarou (2004) reported that 54–55% of litter was of plastic origin while the second most common material were metal items (23–25%), mainly consisting of remnants of fishing materials such as pots and anchors. Moreover, a meta-analysis on global gear loss from Richardson et al. (2019) highlighted that 5.7% of all nets are lost while the loss of traps is slightly higher at 8.6%.

Results from this study highlight that coastal habitats are at risk of accumulating ML items which in turn can affect the conservation of the habitats and organisms in the region. Overall, rocky and sandy patches found within the seagrass meadow transects contained the highest abundances of ML. This indicates that these areas, especially seagrass meadows with sand patches, could be potential accumulation areas of ML. Additionally, in terms of ML weight, seagrass communities retained heavier items than rocky and sandy seafloors. There were a few important observations of marine biota interacting with the ML from the scuba surveys that should be highlighted. The majority of the glass items found where heavily covered with epibionts, primarily bryozoans colonies indicating that these items had been residing on the seafloor for a long period of time. Additionally divers observed an octopus inhabiting a wide mouthed plastic bottle and sea cucumbers entrapped within a glass bottle and laying below a black plastic sheet. These observations with wildlife indicate the co-existence of marine life and marine litter. Up until now, only the ingestion of microplastics by sea cucumbers has been evaluated by several authors (Deudero et al., 2014; Mohsen et al., 2019; Sayogo et al., 2020). However, the physical aspects of species entanglement with large marine litter items is increasingly being reported in seafloor communities. For example, in the Gulf of Mexico, an average of 3.28 $\pm$ 0.27% of the coral colonies were found to be in contact with ML, mostly derelict fishing gear while in the Gulf of Thailand a total of 143 pieces of derelict fishing gear caused damage to 226 coral colonies (Valderrama Ballesteros et al., 2018). In this study, no direct interactions of marine biota with large amount of fishing nets were identified. This may be due to several reasons such as the active management of the removal of lost fishing gear when reported by Cabrera staff or, as previously mentioned, the surveyed areas are shallow depths which are not often fishing grounds for professional artisanal fishermen. Despite this, further research into the connection between lost fishing gear at deeper depths not reached by scuba divers but rather with ROVs should be conducted as previous studies have already highlighted the impact of fishing gear on deeper benthic communities (Consoli et al., 2019).

While the hydrodynamics weren't specifically analysed in this study, it is important to highlight the influence of the connectivity between different MPAs. Compa et al., 2020 identified the hydrodynamic connectivity between the islands of the Balearic Island archipelago with other regions in the western Mediterranean Sea through backtracking models and indicated a strong connectivity between the islands of this archipelago. Hence the transferability of many of the ML items identified in the study area from other regions to Cabrera is very high and possible. Additionally, 3D models of ML distribution highlighted that differences in ML ranged slightly from winter to summer months (<3 kg/km^2–4.5 kg/km^2) with the average depth of neutral buoyant particles found at depths ranging from 15 to 35 m (Deudero et al., 2019; Soto-Navarro et al., 2020). One example of common products found in seafloor coastal areas of Cabrera which are possibly transferred from distant areas are plastic bags used for storing milk

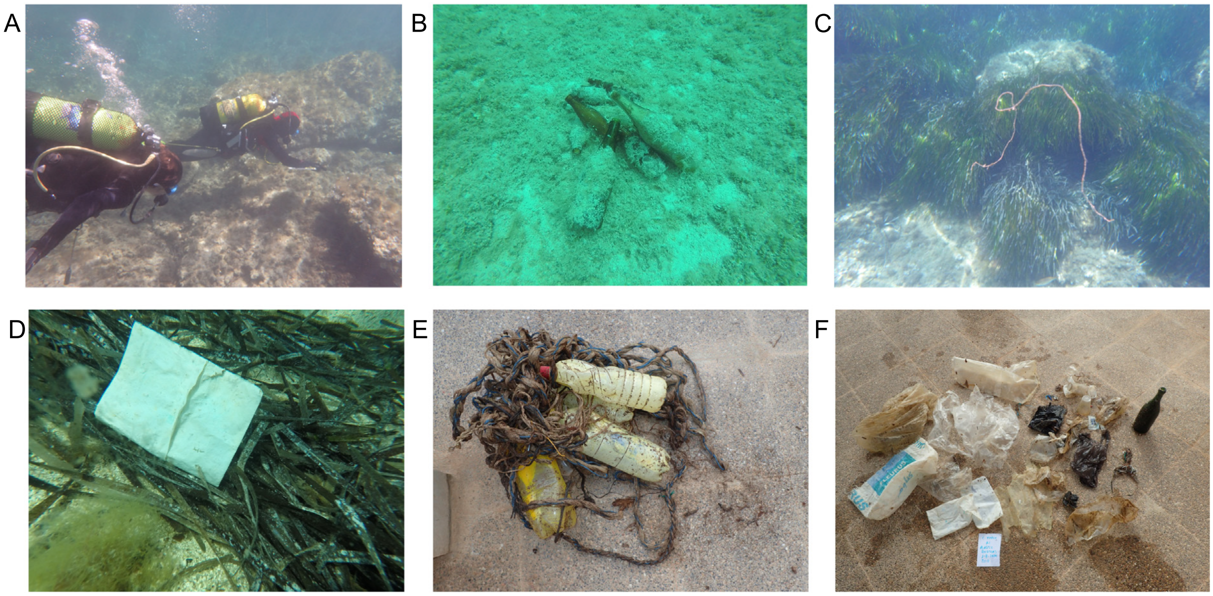

Fig. 7. Examples of marine litter observed on the seafloor in Cabrera National Park during the scuba diving surveys: A) scuba divers surveying in parallel for marine litter on the seafloor, B) glass bottles on the seafloor heavily covered with biota, C) rope entangled in *Posidonia oceanica* seagrass, D) plastic beverage container, E) derelict fishing gear and E) plastic materials and glass bottles marine litter collected from one transect.

products (Fig. 7D), as this item is not only found on the seafloor but it is commonly identified floating on the sea surface throughout the Balearic archipelago.

Many marine litter surveys thus far have relied on marine citizen science surveys performed mainly with diving clubs and schools and Lucrezi et al. (2018) highlights recommendations to improve access to marine citizen science surveys. Considering the growing interest in public participation, this includes for participants to provide feedback after participating in dive surveys. This will aid in avoiding misinterpretation carried out by experienced or trained divers for these items, in addition to large-scale information campaigns regarding the classification and identification of marine litter. Additional improvement is needed in the standardization of methods, transference of protocols and analyses of results to facilitate comparison between regions. In this study with scientific divers, we propose time transects of 15 min using buoys sent from the seafloor to indicate the start/end of each transect which is annotated from the boat on the sea surface. The sampled surface is calculated at posterior using a geographic information system, giving more autonomy to divers to perform underwater transects regardless of the terrain and habitats sampled, especially in coastal waters of small closed inlets and creeks with very heterogeneous seafloors. Additionally, it would be beneficial to include the removal of marine litter quantified during scientific surveys when possible as often this is not achievable due to the presence of larger items (washing machines, shopping carts, fishing nets, etc.), which require additional support for their removal (Fortibuoni et al., 2019; Katsanevakis and Katsarou, 2004). Despite this, the results from this study have highlighted that items such as plastic bottles and fragments, which are feasible for collection and removal during marine litter dive surveys, does not alter the habitat and species from where they are found, and if not removed, they may leave a long-term potential impact to seafloor habitats.

Additionally, there were five locations of scuba dive surveys that coincided with beach clean-ups from 2019, three locations within the harbour area of Cabrera Es Port and two within Santa Maria Bay. Although the correlations obtained were low, similar concentrations of overall marine litter were found in both seafloor and beaches from the same site. In Scotti et al. (2021), almost half of the recognized items from the seafloor (43.2% of total items) could be associated to tourism and beach user activities such as plastic shopping bags and plastic bottles in addition to glass beverage bottles.

The removal of marine litter from the seafloor can often be very costly and preventative measures for reducing ML have been widely considered to be more effective (Scheld et al., 2016). Considering the effectiveness of the first survey campaign and the removal of a large amount of ML from the seafloor at Cabrera MPA, annual or even bi-annual surveys within the park may be sufficient to maintain a low abundance of ML on the seafloor. This recommendation considers that the majority of the items appear to be either transferred to the MPA through oceanographic currents or decades of long accumulation of litter lost directly and indirectly by human beings in the study area. Overall, the scuba surveys covered the coastal area of Cabrera MPA in great detail and highlight accumulation patterns in different regions throughout the MPA with areas outside of public access being primary sinks for accumulation of plastic on the seafloor. Future studies within Cabrera MPA would benefit from analysing the ML-biotic interaction within seafloor areas in addition to surveying depths below 10 m in the adjacent areas to the MPA although other forms of surveying such as ROVs which are non-invasive and provide key descriptions of the surrounding seafloor should be considered for these deeper areas.

CRediT authorship contribution statement

Montserrat Compa: Writing – original draft, Conceptualization, Formal analysis, Visualization, Methodology. **Carme Alomar:** Conceptualization, Writing – review & editing. **Mercè Morató:** Methodology, Visualization, Writing – review & editing. **Elvira Álvarez:** Conceptualization, Methodology, Writing – review & editing. **Salud Deudero:** Resources, Funding acquisition, Conceptualization, Writing – review & editing, Supervision, Validation.

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.

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