Universitat de les Illes Balears

MASTER'S THESIS

ANTHROPOGENIC MARINE DEBRIS ALONG THE SPANISH MEDITERRANEAN COASTLINE: WHAT IS AFFECTING ITS ABUNDANCE?

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Master's Degree in Marine Ecology

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ABSTRACT

Marine litter is a problematic affecting every ecosystem of the planet and trying to solve it is certainly becoming the focus of many studies worldwide. Beach surveys are an effective way of measuring the amount of Anthropogenic Marine Debris (AMD) deposited on beaches and the factors influencing its abundance and deposition patterns. Also, beach surveys suppose an effective method for raising awareness between the local communities and a powerful educational tool for the youngest citizen scientists.

The Mediterranean Sea, being a semi-enclosed basin with densely populated coasts, is not evading this global problematic. In this study, a dataset of 62 beaches from the Spanish Mediterranean coast cleaned from February 2019 to November 2019 has been analyzed, together with data from scientific surveys performed on beaches of the Cabrera Archipelago National Maritime-Terrestrial Park, a Marine Protected Area in the Balearic Islands, Western Mediterranean.

This study aims to understand the variables, anthropogenic and environmental affecting the deposition of AMD in these areas, also describing in depth the composition, sources and patterns of AMD along the Spanish Mediterranean coastline.

The prevailing type of debris in most of the beaches surveyed was plastic, being the light packaging the dominant fraction of the total debris found. The source of the majority of litter was domestic and sampling dates and location were found to have the greatest effect on the abundance of AMD, being Fall the season with higher abundance of debris on the beaches sampled.

1. INTRODUCTION

Anthropogenic Marine Debris (AMD) has been characterized as a global and persistent environmental problem which has considerably increased over the last decades (Galgani et al., 2015). The literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide (Derraik et al., 2002) and the accumulation and impacts of plastic litter appear to be most serious in marine systems (Ryan et al., 2009). AMD is threatening marine and coastal wildlife as well as causing loss of coastline aesthetic quality (Alkalay et al., 2006), since a big amount of marine litter ends up washed up on beaches (Gabrielides et al., 1991). These undesirable contaminants may be of either land or marine-based sources, their origins may be local or distant, and the environmental consequences are many and varied (Gregory et al., 2009).

Land-based litter include items entering the marine environment through rivers, drainage systems, streams and sewage inputs, as well as items discarded by beachgoers. It can also be classified according to its source: recreational, domestic, agricultural and industrial. Marine or ocean-based litter comprises items coming from commercial and recreational fishing, shipping and recreational sailing. (Galgani et al., 2000; Koutsodendris et al., 2008; Pruter 1987).

This study focusses on the Mediterranean Sea, which is a sensitive ecosystem lying amid a densely populated and highly industrialized region, with intense coastal and shipping activities (Katsanevakis et al., 2004). Beaches are a major attraction in Mediterranean coastal areas and are one of the main focuses of attention for coastal and tourism management (Ariza et al., 2007). An increase in marine debris density near metropolitan areas has been reported for several places in the Mediterranean both on the continental shelf (Galgani et al., 1995, 2000) and on beaches (Gabrielides et al., 1991).

The sampling for this study was taken along the Spanish Mediterranean coasts, including those from the Balearic Islands, that are also highly exposed to human stressors that impact coastal habitats (Deudero et al., 2015; Ariza et al., 2007).

1.1 Beach surveys and citizen science

Beaches are the most easily accessible areas for studying marine debris (Barnes et al., 2009). For this reason they have been widely surveyed given their advantages over other methods, which include proximity to sources, simplicity, and cost-effectiveness to monitor large-scale trends in AMD, apart from the aforementioned ease of access (Honorato-Zimmer et al., 2019). This is reflected in beach surveys carried out in many countries around the world, normally involving many volunteer participants (Bravo et al., 2009). The participation of thousands of citizen scientists of different ages and social backgrounds in the data collection process plays a significant role in raising public awareness on marine environmental issues, and in promoting a sense of responsibility in protecting marine resources (Kordella et al., 2013).

On the present study, a dataset from the citizen science program *Proyecto Mares Circulares* has been analyzed. The aim of this project, an initiative from Coca-Cola Spain, is to clean Spanish beaches and aquatic environments every year, in addition to encouraging the population to recycle and to look for long term solutions to the plastic problematic (Proyecto Mares Circulares 2018). 123 beach clean-ups were performed with volunteer citizen scientists collecting residues along 62 beaches from the Spanish Mediterranean coasts, and classifying them on several different categories for further analysis.

1.2 AMD on Marine Protected Areas

There is evidence of plastic litter being greater in more remote or protected areas than in more urbanized ones (Alomar et al., 2015; Derraik et al., 2002). The presence of this litter type within Marine Protected Areas (MPAs) boundaries suggests that dispersion is linked to factors such as winds and surface currents and not necessarily to the nearby coastal populations (Martinez-Ribes et al., 2007).

The Cabrera Archipelago National Maritime-Terrestrial Park (CANMTP), located on the Balearic Islands, is the largest MPA from the Western Mediterranean (Boletín de la Red de Parques Nacionales, https://www.miteco.gob.es/es/red-parques-nacionales/boletin/mar-cabrera.aspx). It has been under study to monitor the amount of marine litter on its coasts within the *Plastic Busters MPAs*

Med Interreg project led by the Balearic Centre of Oceanography of the Spanish Institute of Oceanography. A total of 9 beach surveys were carried out on Cabrera's beaches by a group of scientists and volunteers, classifying the marine debris according to the *Plastic Busters* protocol, which aims to harmonize methodologies for monitoring marine litter in Mediterranean pelagic and coastal MPAs (PlasticBusters MPAs, *https://plasticbustersmpas.interreg-med.eu/what-we-do/).*

Bringing together the data from both projects, to maximize the amount of information possibly obtained about the abundance of marine debris along the Spanish Mediterranean, the main 4 objectives for this study are:

1. Describe the composition of marine litter found in beaches and possible sources according to data from two different projects.
2. Identify possible spatial and temporal patterns of Anthropogenic Marine Debris along the Spanish Mediterranean coasts.
3. Identify which factors are affecting the abundance of AMD and its accumulation patterns.
4. Determine if a conservation network like Natura 2000 has an effect on the distribution and abundance of AMD.

2. MATERIALS AND METHODS

2.1 Study area

A total of 132 beach surveys were conducted at 68 different beaches along the Spanish Mediterranean coastline, belonging to 11 provinces and 43 coastal municipalities (Fig. 1). Given the variability of the locations surveyed, the characteristics of the beaches differed widely, depending on their anthropogenic pressures but also on their natural structure.

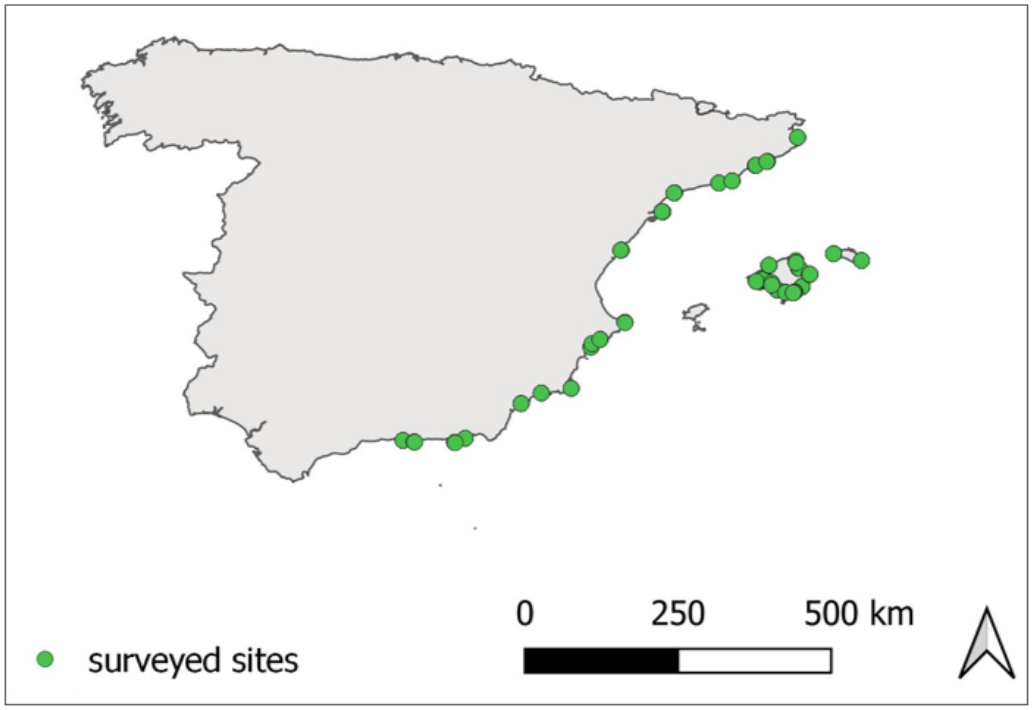

Fig. 1. Total beaches surveyed for the present study.

From those 68 beaches, 6 are located inside the Cabrera Archipelago National Maritime-Terrestrial Park (CANMTP), which is situated off the southeastern coast of the island of Mallorca, in the Balearic Islands. It comprises 19 islands, from small islets to the 38.6 km perimeter Cabrera Island (Fig. 2). This area was declared a National Park in 1991, when conservation policies were implemented to protect both the land and marine components (Marbà et al 2002). The archipelago is not inhabited and there are different regulations on different areas: Es Port and Santa Maria, where some of the surveyed beaches lay, are situated in the Marine Protected Area (MPA) of the park and in the No take area of this MPA respectively. Es Port lies in a sheltered bay with limited and restricted uses where boat access is controlled, whereas Santa Maria is

free of sewage or inorganic inputs and no boat traffic or any other type of activities are permitted (Alomar et al., 2015).

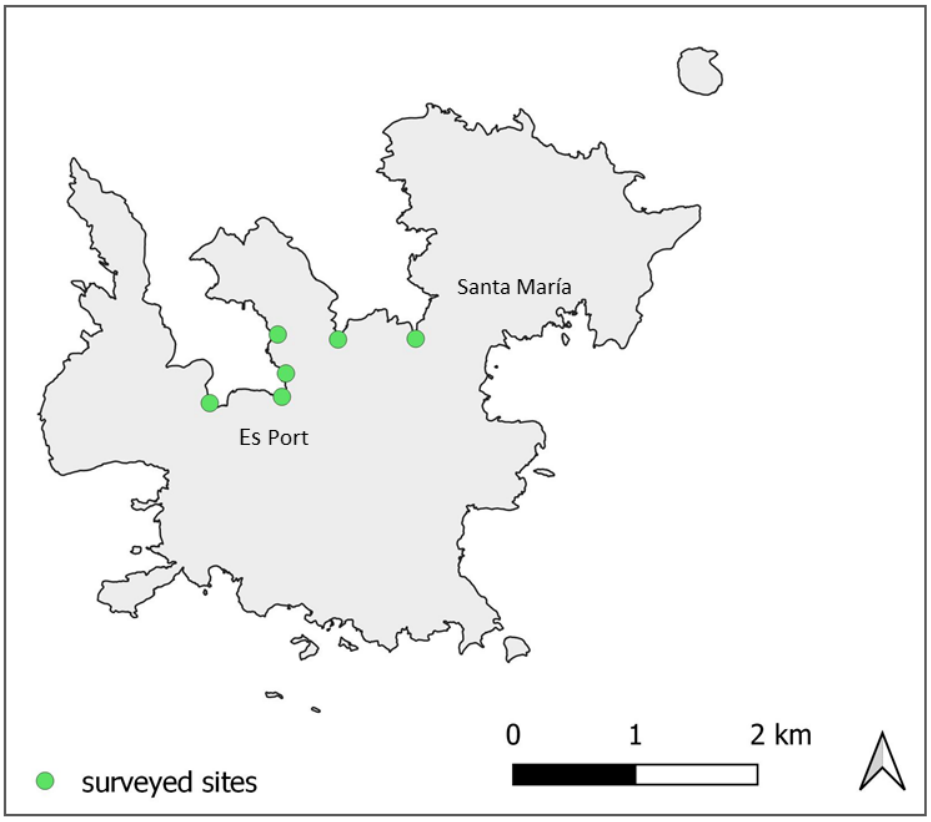

Fig. 2. Beaches surveyed within the Cabrera National Park.

2.2 Beach litter surveys

Data from *Proyecto Mares Circulares* was available from 123 surveys on 62 beaches. 2 surveys per beach on different months were conducted by volunteers within this national project, except for Dragonera island, that was sampled just one time.

A total of 5,415 volunteers from 7 different age groups (Fig. 3) took part on the clean-ups, that occurred from February 2019 to November 2019.

The selection criteria for the beaches sampled prioritized the recommendations and environmental criteria from *Asociación Chelonia*, a collaborating organization of *Proyecto Mares Circulares*. Presented suggestions about adequate beaches by local areas of *Coca-Cola European Partners*, based on their previous knowledge and interest at a local level (municipalities, schools, partners…), were considered when selecting beaches.

After the residues were collected by the volunteers during the clean-up events (Figs. 4 and 5), when they covered areas ranging from 150 m^2 to 0.2 km^2, the monitoring and categorization of the debris was executed by professionals from *Asociación Chelonia*, minimizing this way the possible errors and making the dataset more robust. Items were classified into 11 categories and 20 subcategories or fractions within these categories (Table 1), identifying predominant residues from each category plus remnant fractions considering non recognizable items.

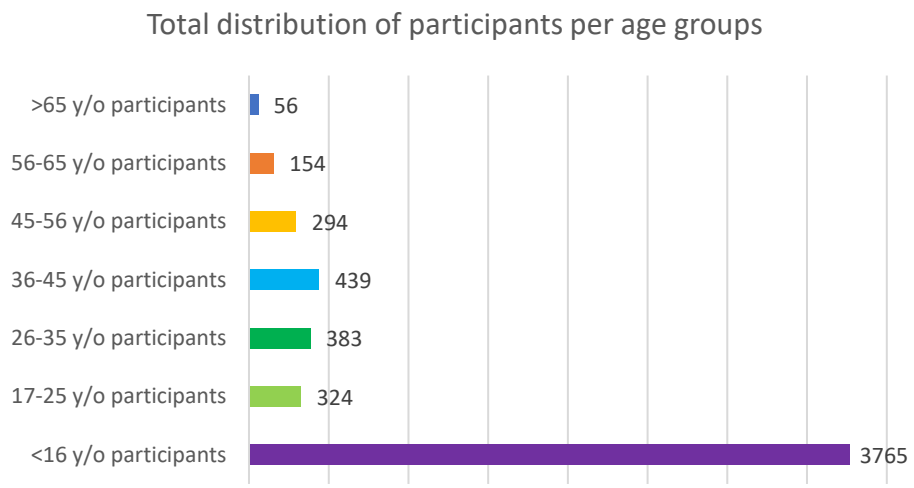

Fig. 3. Total distribution of participants on Proyecto Mares Circulares clean-ups per age group (y/o; years old). Data from Proyecto Mares Circulares.

Figures 4 and 5. Volunteers during two beach clean-ups from Proyecto Mares Circulares. Pictures provided by Proyecto Mares Circulares.

Categories	Fractions	Categories	Fractions
Ceramics	Ceramics and construction material	Paraffin or wax pieces	Remnant fraction (paraffin/wax)
Rubber	Tires Remnant fraction (rubber)	Plastic (polystyrene included)	Light packaging (plastic) Other plastics Remnant fraction (plastic)
Carved wood	Worked wood Remnant fraction (wood)	Hygienic/sanitary residues	Medicines Remnant fraction (hygienic)
Metal	Electric appliances, batteries and metal Light packaging (metalic)	Clothes/fabric	Clothing Remnant fraction (fabric)
Paper/cardboard	Light packaging (paper/cardboard) Paper/cardboard Remnant fraction (paper/cardboard)	Glass	Crystal Glass

Table 1. Categories and fractions considered in Proyecto Mares Circulares surveys.

The second data set includes more local data collected during the 2019 fieldwork season for the *Plastic Busters MPAs Med Interreg project* at the marine protected area of the Cabrera Archipelago National Maritime-Terrestrial Park (CANMTP).

This data set consisted of 9 surveys of marine debris collected by 1 or 2 observers at 6 different locations, one in August 2019 and another one in October 2019, together with 16 volunteers.

In Cabrera island 6 beaches were sampled: *Sa Platgeta, Es Caló de ses Güies, S'Espalmador, Cala en Gandulf, Es Caló des Forn* and *Sa Platgeta des Pagès*.

Sa Platgeta, Es Caló de ses Güies and *S'Espalmador* were sampled in both periods whereas *Cala en Gandulf* and *Es Caló des Forn* were sampled just in August 2019 and *Sa Platgeta des Pagès* just in October 2019.

The beach areas surveyed ranged from 96 m^2 to 480 m^2 and the whole area of each beach was sampled.

The items were identified, measured (volume and weight), counted (number of items) and classified in 7 major groups (Glass/*ceramics, Processed/worked wood, Metal, Paper/cardboard, Artificial polymer materials, Cloth/textile and Rubber*) following the *Plastic Busters MPAs Med Interreg project* protocol.

2.3 Identification of AMD sources and patterns

They were proposed two different sources of the marine debris surveyed: marine or land-based. Within the marine-based source, according to the literature, they were stablished in the present study 2 other source types: fishing or navigational activities, whereas within the land-based source, recreational activities or other activities conformed the subdivision. Within other activities in turn another classification was proposed in this study, separating the residues in domestic, agricultural or industrial sources for further knowledge about the debris sampled.

GIS software was employed to plot the abundance of debris types per province, in order to identify (if present) a latitudinal pattern on the abundance of AMD along the Mediterranean Spanish coastline.

2.4 Data analysis

Both datasets, from *Proyecto Mares Circulares* and *Plastic Busters MPAs project* carried out in CANMTP, were standardized with the purpose of analyzing both as one from this point onwards. The debris abundance was provided in items/m^2, given the disparity of beach surface surveyed, ranging from 96 m^2 to 0.2 km^2. Also, the litter classification categories from *Proyecto Mares Circulares* were used on the final dataset.

6 factors shaped this merged dataset, consisting of: *Beach* (the 68 beaches surveyed), *Date* (the exact dates from February 2019 to November 2019 when the surveys were undertaken), *Season* (Fall, Winter, Spring or Summer, assigned depending on the variable *Date*), *Municipality* (the 43 municipalities that the beaches surveyed belonged to), *Province* (the 11 provinces that the beaches surveyed belonged to), *Residue category* (the 11 AMD categories from *Proyecto Mares Circulares*) and the response variable, *Items/m^2* (the total of items found per residue per m^2).

To complete this final dataset, a compilation of 15 factors were added to the study, to increase the number or variables possibly affecting the abundance of marine debris. These factors were anthropogenic pressures related and

environmental characteristics from the beaches, and 11 of them entered the final analysis after preliminary statistics to test for correlation (Table 2).

The information regarding these variables was obtained from the *Guía de playas,* an application from the Spanish Government (*MITECO: Ministerio para la Transición Ecológica y el Reto Demográfico*) that provides data on Spanish beaches, their natural characteristics and their level of anthropization (Guía de playas,https://www.miteco.gob.es/es/costas/servicios/guia-playas/default.aspx); the Natura 2000 Network Viewer (Natura 2000 Network Viewer, https://natura2000.eea.europa.eu/), to select the beaches sampled that fall under this protection figure; and the Blue Flag Viewer (Blue Flag, https://www.blueflag.global/all-bf-sites), to note which beaches from the final dataset had been awarded with this eco-label.

Factor	Levels	Factor	Levels
Wave action	calm waters	Anchorage	yes
	calm waters/windy		no
	moderate wave action		
	moderate wave action/windy		
Blue flag	yes	Access	on foot difficult
	no		on foot difficult/car
Distance to port	0-20 km²		on foot difficult/car/boat
Coastline	cliff		on foot easy
	dunes		on foot easy/car
	dunes/wetland		on foot easy/boat
	wetland		on foot easy/car/boat
	wetland/mountain		boat
	mountain		car
	semi-urban	Cleaning services	yes
	urban		no
Beach composition	sand	Beach bar	yes
	sand/pebbles		no
	sand/gravel	Natura 2000	yes
	sand/gravel/pebbles		no
	sand/gravel/rock	Occupancy	low
	sand/rock		medium
	pebbles		high
	pebbles/rock		
	pebbles/rock/gravel/sand		
	gravel		
	rock		
	rock/gravel		

Table 2. Factors likely affecting the abundance of AMD.

Given the nature of the final dataset, to test objectives 3 and 4 (Identify which factors are affecting the abundance of AMD and its accumulation patterns and discern if a conservation network like Natura 2000 affects the abundance of AMD), a Welch ANOVA analysis was conducted.

Afterwards, in order to calculate the effect size of each significant variable, an adjusted ω^2 was calculated with the following formula:

$$est.\omega^2 = \frac{df_{bet}(F-1)}{df_{bet}(F-1)+N_T}$$

Where df_{bet} are the degrees of freedom from the model, F is the result from the *Welch's F test* and N_T is the total of cases.

Finally, a post hoc test was performed to analyze differences (if present) between the groups of one categoric variable influencing the abundance of AMD on the surveyed beaches from this study.

3. RESULTS

3.1 Description of marine litter and its sources

3.1.1 Characterization and distribution of AMD

246,560 items of marine debris from different sources were collected during the 132 surveys carried out, resulting in a total abundance of debris of 76.76 items/m^2 with an average of ±1.13 items/m^2.

The average surveyed surface was ±15,291 m^2 and the average number or surveyors per month was ±492.

According to categories, 79.8% of the litter found were *Plastics*, followed by *Paper/cardboard* (6.82%) and *Glass* (4.96%) (Fig. 6). The largest fraction within the category *Plastics* was the one corresponding to light packaging.

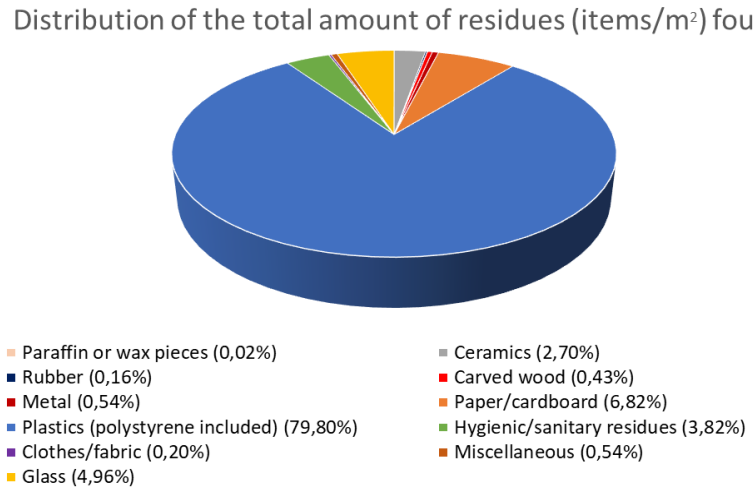

Fig. 6. Distribution of the total amount of residues found on the beaches sampled.

From the 68 beaches surveyed (62 from *Proyecto Mares Circulares* and 6 from the CANMTP) the Top 5 litter items identified are shown in Table 3.

Residues	Items/m2	Category
Non identifiable plastic pieces (polystyrene included) from 0-2,5 cm	38.588	Plastic
Cigarette butts	4.868	Paper/cardboard
Non identifiable plastic pieces (polystyrene included) from 2,5-50 cm	3.025	Plastic
Bottles, cans and pots	2.027	Glass
Construction materials (bricks, tiles)	1.937	Ceramics

Table 3. Top 5 marine litter items found on the beaches surveyed.

3.1.2 Marine debris sources

From the total of items/m^2 found (76.76 items/m^2), around 1.43 items/m^2 were identified as marine-based sources, being mainly plastic strings from ropes and fishing material, mostly from commercial and recreational fisheries but also navigational activities like merchant ships, passenger ferries and recreational boats.

On the other hand, the vast majority of items, 75.33 items/m^2, belonged to land-based sources, that could be separated into recreational activities near or on beaches (e.g. bathing, sunbathing, picnics) and inputs from domestic, agricultural and industrial activities, which can reach the coast through sewage systems or direct dumping on the beaches (Fig. 7).

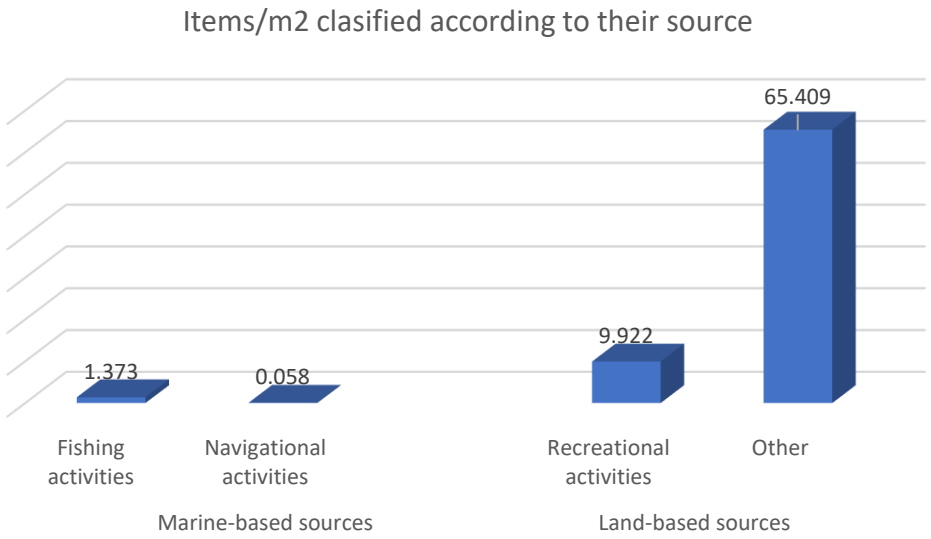

Fig. 7. Items/m2 classified given their source.

In the present study, most of the debris found on the clean ups was, according to figure 7, coming from land sources not related to recreational activities (on the beach), but mostly coming from sewage inputs, being a miscellaneous of objects difficult to characterize accurately. Nevertheless, a probable classification is proposed in figure 8, excluding the 'non-identifiable plastic pieces', which make a significant proportion of the total abundance but is impossible to determine their origin given the degree of degradation that they

have undergone. Most of the litter coming from other land sources different from recreational activities appeared to come from domestic sources.

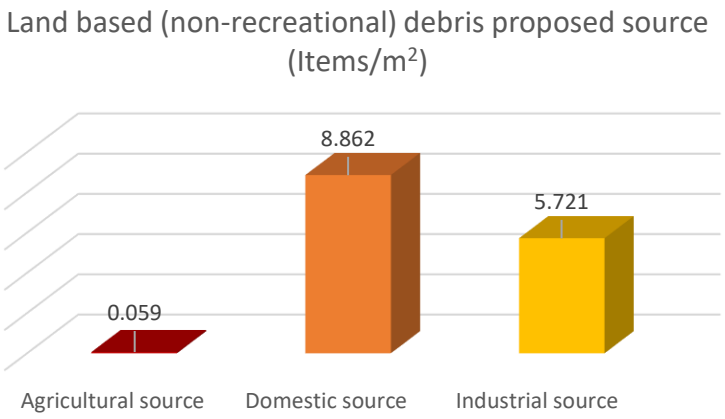

Fig. 8. Proposed source for debris (Items/m²) with land-based but non-recreational sources.

3.2 Spatial and temporal patterns of AMD

Regarding the results from plotting the amount of debris (Fig. 9) separated in the 11 categories previously stablished, from the 11 provinces where beaches were sampled, it becomes evident that specially in Valencia (12.65 items/m^2), Murcia (0.81 items/m^2) and Baleares (44.86 items/m^2) the category *Plastic (polystyrene included)* supposes the vast majority of residues found.

It is also remarkable that in some provinces the category *Paper/cardboard* is the predominant. Málaga (0.18 items/m^2), Granada (0.34 items/m^2) and Almería (0.82 items/m^2) are the 3 provinces from Andalucía that have beaches sampled in this study and they have *Paper/cardboard* as their main residue, while in Alicante (1.04 items/m^2) and Tarragona (0.28 items/m^2) this same pattern is happening (Fig. 9).

Finally, it should be noted that in Málaga (0.05 items/m^2), Granada (0.31 items/m^2), Alicante (0.63 items/m^2) and Tarragona (0.18 items/m^2), the category *Ceramics* is notably present, even surpassing the abundance of *Plastics* in the case of Granada (Fig. 9).

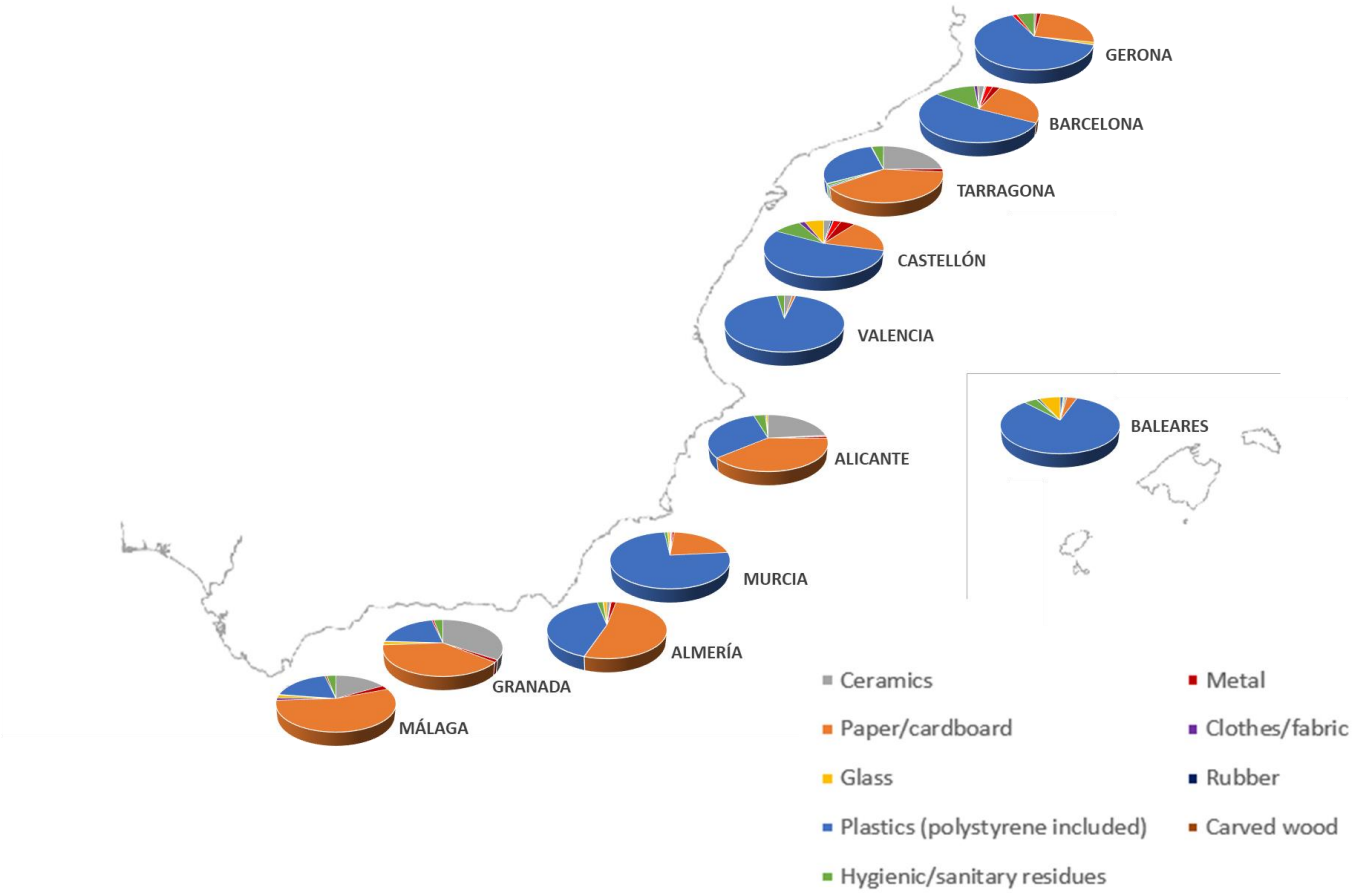

Fig. 9. Representation of the distribution of marine debris per province along the Spanish Mediterranean coastline.

Concerning the temporal (seasonal) pattern of marine debris abundance along the Spanish Mediterranean (Fig. 10), it is possible to see that apparently in Fall is when more residues were found except for *Plastic* and *Glass*. In Fall they were higher the abundances of this residues than in Winter or Summer but not than in Spring. In figure 10 just 5 categories are represented, since this pattern appeared in every category but was more evident in these ones, which are also the most found ones in general terms.

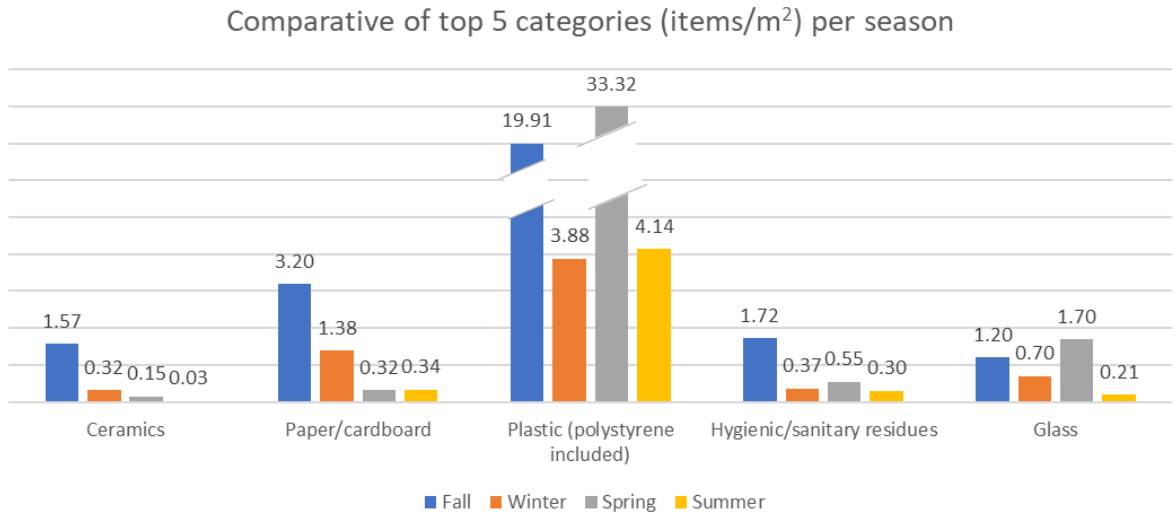

Fig. 10. Top 5 categories of litter found and their abundance per season.

3.3 Factors affecting the abundance of AMD and its accumulation patterns: Statistical analysis

The final dataset did not follow a normal distribution (Lilliefors's test; $p < 0.0001$) neither had homogeneous variances, (Bartlett's test; $p<0.0001$), so a Welch ANOVA analysis was the best fitting model (Table 3). Most of the variables appeared to influence significantly the AMD deposition, just the blue flag distinction (*Blue flag*), the possibility of anchorage (*Anchorage*), the presence of beach bars (*Beach bar*) and the belonging to the Natura 2000 network (*Natura 2000*) appeared to not influence the abundance of AMD on the beaches sampled, according to the analysis performed.

After calculating the adjusted ω^2 it showed that *Beach, Date* and *Municipality* were the variables that explained the most the abundance of AMD on the Mediterranean beaches sampled.

Factor	*p-value*	df	*est.* ω^2
Wave action	$1.80e^{-6}$ ***	3	0.0083
Blue flag	0.6935	1	
Distance to port	$<2.2e^{-16}$ ***	29	0.0422
Coastline	0.0001 ***	7	0.0073
Beach composition	0.0001 ***	11	0.0086
Anchorage	0.5235	1	
Access	$7.17e^{-5}$ ***	8	0.0081
Cleaning services	0.0490 *	1	0.0009
Beach bar	0.1042	1	
Natura 2000	0.1449	1	
Occupancy	0.0315 *	2	0.0015
Beach	$<2.2e^{-16}$ ***	67	**0.0783**
Date	$<2.2e^{-16}$ ***	48	**0.0797**
Season	$3.76e^{-09}$ ***	3	0.0122
Municipality	$<2.2e^{-16}$ ***	42	**0.0734**
Province	$8.38e^{-11}$ ***	14	0.0204
Residue category	$3.02e^{-10}$ ***	11	0.0216

Table 3. Results from Welch ANOVA and estimated ω^2. In bold the 3 variables with the highest effect size.

*[p<0.05 * p<0.01 ** p<0.001 ***]*

Even though the variable *Season* did not appear to specially affect the abundance of AMD on the study, according to the statistical analysis performed, a post hoc test was carried out to try to find a significant difference between the different periods of the year, likely verifying statistically that Fall was the season with higher abundance of marine debris, as it was previously seen graphically.

Seasons were taken as Summer (July–September), Fall (October–December), Winter (January–March), and Spring (April–June).

In line with the previous graphical representation (Fig. 10), significant differences were found between the abundance of AMD in Fall compared with every other season (*p-value*=0.05).

3.4 Effects of Natura 2000 Network on the abundance of AMD

From the present study, 27 beaches were under the Natura 2000 protection policies and 41 were not. It was tested with a Welch ANOVA if the belonging to this protection figure meant a significant difference on the abundance of AMD on the beaches sampled (Table 3). It resulted not significant, so Natura 2000 Network is not affecting the abundance of debris surveyed for this study.

4. DISCUSSION

In recent decades, the pollution of marine waters by anthropogenic litter has been identified as a serious global environmental problem (Consoli et al., 2018). Marine debris can be found in all oceans and both its abundance and distribution have increased consistently over the last decades (Honorato-Zimmer et al., 2019). A total of 246,560 marine debris items were found and identified on the beach surveys undertaken for the present study, from February to November 2019. This high abundance of litter and the fact that most of the items were made of plastic was highly predictable.

Within just a few decades since mass production of plastic products begun in the 1950s, plastic debris has accumulated in terrestrial and marine environments worldwide (Barnes et al., 2009). It could therefore be expected that plastics would make up almost 80% of the debris found on this study, since this is the current trend worldwide. Plastics have made themselves a permanent part of the marine environment (Galgani et al., 2015) and the results of this study corroborate this fact.

It should be noted that light packaging was the main residue found within the category *Plastics*. To promote end-user responsibility as well as legislative efforts to decrease single use plastics (Rosevelt et al., 2013) is a global need. Also emphasize that the Top 5 residues found on the beaches surveyed match exactly with the Top 5 residues on Bravo et al., 2009, a study carried out on the Chilean coast. This fact reconfirms the marine debris problematic as a global issue, and that awareness campaigns and environmental education are essential tools to fight the AMD problem needed in every country.

Non-identifiable plastic pieces (#1 and #3 residues from the Top 5) may come from plenty of different objects from numerous different sources, so it is difficult to manage their appearance. However, it should be underscored the enormous appearance of cigarette butts on this study. Cigarette butts appear in several papers (Ariza et al., 2012, Bravo et al., 2009, Berger 2005) as a very common residue on beaches. Campaigns for smokeless beaches but also smoking bans have been implemented in some areas, and seems that the Spanish

Mediterranean coastline is in need of this measures, together with more awareness raising from citizens.

All possible tools are needed to increase awareness on the population visiting the beaches because not only cigarette butts but also bottles and cans are supposed to be left directly on the beach by visitants. Beach tourism is often the most important source of revenue for coastal communities (Ariza et al., 2012) and this is a reality in particular for coastal Mediterranean regions (Ariza et al., 2007). Preserve the coastline should be a must for everyone visiting it or not, and not just for its economical value.

The source of coastal litter is perhaps the most important issue of the litter problem because it has a direct bearing on the strategy which should be employed to control it (Gabrielides et al., 1991).

Several papers (Gregory et al., 2009, Moore et al., 2000) have found that most residues sampled on their surveys had marine-based sources. Other studies (Alkalay et al., 2007, Gabrielides et al., 1991) as the present one detect that most of the residues have land-based sources.

Also, attributing a source to litter found on beaches is very complex and several factors influence source identification (Koutsodendris et al., 2008). In this case, most of the residues were allegedly coming from domestic sources, suggesting that a good management of litter by citizens and afterwards sewage treatment plants is needed to prevent the high input that the domestic source implies for the abundance of AMD on beaches.

Concerning the geographical sources of the marine litter, according to Liubartseva et al., 2018, it appears that in the majority of Mediterranean countries more than 50% of plastics come from their own terrestrial inputs. Furthermore, plastic emissions from Spain contribute more than 80% of their own coastline pollution, this study claims.

Also in Liubartseva et al., 2018 the Catalan sea was pointed out as one of the most contaminated areas, remarking the Valencian gulf as a local inshore band of plastic debris sources, what can maybe explain why Valencia and Baleares have this specially high abundance of plastic that the results of this study show.

The mightiest river in Spain, the Ebro River, flows out into the sea at the north limit of the Valencia region. Also, big coastal population size and marine traffic (Domenech et al., 2019), together with high agricultural development (Sanjuán et al., 2005) might be influencing as well the prevalent abundance of plastic in the province of Valencia. It should also be noted that in the Valencia region there is a higher likelihood of debris retention and beaching due to ocean current dynamics (Mansui et al., 2015).

In the case of the Balearic area, the surface currents are conditioned by the North Current (NC) that runs along the coasts of southern Europe and by the mesoscale circulations coming from the Algerian sub-basin (Ruiz-Orejón et al., 2018). This fact can lead to the concentration of plastic debris coming from the NC and the Algerian mesoscale gyres resulting in a high deposition and therefore abundance of plastic litter on the Balearic coastline.

Murcia's dominant residue might be plastic because this province is subjected to many human activities, with important urban and touristic nuclei, agricultural plots and Murcia-San Javier Airport input (León et al., 2018).

The proportion of plastic articles among litter increases with distance from source areas because they transport more easily than do more dense materials such as glass or metal (Ryan et al., 2009). Considering this, it is possible that plastic debris high abundance will not be responding specially to a high local input and, as stated before, currents also play an important role in debris distribution.

Consequently, low-density materials such as paper last shorter on the marine environment (Abu-Hilal and Najjar, 2004, Ryan et al., 2009). This fact allows us to hypothesize that in the Andalusian coast and Alicante and Tarragona, where, according to the graphics, the amount of paper and cardboard is even bigger than that of plastic, it is happening a severe discharge of debris coming from land. Many factors may affect this unexpectedly high occurrence of paper litter, such as the date when the sampling was conducted or the location where the beaches are, maybe close by a specific input of paper and cardboard. Nevertheless, having a closer look to the dataset the most probable explanation to this fact is the classification of cigarette butts under the 'Paper/cardboard'

category. This is a common error happening in other studies (Bravo et al., 2009) but makes evident the actual problematic regarding this residue, which is also normally found within the Top 5 residues in many studies concerning AMD, including the present one, and as mentioned above, is in severe need of regulations.

Anthropogenic debris is believed to be transported into streams, rivers, stormwater drainage systems and finally to coastal waters and beaches (Cheung et al., 2016). To explain the high relative abundance of Ceramics on provinces such as Málaga, Granada, Alicante and Tarragona it is hypothesized that material construction such as tiles or bricks are dumped into rivers and streams, reaching this way the beaches surveyed on this study.

Regarding the temporal patterns of AMD found on this study, a seasonal trend was noted: in Fall the abundance of marine litter was significantly higher than in any other season. As stated in Gabrielides et al 1991, seasonal fluctuations in coastal litter are caused by storm waves which wash the litter landward. This statement matches the fact that Fall is the season when storms frequently happen along the Mediterranean, what could mean that the higher abundance of AMD found on Fall has been brought indeed by storm waves.

This seasonal storms evidently also result on intense rainfall (Pantillon et al., 2015) so it is probable that the high abundance of marine litter is not only due to marine litter washing up on beaches but also due to run-off and transportation of AMD into stormwater drainage systems, ending up on the beaches as well.

Presumed more extreme seasonal storms due to global change could also influence positively the higher input and abundance of debris on the Spanish Mediterranean coastline in Fall.

Also, it should be underlined the fact that specially in summer many beaches are cleaned, given the high influx of visitants, what can disguise the real seasonal pattern of marine litter happening on the coastline.

The statistical analysis performed on this study showed that the location (variables *Beach* and *Municipality*) and the season (*Date* and *Season*) were the factors that explained the most the abundance of marine debris on the

Mediterranean beaches sampled. This coincide with the results on Rosevelt et al., 2013, a study undertaken in central California.

Again, the outcome of this study matches the results of another one carried out in a very distant region of the world, leading to think that the patterns and trends concerning the abundance of marine litter replicate globally.

MPAs and marine litter

It should be noted that the fact that the Natura 2000 Network is not affecting the abundance of AMD on the beaches sampled is providing important information: It is likely showing that the belonging to a protection figure does not imply the reduction on the abundance of debris, since the residues mainly reach these areas by transference, i.e. coming from the marine environment (Ruiz-Orejón et al., 2018, Alomar et al., 2015, Derraik et al., 2002, Martinez-Ribes et al., 2007).

The case of the Cabrera National Park is not different from the rest of protected areas surveyed, and there is not a visible lower abundance of debris on the beaches surveyed on this MPA compared with other non-protected beaches surveyed along the Spanish Mediterranean coastline. Again, a reinforcement of policies is apparently needed in order to make protection figures an actual valuable measure against the AMD problematic.

Citizen science data: Limitations and possibilities

The role of citizens in the monitoring of plastic pollution will increase in the coming years, and the truly “big” data they document must become part of the science of plastic pollution (Bergmann et al., 2017). Nevertheless, the use of volunteers to collect data has often been criticized (Rees and Pond 1995), since volunteers may be more or less likely to detect, gather and record certain items of litter due to known or subconscious preference (Nelms et al., 2016). However, in many studies volunteer participation is seen as a knowledge source impossible to achieve in any other way, given the large amount of data that this clean-ups can provide due to the likely high number or volunteers taking part, (Bravo et al., 2009, Rees and Pond 1995, Nelms et al., 2016) thus being the citizen science data of equivalent quality to those collected by researchers (Van del Velde et al., 2017).

5. CONCLUSIONS

- The increase of AMD is an issue or serious concern worldwide, being especially abundant the residues made up of plastic. Legislation to limit the use of single use plastics needs to be reinforced, being this residue the most found on several studies included the present one.
- More community and social awareness are needed to reduce this problematic. Regarding the cigarette butts more information and campaigns are needed to prevent the users of the beaches from leaving this residue, highly polluting and difficult to remove.
- The source of AMD according to this analysis is mainly domestic, thus waste and litter management policies should be reviewed to try to reduce this input.
- The high relative abundance of plastic, paper and ceramics along certain provinces of the Mediterranean Spanish coast is likely due to ocean dynamics, high abundance of cigarette butts and construction material dumping respectively.
- The abundance of litter is significantly higher in Fall than in any other season, likely as a result of seasonal storms taking place along the Mediterranean.
- The season and the geographical location are the main factors affecting the abundance of AMD.
- Protection figures such as Natura 2000 network seem to be inefficient against AMD.
- It is necessary a standardization of the clean-up events happening so that the data that they provide can be comparable and used reliably. A detailed standard protocol could be implemented to reduce the bias that these clean-ups can hold.
- Devices like the cleaning boats used in the Balearic Islands are recommended for other provinces, to keep the coastal areas clean and preventing this way the marine litter to deposit on the beaches.
- Studies like the present one could show their results in litter weight/area, given that items/m^2 could be inaccurate representing the actual abundance of AMD on the beaches.

- Further research is needed regarding the marine litter problematic, since it is a very concerning issue affecting globally. However, it seems that the scientific community and citizenship are responding, but bigger efforts are much needed given the seriousness of the problem.

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