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Marine litter from circalittoral and deeper bottoms off the Maltese islands (Central Mediterranean)

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Abstract

During the 2005 leg of the MEDITS trawl survey, benthic anthropogenic debris around the Maltese Islands (central Mediterranean) was quantified for the first time, with the aim of studying its abundance and distribution in the area. 357 items were sampled from 3.5 km^2 of swept area. Each item was recorded, measured and its planar and surface areas were estimated. Plastic (47%), metal and glass (13% each) were the most prevalent types of litter in terms of number. Limestone slabs, sacks and fabric were the items with the highest planar and surface area per item. This suggests that it is also important to consider the size of debris items as well as numerical abundance in assessing impact of litter on benthic organisms. An attempt was made to correlate anthropogenic and environmental variables, including fishing activities and wave parameters, to litter abundance and distribution but no interpretable correlations were found, implying that litter abundance and distribution depends on factors other than those considered.

Keywords: Marine litter, Malta, Trawling, MEDITS, GSA 15.

Introduction

Marine debris, defined as any manufactured or processed solid material that enters the marine environment (Katsanevakis *et al.*, 2007) started to be recognised as a major form of pollution in the 1970s (North Atlantic Ocean: Carpenter & Smith Jr, 1972; Colton *et al.*, 1974; Wilber, 1987; Pacific Ocean: Wong *et al.*, 1974; Day & Shaw, 1987). Apart from having negative socio-economic impacts, marine anthropogenic waste also leads to environmental degradation. Marine litter is known to cause mortality in larger marine organisms such as mammals, turtles and seabirds due to either ingestion or entanglement (Katsanevakis, 2008), to transport alien species (Barnes, 2002) and algae associated with red tides (Maso *et al.*, 2003), to release toxic compounds (Mato *et al.*, 2001), and to alter the structure of benthic communities (Katsanevakis *et al.*, 2007).

Numerous studies on marine litter, whether washed ashore, floating, or on the seabed, and its effects on the environment, have been made worldwide (Derraik, 2002, Ivar do Sul & Costa, 2007; Galgani *et al.*, 2010 for reviews). Marine litter has also received some attention in the Mediterranean where studies on beached anthropogenic waste (e.g. Shiber, 1979, 1982, 1987; Gabrielides *et al.*, 1991; Golik & Gertner, 1992; Gardiner, 1996), floating debris (e.g. Morris, 1980; McCoy, 1988; Kornilios *et al.*, 1998; Aliani *et al.*, 2003) and the accumulation of litter on the sea floor (e.g. Bingel *et al.*, 1987; Ragonese *et al.*, 1994; Galgani *et al.*, 1995; Galil *et al.*, 1995; Cannizzaro *et al.*, 1996; Galgani *et al.*, 1996; Galgani & Andral, 1998; Bianchini & Ragonese, 1999; Stefatos *et al.*, 1999; Galgani *et al.*, 2000; Katsanevakis & Katsarou, 2004; Koutsodendris *et al.*, 2008) have been made. However, benthic litter in the 25 nautical mile Fisheries Management Zone (FMZ) around the Maltese Islands (Camilleri, 2003) has not been included in any of the surveys carried out in the central Mediterranean region (Cannizzaro *et al.*, 1996; Bianchini & Ragonese, 1999); all studies to date have focused on the northern part of the Sicilian channel and have excluded this area and the surrounding circalittoral waters. To date, the only information on marine litter in the Maltese Islands concerns beached litter (Sciberras, 1992; Gardiner, 1996; Axiak & Zammit, 1998; Tudor *et al.*, 2002; O'Neill, 2003), coastal floating debris (Morris, 1980; Sciberras, 1992; Axiak & Zammit, 1998) and plastic pellets found on beaches (Turner & Holmes, 2011). Benthic marine litter has not been considered.

This study was undertaken to address this gap in knowledge and to serve as a baseline study for future comparisons. This is especially important in light of the Marine Strategy Framework Directive (EC Directive 2008/56/EC), applicable to all EU Member States, including Malta, where one of the qualitative descriptors for determining good environmental status of the marine environment concerns “properties and quantities of marine litter that do not cause harm to the coastal and marine environment”. An objective suggested by Task Group 10 for marine litter is to work towards a measurable and significant decrease (e.g. 10%/year) in the total amount of litter in the environment by 2020 (Galgani *et al.*, 2010). Implementation of this requires the availability of baseline data against which to compare.

In order to develop such operational targets and link them to measures, important sources of marine litter need to be identified and addressed (MSFD GES Technical Subgroup on Marine Litter, 2011). Benthic debris can originate from both land and ocean-based sources, which may be ‘point’ or ‘diffuse’. Marine litter can be either indirectly transported from land through rivers, drains, sewage outlets, storm water outflows, road run-off or blown by the wind, or directly disposed of at sea by vessels of all kinds, offshore installations such as oil and gas platforms, drilling rigs, and aquaculture operations (MSFD GES Technical Subgroup on Marine Litter, 2011). This makes the identification of litter sources very complex, since the same type of litter item can origine from completely different sources. The task is further complicated by the long distances that debris can travel from its point of introduction into the marine environment until its final deposition on the seabed.

Attempts to attribute litter items to their source were made for beach litter. Whiting (1998) experimented with a matrix scoring method, attempting to proportion a percentage allocation of each debris item to each source and thus produce an overall percentage allocation figure (Tudor *et al.*, 2002). On the other hand Tudor *et al.* (2002) and Williams *et al.* (2003) managed to distinguish between riverine, sewage-related and items sourced from fishing/shipping using Principal Component Analysis and cluster analysis. Following this study, Koutsodendris *et al.* (2008) were able to identify the dominant sources of benthic debris in four Greek gulfs through R and Q-mode factor analysis.

This study attempts to correlate the abundance and distribution of benthic debris with possible sources of litter, such as fishing and coastal activities together with other factors that are known to affect the transport of litter in the marine environment, which include currents, meteorological factors, and proximity to urban centres, industrial and recreational areas, shipping lanes, and fishing grounds (MSFD GES Technical Subgroup on Marine Litter, 2011).

Thus, the main objectives of this study are: (1) to determine litter density and composition in terms of abundance, planar and total surface area in circalittoral waters around the Maltese Islands and to compare these with other areas in the Mediterranean; (2) to estimate the contribution of different sources of litter; and (3) to explore the factors influencing the abundance and distribution of marine debris in the circalittoral waters around the Maltese islands.

Methods

The study was carried out in FAO’s General Fisheries Commission for the Mediterranean (GFCM) Geographical Sub-Area 15 (GSA 15); 44 stations distributed on trawlable bottoms (bottoms which due to the bottom substratum and homogenous depth are suitable for trawling) were sampled (Fig. 1, Table 1).

Litter samples were collected in the period 11-21 July during the 2005 session of the Mediterranean International Trawl Survey (MEDITS) in GSA 15. The scope of this annual MEDITS survey is to provide basic information on benthic and demersal species important to fisheries, by monitoring distribution and demography of selected target species (Relini *et al.*, 2008). However, anthropogenic waste is collected in abundance during these surveys and the opportunity was taken to use this for the present study. The

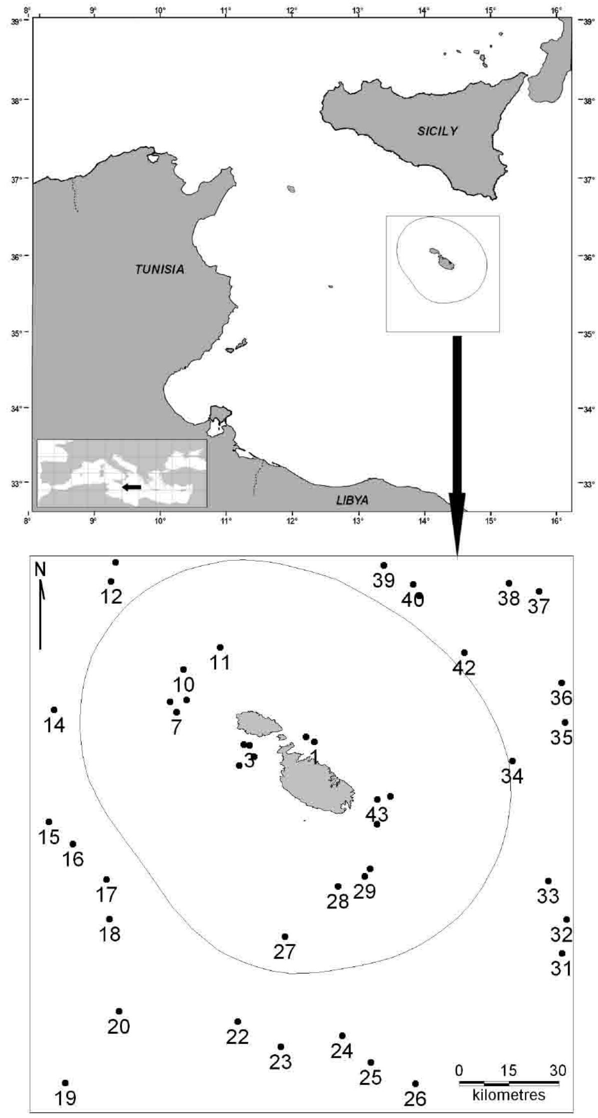

Fig. 1: Map showing the location of the Maltese Islands in the Mediterranean and the 44 stations sampled for litter (black dots) within the study area, FAO’s GFCM GSA 15 (black square). The map also illustrates the Malta 25 nautical miles Fisheries Management Zone (the oval around the islands).

Table 1. Date, location and depth of trawl hauls sampled for litter during the MEDITS 2005 survey.

Station	Date	Haul start		Haul end		Start depth (m)	End depth (m)	Estimated swept area (km²)
		N	E	N	E			
1	11 July	35°59’59”	14°26’33”	36°00’48”	14°25’02”	50	49	0.043
2	11 July	36°00’46”	14°24’53”	36°01’26”	14°23’11”	48	56	0.042
3	11 July	35°59’25”	14°13’40”	36°00’28”	14°12’15”	192	188	0.048
4	11 July	35°59’32”	14°12’32”	35°58’23”	14°13’45”	200	198	0.048
5	11 July	35°57’33”	14°14’32”	35°57’07”	14°16’19”	193	184	0.048
6	12 July	35°56’10”	14°11’37”	35°58’59”	14°11’04”	208	210	0.097
7	12 July	36°04’44”	13°59’13”	36°06’56”	13°56’45”	580	628	0.103
8	12 July	36°06’25”	13°57’54”	36°08’29”	13°55’18”	577	691	0.099
9	12 July	36°06’44”	14°01’09”	36°08’19”	14°04’14”	486	538	0.101
10	13 July	36°11’41”	14°00’35”	36°12’52”	14°04’03”	271	269	0.102
11	13 July	36°15’14”	14°07’50”	36°18’09”	14°07’48”	380	454	0.101
12	13 July	36°25’53”	13°46’09”	36°27’34”	13°49’13”	387	350	0.102
13	13 July	36°28’58”	13°47’04”	36°31’34”	13°45’18”	338	307	0.102
14	13 July	36°05’07”	13°34’50”	36°06’07”	13°31’34”	697	564	0.103
15	14 July	35°47’04”	13°33’50”	35°44’56”	13°36’25”	682	677	0.100
16	14 July	35°43’28”	13°38’35”	35°41’45”	13°41’19”	622	667	0.100
17	14 July	35°37’43”	13°45’17”	35°35’08”	13°45’58”	554	588	0.101
18	14 July	35°31’22”	13°45’53”	35°31’49”	14°42’23”	673	713	0.103
19	15 July	35°04’53”	13°37’02”	35°01’53”	13°37’39”	443	417	0.101
20	15 July	35°16’26”	13°47’46”	35°16’25”	13°51’23”	603	541	0.101
22	15 July	35°14’49”	14°11’20”	35°13’17”	14°14’23”	622	594	0.099
23	16 July	35°10’43”	14°19’53”	35°08’25”	14°22’10”	576	653	0.101
24	16 July	35°12’32”	14°32’04”	35°10’38”	14°34’49”	540	547	0.099
25	16 July	35°08’13”	14°37’46”	35°09’25”	14°41’04”	583	546	0.101
26	16 July	35°04’44”	14°46’36”	35°05’41”	14°50’04”	546	538	0.103
27	17 July	35°28’32”	14°20’41”	35°29’36”	14°23’59”	567	516	0.099
28	17 July	35°36’40”	14°31’15”	35°39’02”	14°33’25”	421	302	0.101
29	17 July	37°38’13”	14°36’33”	35°40’42”	14°34’32”	231	216	0.100
30	17 July	35°39’30”	14°37’36”	35°38’16”	14°38’45”	177	181	0.049
31	18 July	35°25’49”	15°15’43”	35°25’48”	14°12’02”	352	303	0.100
32	18 July	35°31’17”	15°16’40”	35°34’19”	15°16’40”	264	216	0.100
33	18 July	35°37’29”	15°13’02”	35°38’49”	15°12’16”	148	131	0.048
34	18 July	35°56’54”	15°05’50”	35°58’20”	15°05’44”	101	102	0.046
35	19 July	36°03’07”	15°16’19”	36°03’53”	15°17’58”	142	189	0.048
36	19 July	36°09’29”	15°15’38”	36°10’35”	15°16’59”	139	146	0.048
37	19 July	36°24’19”	15°11’11”	36°25’40”	15°10’16”	94	88	0.045
38	19 July	36°25’36”	15°05’11”	36°27’07”	15°05’09”	84	82	0.045
39	20 July	36°28’29”	14°40’18”	36°28’10”	14°42’05”	134	132	0.049
40	20 July	36°25’23”	14°46’09”	36°23’58”	14°46’41”	130	131	0.047
41	20 July	36°23’32”	14°47’24”	36°23’41”	14°49’12”	131	128	0.047
42	20 July	36°14’21”	14°56’20”	36°14’08”	14°54’29”	108	115	0.047
43	21 July	35°50’40”	14°39’02”	35°51’01”	14°40’47”	83	84	0.044
44	21 July	35°51’11”	14°41’40”	35°51’05”	14°43’28”	81	75	0.046
45	21 July	35°46’42”	14°38’56”	35°45’30”	14°37’44”	122	137	0.049

stations sampled during MEDITS remain constant from year to year and have been distributed applying a stratified sampling scheme with random stations inside five depth strata: 10-50, 50-100, 100-200, 200-500 and 500-800 m (Relini *et al.*, 2008).

Samples were collected using the IFREMER GOC 73 otter trawl (width: 16 m; height of vertical opening: 2 m; stretched mesh size at cod-end: 20 mm; Fiorentini *et al.*, 1999). Trawl duration depended on the depth: bottoms less than 200 m deep were trawled for 30 minutes while deeper bottoms were trawled for one hour. The average trawling speed was 3 knots.

A trawl sample was collected from each station. The debris brought up in the net was classified into the following litter type categories: fabric (F); glass (G); limestone slabs (L) (Pace *et al.*, 2007a); metal (M); plastic (P); pottery (Pot); rope (R); sacks (S); wood (W) and others (Oth - for litter material that did not fall in any of the other categories), and was standardised per 1 km^2 of swept area. Litter was categorised into these classes to determine the most frequent types of litter found on the bottom and those providing the largest coverage on the seabed, as well as to analyse abundance and distribution of litter types in correlation with anthropogenic and environmental factors.

Since Williams *et al.* (2003) found problems in the multivariate analysis of such broad categories, as items with potentially different sources were grouped together, items were also categorised following the OSPAR classification used for monitoring marine litter on beaches (OSPAR Commission, 2010).

Considering that some of the impacts of litter on the benthic environment are dependent on the area of substratum covered by the settled litter items (for example the smothering of fauna and the inhibition of gas exchange between the overlying waters and the pore waters of the sediments (Goldberg, 1994), or on the surface area provided for the colonisation of hard-substratum sessile species (Katsanevakis *et al.*, 2007), litter was also quantified in terms of both planar and surface area.

For each litter item, the planar and surface areas were estimated by treating irregularly-shaped objects as a combination of regular shapes. The planar area was taken to be the length multiplied by the width for flat objects (e.g. plastic bags), the area of the largest face for cuboids (e.g. for limestone slabs), or the diameter multiplied by the height for bottles and cans. The total surface area was taken to be the actual surface area provided by all faces of the litter items. Analyses were carried out using all three quantifications – litter abundance, planar area and surface area – to identify any differences between these three ways of quantifying litter. The planar area was also used to calculate the percentage of sea floor covered by marine debris.

Maps showing the abundance of total litter and of the three most frequent litter types in each station were produced to illustrate the distribution of litter in terms of frequency, planar and litter surface areas within GSA 15. The study area was divided into North, South, East and West sectors. One way ANOVA was used to test for differences between stations in the different sectors as well as between stations inside and outside the Malta FMZ.

The relationship of litter abundance, planar and surface area with fishing, other anthropogenic activities, as well as other variables was studied using the Pearson product moment correlation coefficient and multivariate techniques.

Fishing, a known major contributor of marine litter (Pruter, 1987), was quantified within the study area using VMS 2008 data obtained for all vessels longer than 12 meters registered in Malta, as provided by the Agriculture and Fisheries Regulation Department of the Government of Malta. VMS points were categorised into bottom and surface longlining, trawling, and tuna fishing activities, by taking into consideration the type of vessel, the catches landed at the market at the end of each trip and boat speed. VMS data were also considered collectively since littering can still occur when boats are not actually fishing (as for example in the case of trawlers which are sometimes engaged to transport tuna cages from other countries to Malta). The hauls carried out during the MEDITS 2005 survey were plotted on a map using MapInfo Professional Version 8.5 (Pitney Bowes Software). Boundaries with 0.5, 1 and 2 km radii as well as with the same radius as half the horizontal net opening in each particular haul, were plotted around each trawl transect. Fisheries activities around each station were quantified by counting the associated number of VMS points falling within the described boundaries. Since trawled stations should presumably be cleaner due to the clearing effect of trawling, the map obtained was also used to calculate the percentage of the sampled stations coinciding with commercial trawling zones.

Marine bottom debris may also originate from land as litter carried to the sea by rivers and municipal drainage systems or litter left behind by beachgoers (Pruter, 1987). Although there are no rivers in the Maltese Islands, beaches are heavily frequented during the summer months with the possibility of litter being introduced into the sea. Therefore, the distance between each station and the nearest shore was calculated and correlated with litter abundance. Similarly the distance between each station and bunkering areas was calculated.

The relationship between bottom litter and depth was explored to determine if litter or any specific type of litter accumulates at particular depths, either due to the debris being transported there or due to the anthropogenic waste originating from activities taking place at specific water depths. Litter introduced at different points can then be transported to other places by currents and winds. Mean wave energy density, height and mean wind speed, obtained from the WERMED Malta Page (Drago, 2006) were correlated with the litter data.

Multivariate analyses were carried out using the PRIMER v6 statistical software package (Clarke & Warwick, 2001). Resemblance matrices for the different stations based, separately, on abundance, planar and surface area of the different litter types and the OSPAR sub-categories at each station, were calculated using the Bray-Curtis similarity measure. The similarity matrices were then subjected to hierarchical agglomerative clustering and non-metric multidimensional scaling (nMDS) ordination. The SIMPER routine was used to attribute the factors contributing to the resultant groupings. Relationships between the groups identified and the studied variables were then explored by superimposing the scaled individual variables onto the sample locations in the two-dimensional nMDS plots (Field *et al.*, 1982; Clarke & Warwick, 2001) and using the BEST analysis in PRIMER.

Results and Discussion

Altogether, 357 items were collected from 3.5 km^2 of swept area, giving a mean count of 97 ± 78 items km^{-2}. Of the 44 stations sampled, of which 38 are not commercially trawled (85% of the area sampled), only 5 were found to be totally litter-free.

This mean litter count shows that the seabed around the Maltese Islands deeper than 50 m is relatively clean when compared to most other areas in the Mediterranean (Table 2). The majority of studies ranking higher in marine debris than the present one were carried out near ports surrounded by large cities, which are significant

Table 2. A summary of studies on benthic debris carried out in the Mediterranean adapted from Koutsodendris *et al.*, 2008 and Barnes *et al.*, 2009, with the addition of studies by Ragonese *et al.*, 1994 and Bianchini & Ragonese, 1999, and data on depth, year of study and sampling gear. Average values of items/km^2 rather than ranges were adopted when these were available. Studies presented in order of higher abundance of items/km^2. The study by Bingel *et al*. (1987) could not be compared to the other studies as results were given in kg/km^2 and only plastics were considered.

Area	Year of sampling	Sampling gear (horizontal opening, mesh at cod-end)	Depth	Items/km^2	Plastic (%)	Source
Greece	2003	Scuba dives	0-25 m	15,000	55.5	Katsanevakis & Katsarou, 2004
NW Mediterranean	1993-1994	Drezen-type bottom trawl (10 m, 55 mm)	Continental shelf	1,935 ± 633	77.1	Galgani *et al.*, 1995; Galgani *et al.*, 2000
Adriatic Sea	1998	Trawling (10 m, 20 mm)	Deep sea down to 700 m	378 ± 251	69.5	Galgani *et al.*, 2000
Patras Gulf (W Greece)	1997	Beam trawl (15 m, 15 mm)	80-120 m	240	83	Stefatos *et al.*, 1999
East Corsica	1994	Boc 73 trawl (16 m, 10 mm)	Continental shelf	229 ± 72	45.8	Galgani *et al.*, 1995; Galgani *et al.*, 2000
W & S Greece	2000-2003	Bottom trawling 2 different nets differing in opening but not in cod-end mesh size (15 m, 7 m, 15 mm)	15-320 m	165	56	Koutsodendris *et al.*, 2008
Gulf of Lions	1994-1997	Several surveys including the use of the GOC 73 trawl (16 m, 10 mm) and pole trawling with 2 different nets differing in opening but not in cod-end mesh size (4.4 m, 6.2 m, 10 mm)	Continental shelf	143 ± 19	70.5 ± 5.4	Galgani *et al.*, 2000
Maltese circalittoral waters	2005	GOC 73 trawl (16 m, 20 mm)	49-697 m	97 ± 78	47	Present study
Echinadhes Gulf (W Greece)	1998	Beam trawl (15 m, 15 mm)	247-360 m	89	79	Stefatos *et al.*, 1999
E Mediterranean	1993	Beam trawl (2 m, 10 mm)	194-4,614 m	48	36	Galil *et al.*, 1995
Strait of Sicily	1994	Bottom trawling (opening and cod-end mesh size not specified)	0-800 m	40	75	Cannizzaro *et al.*, 1996
Strait of Sicily	1993	Bottom trawling (opening not specified, 14 mm)	500-700 m	33	-	Bianchini & Ragonese, 1999
Strait of Sicily	1991	Bottom trawling (opening and cod-end mesh size not specified)	70-659 m	-	40.8	Ragonese *et al.*, 1994

sources of litter items on the seabed. With a total population of ca. 400,000, the Maltese islands produce much less litter than these larger conurbations.

Nevertheless, the seabed around Malta was more littered than that of the nearby Strait of Sicily (Cannizzaro *et al.*, 1996; Bianchini & Ragonese, 1999), Echinadhes Gulf (Stefatos *et al.,* 1999) and some eastern Mediterranean areas (Galil *et al.,* 1995), where benthic litter was studied in commercially trawled areas by means of trawling. The higher litter abundance around the Maltese Islands might be attributed to the yearly influx of tourists which add to the already high population density of the islands. In 2004, tourist arrivals totalled ca 1.2 million, with an average stay of 8.6 nights per person (National Statistics Office, 2005). Tourists visiting during the warmer months of the year (in 2004 38% visited in summer, and 43.8% during the shoulder months; National Statistics Office, 2005) generally spend a lot of time at beaches, resulting in a huge potential point source of litter. On the other hand, the litter density recorded in the present work was found to be fairly similar to that off the French Mediterranean coast (Galgani *et al.*, 1996), as well as in some areas in southern and western Greece (Stefatos *et al.*, 1999; Koutsodendris *et al.*, 2008).

When comparing different studies, it is important to consider the methodology and equipment used, as variations may also arise due to the diversity in sampling gear, such as the mesh size, horizontal opening and other features of the net. Even though trawl surveys are the most suitable method to estimate the abundance of bottom litter on the continental shelf (MSFD GES Technical Subgroup on Marine Litter, 2011), litter abundance might be underestimated by this type of survey since not all bottom types can be explored and debris can be lost from the mesh and from the net opening when hauling the net back onto the vessel (Spengler & Costa, 2008). The MSFD GES Technical Subgroup on Marine Litter, 2011 recommends trawling to be considered as a method for estimating relative litter densities rather than absolute densities.

In this study, ANOVA showed seabed debris to accumulate significantly south of the islands compared to the other compass sectors (Fig. 2). This trend is difficult to explain as there is no information on the bottom currents in the area. On the other hand, it was found that the distribution of litter was not related to the Malta Fisheries Management Zone, extending to 25 nautical miles around the baseline of the islands. Since the FMZ serves as a management tool for fisheries control, contrary results would have been expected only in the case that a direct correlation between regulated fishing activities and marine litter existed.

The most abundant type of litter, based on number of items, was plastic (47%), followed by metal and glass,

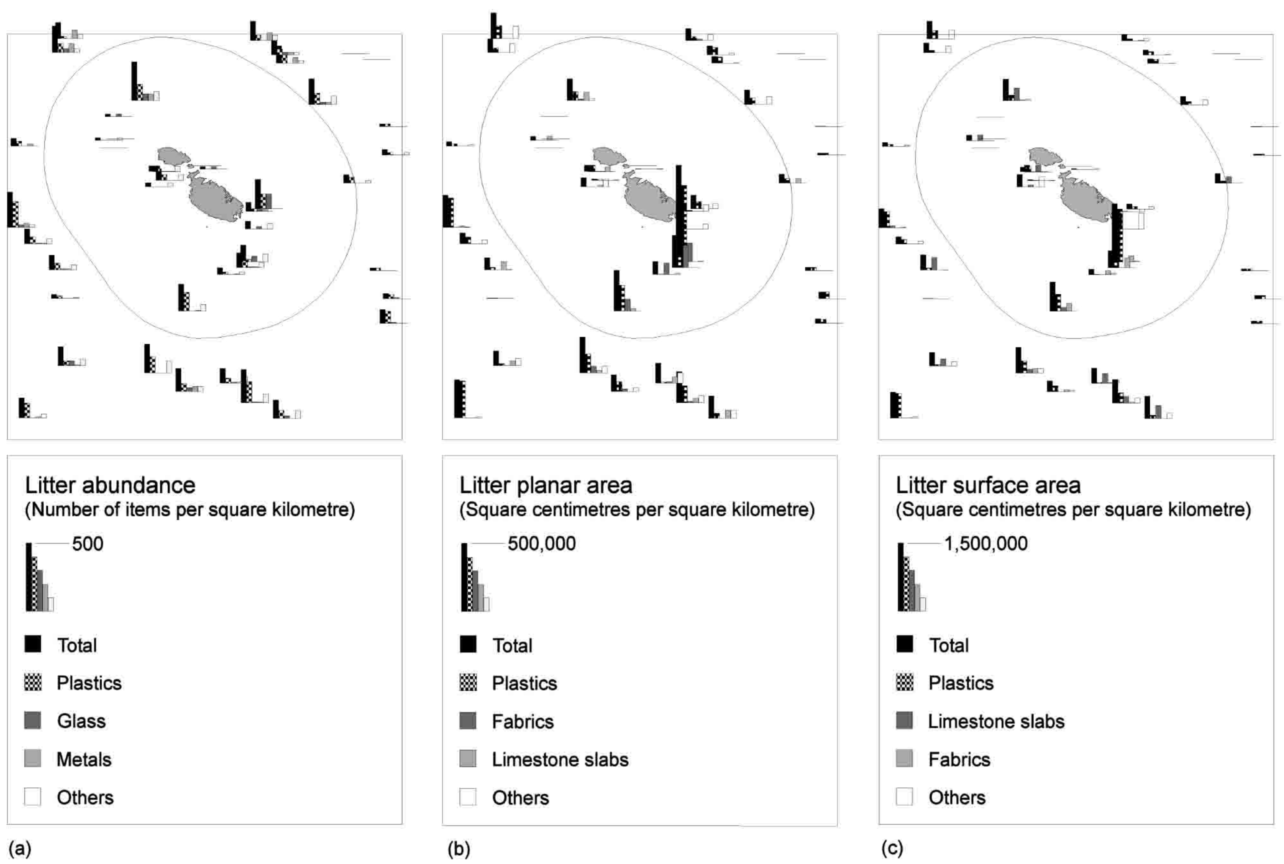

Fig. 2: Maps illustrating the distribution of litter according to (a) abundance, (b) planar area, and (c) surface area, in the area of study (GFCM GSA 15).

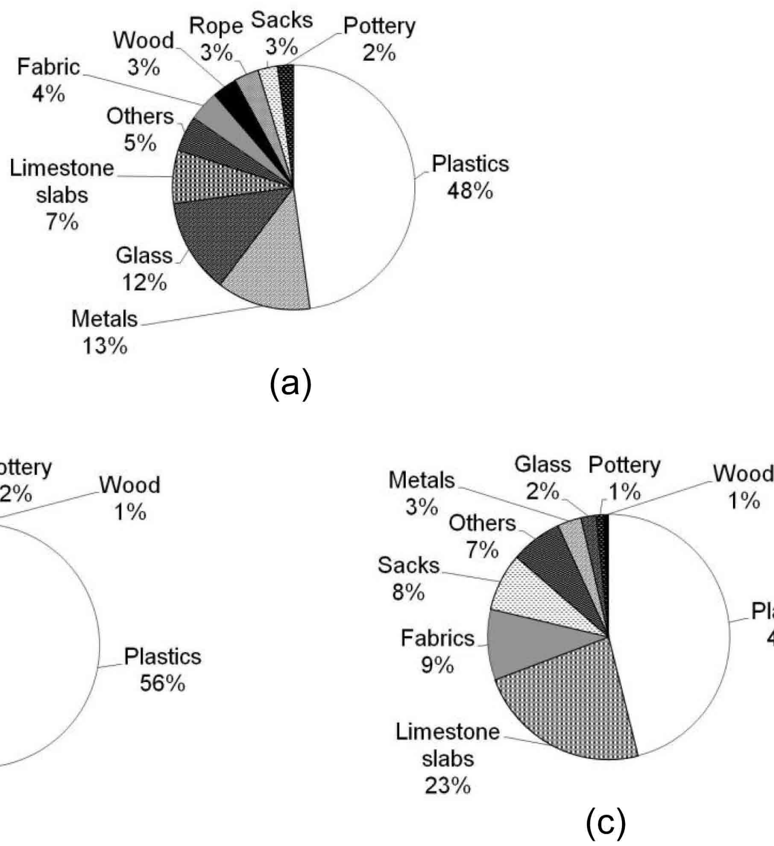

Fig. 3: Percentage composition of different litter types based on (a) abundance (total number of litter items recovered = 357), (b) planar area (total planar area of all litter items = 37.34 m^2) and (c) surface area (total surface area of all litter items = 83.53 m^2).

both constituting 13% of the total number of samples (Fig. 3). This agrees well with the results of other studies on seabed litter carried out around the world (Derraik, 2002) and in the Mediterranean (Ragonese *et al.*, 1994; Galgani *et al.*, 1995; Cannizzaro *et al.*, 1996; Galgani *et al.*, 1996; Bianchini & Ragonese, 1999; Stefatos *et al.*, 1999; Galgani *et al.*, 2000; Koutsodendris *et al.*, 2008). Previous studies on marine litter in the Maltese Islands (albeit not on benthic litter) also found plastic to be the most common litter type; plastic accounted for 60-70% and 50.6% of all floating litter found by Morris (1980) and Sciberras (1992) respectively, and for 39% (Gardiner, 1996) and 69.7% (O'Neill, 2003) of all beach litter recorded. Of the litter surveys carried out in Malta, only Axiak & Zammit (1998) reported plastic as being the second most frequent type (26%), after paper items (33.5%), in the floating and drift material surveyed. The next most abundant litter types in this study were glass and metal, each constituting 13% of the total items recorded. These values are comparable to those recorded by Gardiner (1996) for beach litter on the Maltese coast (7% for glass and 8% for metal).

The majority of the plastic items found during this study were plastic bags (22% small plastic bags e.g. freezer bags [OSPAR sub-category 3], 19% plastic/polystyrene pieces (2.5 – 50 cm) the majority of which appeared to be remnants of shopping and garbage bags [OSPAR sub-category 46] and 18% bags (e.g. shopping bags) [OSPAR sub-category 2]). The next most abundant items were beverage containers making up 6% of all the plastic items recorded. Both plastic bags as well as beverage containers might have ended on the seabed through several sources: as beach litter, or from passing marine traffic, which may have been fishing, merchant or recreational vessels. Nevertheless, limestone slabs and the lengths of nylon rope observed could be attributed to the Maltese fishing industry. Slabs are used as mooring weights for the fish aggregating devices (FADs) deployed in transects around the Maltese Islands to fish for *Coryphaena hippurus* (dolphinfish) (Galea, 1961). Nylon ropes are used to secure the FADs to the slabs on the seabed. Other than these items no other type of derelict fishing gear was observed.

Due to the large amount of plastic retrieved, it was also the material with the largest planar (56%) area. In terms of this parameter, fabric (13%), limestone slabs (11%) and sacks (7%) were next in importance (Fig. 3). Although the percentage composition of these items was low, they resulted in relatively high planar area contributions as both fabric and sacks were larger in size than the average plastic item; fabric and sacks had a large average planar area per item; plastic, pottery, limestone slabs and 'others' were intermediate, while metal, wood and glass had relatively small values. Taking into consideration the type of material, the larger the planar area of seafloor debris, the higher the inhibition of the gas exchange between the sediment and the overlying water, potentially leading to hypoxic or anoxic conditions (Goldberg, 1997), as well as the smothering of biota.

Litter coverage was calculated to enable a comparison between the present study and that by Galil *et al.* (1995) in the Eastern Mediterranean (from Italy to Syria). While the overall litter coverage in the present study was 0.0011% (1.1 x 10^{-5}) collectively, plastic covered 0.0006% (5.89 x 10^{-6}) of the seabed sampled, while flat plastic items such as bags and sheets covered 0.0005% (5.22 x 10^{-6}). This lies in the lowest range quoted by Galil *et al.* (1995) for plastic; these authors recorded a high coverage of 2 x 10^{-4}% on the upper shelf, 2 x 10^{-5}% in the deepest stations if close to the shore or near busy shipping lanes, and lower values (1-8 x 10^{-6}%) in deep waters or away from shipping lanes. In this study, efforts were made to obtain information about shipping density around the Maltese Islands, especially through AIS (Automatic Identification System) data. However, this was not possible. Such data is not yet readily available to scientists and this information is generally lacking from marine debris surveys worldwide (see, for example, Ribic *et al.*, 2011).

On the other hand, litter surface area plays an important role in the availability of hard substratum for colonisation by sessile biota in areas where soft substrata prevail (Pace *et al.*, 2007b). The results of litter abundance in terms of surface area were very similar to those obtained for planar area. In this case, items ranked as follows; plastic (46%), limestone slabs (23%), fabric (9%) and sacks (8%) (Fig. 3). Again, the latter three items showed higher contributions in terms of surface area than expected from their abundances due to being much bulkier than the average plastic article, while certain items, such as limestone slabs, have several faces. This is also reflected by the mean surface area per article for the different litter categories where limestone slabs, sacks, fabric, and 'others' ranked high, plastic ranked intermediate, and pottery, metal, wood and glass ranked as having the lowest values.

In the Strait of Sicily, litter abundance was found to be positively correlated with depth (Ragonese *et al.*, 1994). In the Maltese Islands, this correlation was exhibited only by plastics. Litter was found to be significantly positively correlated to mean wave height, mean wave energy density and distance to the nearest shore (Pearson product-moment correlation coefficient) (Table 3). Plastic, the main litter constituent, showed the same correlation patterns, also including depth and distance to the nearest bunkering area. Glass was positively correlated to all of the different fishing activities considered, while metal was not correlated to any of the variables considered. Contrary to the results obtained, litter was expected to be more abundant in areas with lower wave energy densities given that, in general, bottom debris tends to become trapped in areas of low water movement and high sediment accumulation (Galgani *et al.*, 2010). The same was expected for areas with low wave height as this factor is generally positively correlated to wave energy density. On the other hand, the increasing abundance with increasing distance from the source area observed for plastic can be explained because plastic items are more easily transported than dense materials such as glass or metal, and because such items last longer than other low-density materials such as paper (Ryan *et al.*, 2009). Plastic is also usually found at greater depths than other litter types due to accumulation in sink areas (Ryan *et al.*, 2009). Using the same argument, glass was

Table 3. Pearson product moment correlation coefficients of significant correlations between different variables and the most abundant litter items in terms of abundance, planar and surface areas (n = 44; P = 0.02; Pearson product-moment correlation values at the stated level of confidence = 0.350). P = plastic; M = metal; G = glass; F = fabric; L = limestone slabs.

Variables	Litter abundance				Litter planar area				Litter surface area			
	Total litter	**P**	**M**	**G**	**Total litter**	**P**	**F**	**L**	**Total litter**	**P**	**L**	**F**
Mean wave height	0.365	0.404						0.350	0.370			
Mean wave energy density	0.359	0.401						0.357	0.361	0.353		
Depth		0.370										
Distance to nearest shore	0.363	0.458										
Distance to nearest bunkering area		0.387										
All VMS points (Horizontal spread)				0.643								

correlated to the intensity of fishing activities due to its high density, sinking immediately on the seabed where introduced into the marine environment.

While some correlations were found through correlation analysis, the superimposition of variables on the nMDS plots and the BEST analysis did not give any significant results. The nMDS ordination plot based on the abundance of the different litter types in each haul (stress values 0.18), separated the sampled stations into three groups at 30% similarity. Similar results were also obtained from the hierarchical cluster analysis. The main contributors to the similarity within each of the three groups were glass (100% contribution), limestone slabs (100% contribution), and plastic (74.77%) followed by metal (9.17%) in the third group (SIMPER analysis). However, no significant correlations resulted, either from the superimposition of the variables on the nMDS plot, or from the BEST analysis. Similar results were obtained when the same analysis was made using the OSPAR subcategories for marine litter, with the difference that at 30% similarity, the nMDS ordination plot based on the abundance of the different types of litter as per the OSPAR classification, resulted in 14 superimposed groups (stress values 0.19).

Several factors influence source identification, including correct identification, function, quantity and associations of the observed litter (Tudor *et al.*, 2002). The function of litter items reflects the usage of the item, taking into consideration secondary usages, such as the use of discarded clothes used as rags for cleaning vessel engines. Quantities of certain litter types on beaches or on the seabed where currents are weak can give an indication of particular sources. For example, while a piece of netting on a beach does not point to fishing as the main source of litter on that beach, large quantities can lead to such a conclusion. This leads to association, whereby it can be deduced that litter items found with quantities of debris from a distinct source (such as fishing items or items specific to sewage pathways) mainly originate from the same source. Thus, even though broad litter type categories were used, source identification of the litter observed was still not successful. While multivariate analysis was found to be useful in the identification of the sources of beach litter (Tudor *et al.*, 2002; Williams *et al.*, 2003), it is more difficult to apply these methods for benthic litter.

These results imply that the final distribution and abundance of litter depends on a number of factors acting synergistically, which may include the abundance and source of litter, its shape, composition, weight, residence time in the water column, winds, waves, water circulation and the bottom topography (Bauer *et al.*, 2008). Even the productivity of the surrounding seawater may play a role in litter distribution, as this affects the early microbial biofilm formation, which in turn was found to affect the buoyancy of plastic debris (Lobelle & Cunliffe, 2011). These factors all influence the introduction, transportation, sinking rates and transport trajectories of litter. Furthermore, once on the seabed there is also the possibility of transport elsewhere, either through anthropogenic activities (e.g. trawling) or through natural processes (bottom currents), especially for materials with very long longevity. While an attempt was made to find correlations between litter distribution and abundance, and selected environmental parameters, the purpose of this study was not to elucidate in detail the factors contributing to distribution of benthic litter.

Although circalittoral and deeper bottoms off the Maltese Islands were found to be relatively clean when compared to most other Mediterranean areas studied, most stations sampled were still far from free of bottom litter. While certain types of litter may have some positive effects on biota, for example limestone slabs may ‘protect’ benthic assemblages from trawl fishing (Cannizzaro *et al.*, 1996) and litter with a rough surface and a stable position on the sea bed can act as islands of hard substratum in deep-water muddy bottoms and provide a habitat for sessile biota (Pace *et al.*, 2007b), the effects of debris on deep water bottoms are still largely unknown and may be different than in shallow waters; clearly further studies are required.

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