Spatial distribution of marine litter along italian coastal areas in the Pelagos Sanctuary (Ligurian Sea - NW Mediterranean Sea): a focus on Natural and Urban beaches.

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Abstract

Our paper will show data on quantity, typology, distribution of beach litter (Anthropogenic Marine Debris - AMD) within a coastal macroarea surrounding the Pelagos Sanctuary, an International Protected Area in the NW Mediterranean Sea. AMD Monitoring and characterisation have been performed by using SEACleaner Protocol: an adapted version of UNEP/IOC, OSPAR and EU guidelines. 11 beaches located in 5 different areas, have been monitored with a total amount of thirty three survey, from January 2014 to December 2015, during different seasons. Three kind of beaches have been considered: Natural (belonging to MPAs), Urbanized and Urban. A total of 34,027 items on a total area of 32,154 m2 have been removed and classified. Spatial difference in abundance and composition of AMDs - as well as beach environmental quality - has been detected. Natural sites, and particularly protected areas close to river mouths show a major density compared to other areas.

Highlights

1. MPAs close to important river mouths show major abundance of beached AMD.
2. Plastic is the most present material in all Sites surrounding the Pelagos Sanctuary.
3. All monitored beaches are polluted despite the degree of protection or cleaning activities.

1. Introduction

The growing interest in recent years to the problem of anthropogenic marine litter (AMD) has led to a significant increase of studies describing abundances, kind and accumulation rates in pelagic

and coastal areas of many parts of the world (Convey *et al.* 2002; Thiel *et al.* 2003; Zarfl and Matthies 2010; Andrady 2011; Eriksen *et al.* 2013, 2014; Smith and Markic 2013; Topçu *et al.* 2013; Cózar *et al.* 2014; van Sebille *et al.* 2015) and, more specifically, of the Mediterranean sea (Cannizzaro *et al.* 1995; Galgani *et al.* 1995, 1996, 2000, 2014; Gardiner 1996; Tudor *et al.* 2002; Aliani *et al.* 2003; Martinez-Ribes *et al.* 2007; Ariza *et al.* 2008; Koutsodendris *et al.* 2008; Barnes *et al.* 2009; Turner and Holmes 2011; Collignon *et al.* 2012, 2014; Fossi *et al.* 2012, 2014; Güven *et al.* 2013; Kordella *et al.* 2013; Micheli *et al.* 2013; Mifsud *et al.* 2013; Vianello *et al.* 2013; Poeta *et al.* 2014, 2016; Suaria and Aliani 2014; Laglbauer *et al.* 2014; Cózar *et al.* 2015; Faure *et al.* 2012, 2015; Alomar *et al.* 2016; Munari *et al.* 2016; Suaria *et al.* 2016; Vlachogianni *et al.* 2017). In the specific case of Italy, the latest studies are mainly focused on floating litter in areas surrounding the peninsula (Suaria *et al.* 2014, 2016) instead of beached litter. The Italian Institute for Protection and Environmental Research (ISPRA 2012) has pointed out an overall lack of knowledge concerning beach litter that encouraged different Italian actors (i.e. Universities, Research Institutes, Aquariums and Museums, NGOs, regional and national EPA) to start monitoring programmes devoted to fill this gap. Some of these studies have been focused on specific beaches, that have been monitored during an entire year with several replicas (Poeta *et al.* 2014, 2016), while other surveys have been carried out on more beaches in a short time range, such as the one of Munari *et al.* (2016) and Vlachogianni *et al.* (2017) on the north central Adriatic coast. Moreover, the recent surveys promoted by the Italian Ministry for the Environment Land and Sea and carried out by Legambiente (the non-profit leading environmental organisation in Italy that works for safeguarding and enhancement of natural resources) provided data on beached litter on several Italian beaches (Legambiente 2014, 2015, 2016) but often with only one survey per year for each beach. Nevertheless, the knowledge gap is still far from be fulfilled, hence, more studies are needed for gathering satisfactory long-term data series possibly planning several surveys per year, in order to understand seasonal and annual trends, to plan management strategies (such as targeted cleaning activities) and correlate, in a proper way, beached litter distribution with its main sources (urban areas, rivers, main currents, winds) within a specific macroarea that may be considered as a homogeneous managerial unit under several oceanographic features, ecological processes and species distribution, or other aspects such as fisheries and jurisdictional purposes (ISPRA 2012). The urgent need of such data series concerning this important issue should be satisfied by the so-called “citizen science”, i.e. the involvement of citizens and their active participation in scientific projects (Newman *et al.* 2012, Kordella *et al.* 2013, Eastman *et al.* 2014), as suggested, also, by the UNEP/IOC Guidelines (Cheshire *et al.* 2009; UNEP 2012), in order to increase the volume of collected and processed data (Khatib 2011; Lehan and Gay 2011). Citizen participation in these kind of programs has been demonstrated by several studies to be effective both from the scientific and social point of view, since it brings people closer to science, filling the gap between those who produce science and technology and those who benefit from it (Cheshire *et al.* 2009; Tudor and Williams 2003; Cerrano *et al.* 2013; Thiel *et al.* 2014) and this has also been validated by the Joint Report of MSFD (2010).

Thus, in 2014 the Institute of Marine Sciences of the National Research Council (ISMAR – CNR),

in collaboration with INGV (Istituto Nazionale di Geofisica e Vulcanologia) and with DLTM (Liguria Cluster of Maritime Technologies), decided to undertake a monitoring programme within a macroarea that extends from southern Tuscany up to the Ligurian area of Cinque Terre (La Spezia) and surrounds the Pelagos Sanctuary (**Figure 1**). The principal objective of our study is to to analyse the presence and density (number of items per unit area), kind, and size of Beach Litter in this specific macroarea, and to suggest a first evaluation of the environmental quality of all considered Sites within this macroarea, following the criterion suggested by Schulz *et al.* (2013) by providing an aggregate indicator, understandable and usable by territorial managers and decision makers. Last but not least, students of primary and secondary school have been involved in project activities, in order to start a process for raising awareness in new generations (and their families) on the problems caused by waste to marine ecosystems.

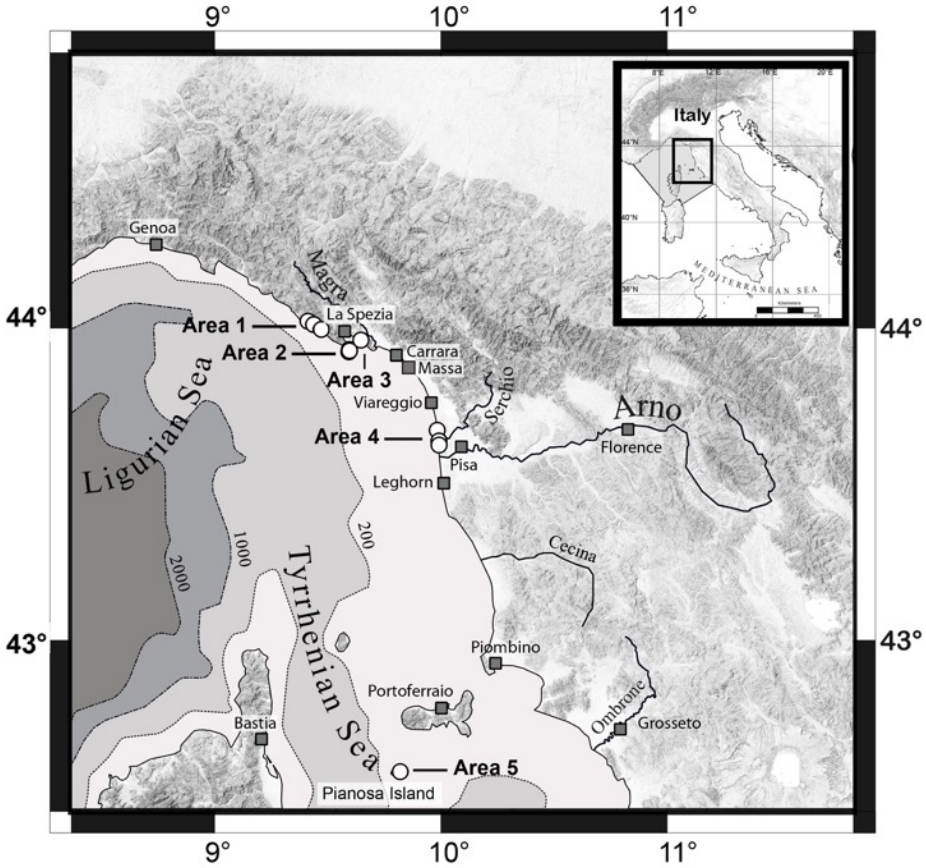

Figure 1. Main rivers, cities and harbours (gray squares) are shown in figure as well as the 5 Areas and the 11 Sampling Sites (white dots) surrounding the chosen Macroarea (bold square) for monitoring AMD: Area 1 - Cinque Terre beaches belonging to Cinque Terre National Park and its MPA; Area 2 - Palmaria island, belonging to Porto Venere Natural Regional Park and its MPA; Area 3 - Lerici beach; Area 4 - San Rossore restricted area belonging to Migliarino-San Rossore-Massaciuccoli Regional Natural Park; Area 5 - Pianosa island belonging to Tuscan Archipelago National Park and Secche della Meloria MPA. In the small map of Italy, Pelagos Sanctuary is shown as a grey area laying underneath the bold black square of our main Macroarea.

2. Material and methods

2.1 Study area

Our study macroarea has been chosen for its important economic and environmental values (Mangialajo *et al.* 2007; GFCM 2009; ISPRA 2012): an important coastal anthropisation (harbour activities, rail- and highways, metropolitan areas, touristic development) in line with the general increasing trend on Mediterranean coast but also an high number of Marine and Coastal protected areas (i.e. one International Marine Protected Area, two National Parks, three Regional Parks, and three Marine Protected Areas - MPAs - two of which are included in the UNESCO World Heritage List). The high ecosystem complexity, oceanographic dynamics and sea bottom topography makes this area particularly suitable for breeding and foraging needs (Jacques 1990, Cattaneo-Vietti 2010) of several species of cetaceans (striped dolphins or sperm whales are quite common) that are, hence, considered particularly at risk due to the increasing amounts of plastic and AMD coming both from land and sea (Aliani *et al.* 2003; Fossi *et al.* 2012, 2014; Suaria and Aliani 2014; Suaria *et al.* 2016). Five main rivers (and other minors rivers characterised by a torrential regime with an accentuated summer droughts) flow in this Macroarea such are Magra, Arno, Serchio, Ombrone and Cecina.

Five areas (**Figure 1)** have been chosen within the Pelagos Sanctuary macroarea: *Cinque Terre beaches* – Area 1, included in Cinque Terre National Park and its MPA; *Palmaria island - Area 2,* included in Porto Venere Natural Regional Park and its MPA; *Lerici beach* - Area 3, near Montemarcello-Magra Regional Natural Park; *San Rossore restricted area* - Area 4, included in Migliarino-San Rossore-Massaciuccoli Regional Natural Park; *Pianosa island* - Area 5, included in Tuscan Archipelago National Park and Secche della Meloria MPA.

Each Area includes several beaches, that stretch from thousands of meters to kilometers. Beaches have been selected according to land-use planning, kind (linear and pocket beaches) in order to monitor and estimate contribution of urban, riverine or marine inputs to coastal litter pollution (Galgani *et al.* 2013). Beaches have been classified following Ariza *et al.* (2008) as:

- Urban (U) beaches located in residential and touristic areas, that are cleaned on a regular basis - especially during touristic seasons - and as public service.
- Urbanized (Uz) beaches, close to urban centres and may be visited by tourists but with a lower human presence compared to the previous ones and less regular cleaning activities.
- Natural (N) beaches with low human impact. Some of the chosen Sites are located in MPAs, in many cases in the most restricted sub-areas (“A Zone” - high degree of protection and prohibition for boating activities). These beaches receive AMD transported by marine currents, rivers, waves and wind. Cleaning activities are usually not performed and may be carried out exceptionally during focused awareness campaigns by NGOs and volunteers.

  Further details on study Area, Sites and used abbreviations are shown in **Table 1.**

AREA	Site and Abbreviation*	Description	Resident Population (n)	Access to beaches	Survey Date(s)	Cleanup Activities **	Proximity (< 50 km) to AMD sources	Coordinates
1	Monterosso II $1MO_U$	Large sandy beach. frequented by tourist throughout all the year.	1,462[2]	Easy access from the villages of Monterosso. Vernazza and Corniglia.	2015/01/23 2015/04/08 2015/05/21	monthly	Port of La Spezia/City of La Spezia /Magra river)	44° 8' 44.52"N 009° 39' 23.34"E
	Vernazza $1VE_U$	Large beach of pebble stones formed after the 2011 flood. Bathing prohibition.	921[2]		2014/12/17 2015/04/12	monthly		44° 7' 3.3"N 009° 43' 5.82"E
	Corniglia $1CO_U$	Large but isolated beach of pebble stones.	195[2]		2014/12/05 2015/02/26	monthly		44° 7' 3.3"N 009° 43' 5.82"E
2	Gabbiani $2GA_{Uz}$	Isolated beach of sand and pebble stones in Palmaria Island. frequented during summer.	3,819	Only from the sea	2014/12/19 2015/04/09	monthly	Port of La Spezia/City of La Spezia/Magra river	44° 2' 29.22"N 009° 51' 4.38"E
	Ammiraglio I $2AR_{Uz}$				2014/03/30 2014/12/19 2015/04/09	monthly		44° 2' 55.02"N 009° 51' 8.64"E
	Ammiraglio II $2AL_{Uz}$				2014/04/30 2014/12/19 2015/04/09	monthly		44° 2' 40.2"N 009° 51' 11.58"E
3	Venere Azzurra $3VA_U$	Urban sandy beach very close to a touristic centre (Lerici).	10,292	Easy access from the city of Lerici.	2015/03/30 2015/05/07	daily	Port of La Spezia and Port of Marina di Carrara/ City of La Spezia and "Versilia Riviera"/ Magra river)	44° 4' 54"N 009° 54' 23.22"E
4	Foce Serchio $4FS_N$	Large sandy beach manly formed by sediments coming from River Arno. Restricted area in a Natural Park.	87,737	Special permit needed for access from land.	2014/11/24 2015/01/13 2015/03/10 2015/12/09	No	Port of Livorno/ City of Pisa and"Versilia Riviera" /Arno and Serchio river	43° 46' 21.30"N 010° 16' 11.7"E
	Morto Nuovo $4MN_N$				2014/10/28 2015/01/17 2015/03/30 2015/07/24	No		43° 44' 7.38"N 010° 16' 43.20"E
	Buca del Mare $4BM_N$				2014/04/06 2014/11/15 2015/07/29 2015/12/15	occasionally by volunteers		43° 43' 10.74"N 010° 16' 40.2"E
5	Cala Giovanna $5CG_{Uz}$	Sandy beach on a very restricted Area of an Island that hosts a jail. Tourists are allowed to go with special permit.	10[3]	Easy access from the nearby village.	2014/05/09 2014/11/02 2015/02/15 2015/05/13	monthly	No	42° 35' 23.28"N 010° 5' 37.02"E
Notes	*Subscripts in Sites Abbreviations: U (Urban); Uz (Urbanized); N (Natural). **Cleaning activities are performed from June till September. [2]Cinque Terre is is subject to a massive touristic activity since the late nineties of the last century and has reached only in 2014 an average of 4977 visitors per day. [3]Pianosa Island is located 13 km south-west of the Island of Elba to which it is connected only during the tourist season with regular shipping services. Pianosa has a very low population density: there is still a limitation for visitors, that can't exceed the number of 250 per day.							

Table 1 Surveyed Areas and Beaches, with general description.

2.2 Monitoring Protocol and Litter Sampling

Since monitoring campaigns have been planned in order to be carried out with teams of researchers, volunteers, and students, a monitoring protocol to support operators with instructions to follow for field work has been purposely developed in order to be suitable for any kind of user but also enough exhaustive and rigorous for obtaining compatible, coherent, consistent and comparable datasets (Merlino *et al.* 2015).

This monitoring protocol (made up by a Survey Datasheet for cataloguing AMD and its Users' Manual/Guidelines i.e. SEACleaner Monitoring Protocol as shown in Merlino *et al.* 2015) is hence, the result of the integration of direct observations with all guidelines and methodological instructions identified in literature: size and position of transect on the shoreline (Cheshire *et al.* 2009; Williams and Tudor 2001a, 2001b; Velander and Mocogni 1999); kind and material categories and all other characteristics of the studied area (OSPAR 2010; Lippiatt *et al.* 2013), such as conformation of the territory (different kind of beaches, proximity to outlets of rivers and harbours; the presence of aquaculture / fishing activities).

The Survey Datasheet reduces the number of kind of articles from 121 to 33, and the number of Materials from 12 to 9 (plastic, foamed plastic, textiles, glass and ceramic, metal, paper and cardboard, rubber, wood, other, following Cheshire *et al.* 2009), because our goal was to obtain definite data, minimizing the bias of a wrong classification, and only predominant AMDs were taken into account; however, objects that could not be identified have been photographed and stored in a repertoire for their subsequent identification.

Special attention has been given to beached Macro Litter, i.e. the AMD with more than 2.5 cm in size (Cheshire *et al.* 2009; UNEP 2012). Distinction in three (3) size classes of length (L) items has been also considered: small (2.5 cm < L < 15 cm); medium (15 cm < L < 50 cm) and big (L> 50 cm). All items have been collected following a standardised approach starting from the seaside line to the beginning of the back dune vegetation (or other back constraints): for sandy and linear beaches, i.e. areas having a basic unidirectional flow patterns (for example $4FS_N$, $4MN_N$, $4BM_N$ or $3VA_U$ beaches) 100 meters long transects have been analysed as suggested by Cheshire *et al.* (2009) from the shoreline to the beginning of the psammophilous vegetation of the dunal system; in other cases, i.e. "pocket beaches" sampling unit had to be resized as suggested by Williams and Tudor (2001a, 2001b) (as in **Figure 2**).

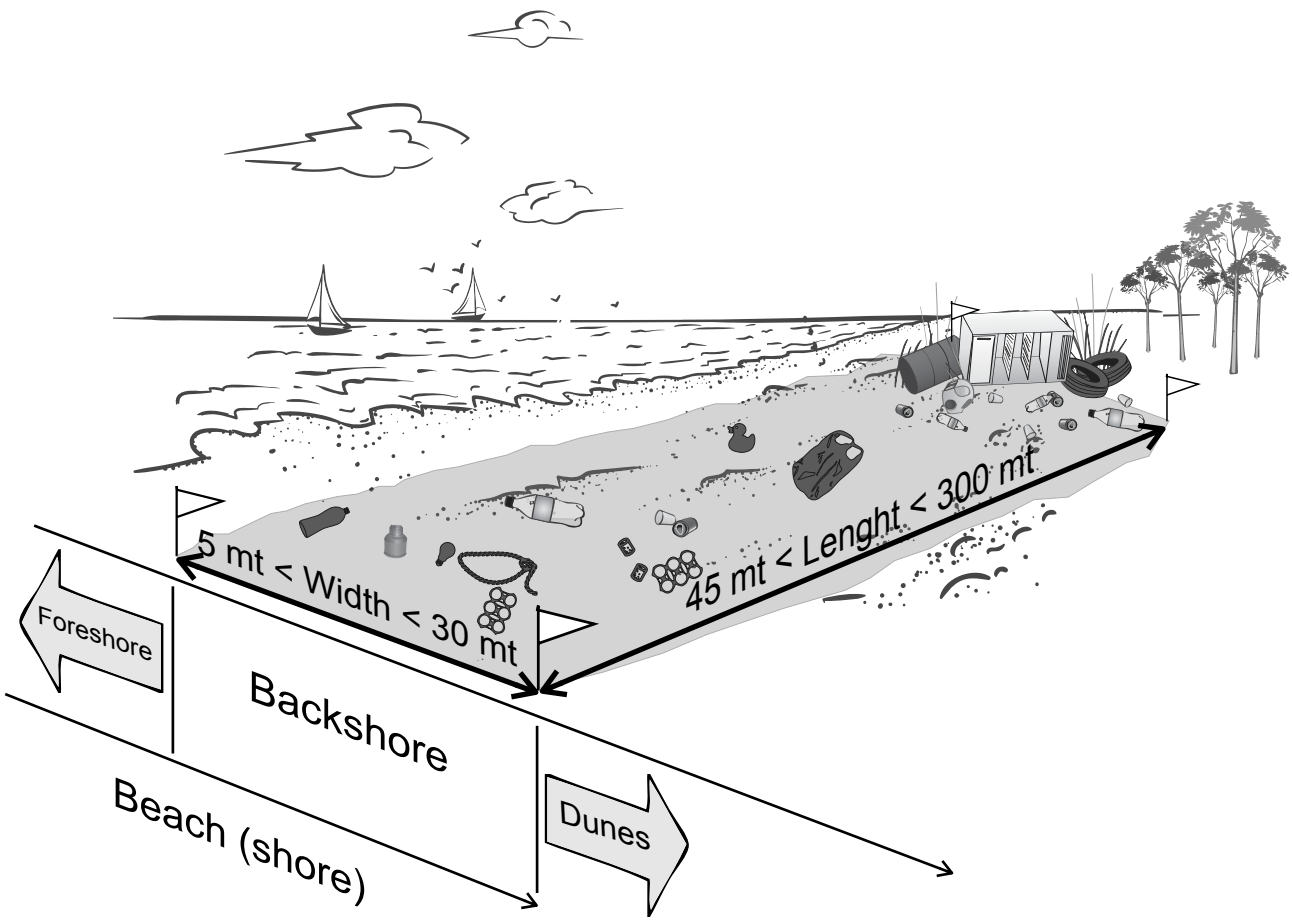

Figure 2. All AMD from the water's edge to the back of the beach (the back shore i.e. from the limit of high water foam lines to dunes or extreme inland limit of the beach) are collected along the length of the sample unit.

In all cases, the initial and final points of the chosen beaches have been georeferenced using a GPS (Garmin GPSMAP® 64st) in order to repeat survey in the same stretch of beach. Taking into account the time required for AMDs to accumulate, we considered a minimum of two months between replicates in the same Site. All litter with dimension bigger than 2.5 cm has been removed and brought to laboratory for sorting and counting. Very large items, which could not be removed, were photographed and their position registered with GPS to avoid pseudo-replication.

Collected Beach Litter has been classified following the SEACleaner Datasheet. Once items classification was completed, garbage was properly thrown away. The total number of litter items in each sampling unit was registered and reported using the density of items per square meter of shoreline (items/m^2).

Data have always been collected by two of the authors, with the help of volunteer operators that have been trained before litter removal, and constantly supervised, during work, by researchers of CNR-ISMAR, INGV and DLTM.

Monitoring programme started in January 2014 and ended in December 2015. Monitoring activities have been carried out in beaches belonging to MPAs with a high degree of protection (Natural) in order to monitor litter coming directly from the sea. For the same reason, monitoring on Urban and Urbanized beaches have not been carried out during the summer season (from June till the end of September) in order to to avoid, as much as possible, contribution from land recreational activities.

2.3 Data Analysis

Statistical analysis has been performed with PAST 3.12 software for Windows and MacOSX (Hammer *et al.* 2001). Different hypothesis have been tested by following two methods of multivariate analysis methods: ordination (i.e. principal component analysis or PCA (Randerson 1993) and clustering (i.e cluster analysis - Ward's method (Aldenderfer and Blashfield 1984)) in order to recognise patterns and to evaluate similarities and dissimilarities amongst Groups of material, Areas and Sites, considering AMD average density, Material and Size. Principal Components Analysis (PCA) has been used to visualise similarity between Sites for the litter average density calculated for the different Materials and averaged for the n replicates of each one of the Sites. An immediate advantage for this kind of simultaneous ordination, both for beach Sites and litter Materials, is the fact that a single analysis allows each individual to be placed on one or more constructed axes, so that its relative geometrical position reflects its similarities its fellows. Cluster analysis has been performed for obtaining a classification (dendrogram) of beaches by using average density of AMD according its Size: similar cases are joined by existing links between properties and grouped in clusters whose position indicates the level of similarity with other clusters, thus providing insights in the average distribution of small, medium and big AMD amongst analysed beaches.

2.4. Beach quality Assessment

In order to assess the current environmental status of all monitored beaches, results have been derived as an integrated and adapted application of Schultz *et al.* (2013) method. This evaluation method provides, an aggregate indicator that translates the quality of the beaches in terms of potential and direct damage to the health of marine organisms - and by extension to human life - with a scale ranging from 1 to 4 (where 1 = Good, 2 = Mediocre, 3 = Unsatisfactory, 4 = Bad) understandable and usable by territorial managers and decision makers

The method implies association of a value (or "Weight") to each AMD object found during sampling following two criteria:

Case a: Weight = 1 if the Article causes an indirect damage (such as glass bottles) but with no direct risk potential such as entanglement.

Case b: Weight =1.5 if the Article causes a direct impact such as entanglement, anoxia, hypoxia, ingestion, bio-fouling/transport of alien species and/or release of Persistent Organic Pollutants (POPs).

Items are weighted only by short term AMD effects as a consequence of the lack of data and scientific literature about the long term AMD effects (DNA damage etc.). Following this value assignment, a weight table has been created for the identified Articles found during our monitoring activities. Subsequently, all values have been processed according to formula (**1**):

(**1**)
$$\bar{X} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}$$

X represents the final evaluation i.e. a weighted average value of the environmental status i.e. a weighted average of all the single weights (w_i) of all the Articles found on a specific beach multiplied for the class (x_i) assigned to the beach based on the presence and abundance of that specific Article within the whole monitoring period. Each beach is evaluated according to the classification system: classes of the environmental status (1, 2, 3, and 4 corresponding to good, mediocre, unsatisfactory, and bad, respectively) that is assigned according to the total number of items found on 100 square meters (for example from 4 to 11 bottles are necessary to classify a beach as in a mediocre status - see **Table 2**). An adapted version of the Alkalay *et al.* (2007) Clean Coast Index (CCI) only for Plastic and Polystyrene has also been calculated for our study according to formula (**2**):

$$(\mathbf{2}) \qquad CCI = \frac{\sum_{i=1}^{n} Pla_i + \sum_{i=1}^{n} Pol_i \cdot x_i}{Z \times Lenght\,[\mathrm{m}] \times Width[\mathrm{m}]} = Plastic\ and\ Polystyrene\ parts/\mathrm{m}^2$$

CCI is the number of plastic and polystyrene parts/m^2, the total area of transect is the product of the transect length and width, and K (constant) = 20. Moreover beaches have been also classified from ‘‘Clean” to ‘‘Extremely dirty” according to the scale provided by Alkalay *et al.* (2007) and shown in **Table 5**.

Material	OSPAR ID	Articles	Weight Wi	Beach Classification (n° of items/100 m²) Xi			
				Good 1	Mediocre 2	Unsatisfactory 3	Bad 4
Plastic	4	Entire Bottles	**1**	<4	4 - 11	12 - 43	>43
	2, 3, 19, 23, 24, 40, 48, 112, 121	Bags (or fragments)	**1.05**	<4	4 - 11	12 - 22	>22
	20	Toys	**1**	<2	2 -4	5 - 6	>6
	46 , 47, 48, 99	Fragments (non id.)	**1.05**	<10	10 - 32	33 - 62	>62
	5, 6, 7, 8, 9,10,11,12,13, 21, 34, 38	Containers/ Fragments of Bottles/ Jerrycans	**1.05**	<2	2 - 5	6 - 7	>7
	29, 30, 31, 32, 33, 35, 49, 98, 115, 116	Filaments/ Tubes/ sticks	**1.05**	<3	3 - 6	7 - 8	>8
	15, 43	Caps	**1.05**	<5	5- 23	24 - 50	>50
	— —	Tubes	**1**	<1	2 -4	5 - 6	>6
	98	Cotton Buds	**1**	<13	13 -25	26 - 59	>59
Polistyrene	46, 47, 117	Fragments	**1.05**	<7	7 - 57	58 -200	>200
Multimaterial	44, 50	Shoes	**1**	<3	3 - 6	7 - 8	>8
	52	Wheels	**1**	-	-	-	-
	88	Electric Plastified Wires	**1.5**	<4	4 - 14	15 - 22	>22
	118	Cardboard	**1**	<3	3 - 11	12 -14	>14
	16, 17, 18, 62, 63, 64, 76, 94, 96, 103, 104, 118,120	Other	**1**	<4	4 - 14	15 - 56	>56
	33	Fishing Nets	**1.05**	<1	2 -4	5 - 6	>6
Fabric Tissue	54, 55, 59	Fragments	**1.5**	<1	2 -4	5 - 6	>6
	100	Filaments/ Nets/cords	**1.05**	<1	2 -4	5 - 6	>6
	— —	Soccer balls	**1.05**	<1	2 -4	5 - 6	>6
Foam Sponge	44, 45	Fragments	**1.5**	<4	4 - 12	13 - 26	>26
Rubber	53	Fragments	**1.5**	<2	2 - 5	6 - 7	>7
	52	Tires	**1**	-	-	-	-
Processed Wood	69, 70, 72, 74, 75,119	Fragments	**1.5**	<1	2 -4	5 - 6	>6
	68	Cork	**1**	<1	2 -4	5 - 6	>6
Glass	91, 93, 105	Entire Bottles	**1**	<3	3 - 8	9 - 10	>10
	92	Other	**1**	<2	2 - 3	4 - 5	>5
Metals	77, 78, 79, 81, 82, 103, 120	Aluminium	**1**	<2	2 - 7	8 - 14	>14
	84, 86, 120	Iron	**1**	<2	2 - 15	16-43	>43

Table 2. Material and Articles classification according to OSPAR and correspondent Weight for Beaches and Classification of beaches according to the number of items collected/100 m².

Results

A total of 34,027 AMD items have been collected, analysed and classified into 33 categories and nine major groups, with an average density of 1.06 items/m^2 (total area: 13,372.5 m^2 - **Table 3**). Area 4 that belongs to Migliarino-San Rossore-Massaciuccoli Regional Natural Park registered the highest average density (1.50 items/m^2), followed by Area 2 (Porto Venere Natural Regional Park and MPA) with an average density of 1.05 items/m^2. The remaining Areas, located in Urban or Urbanized areas show an average density smaller than 1 (**Figure 3** and **Table 3**).

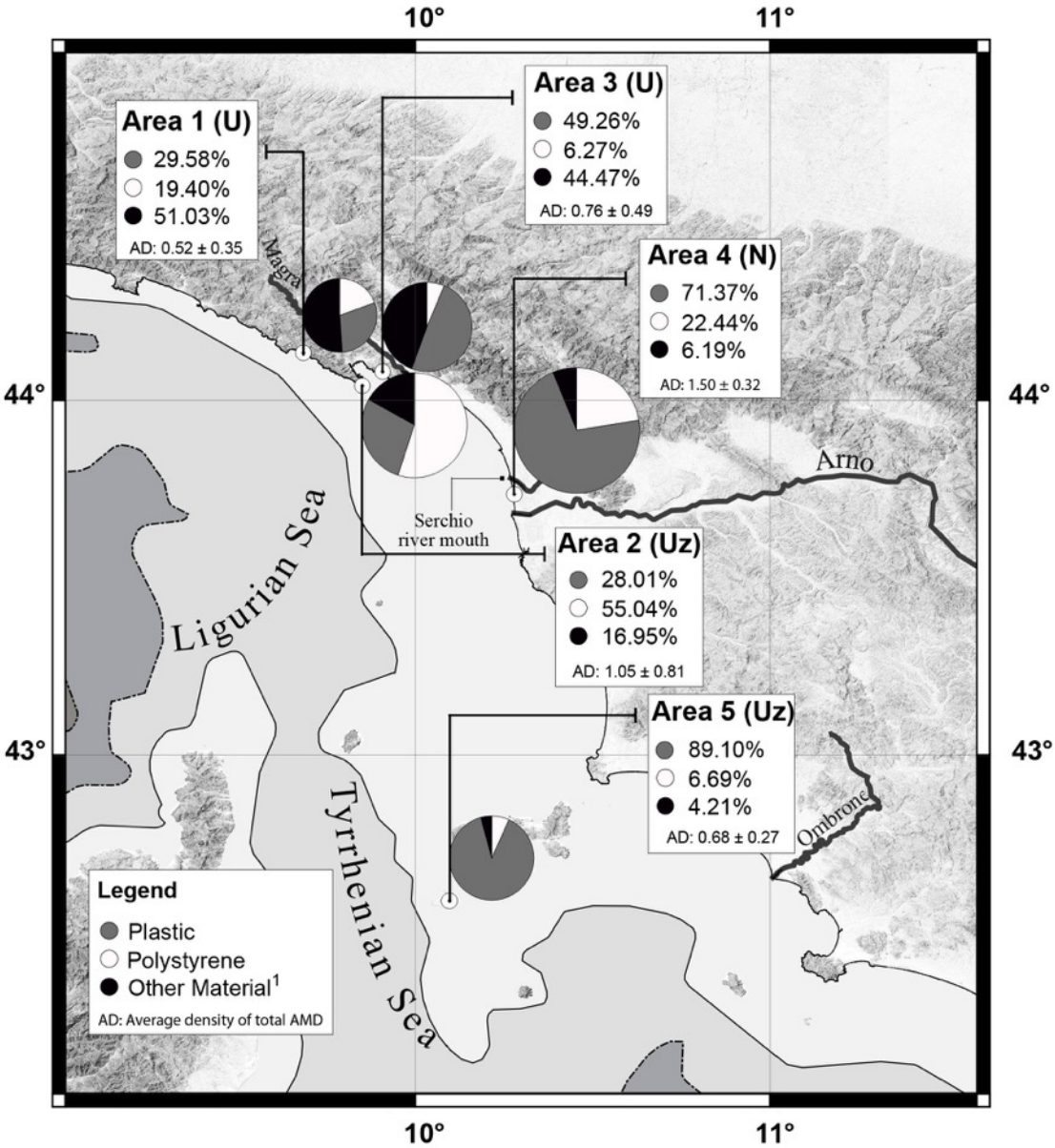

Figure 3. Pie charts overlapped to the Macroarea showing the average percentage density of Plastic, Polystyrene and Other Material1 found for each Area. Pie size is different amongst areas in order to show the difference in the total AMD average density.
[1]Sum of Multimaterial, Metals, Processed Wood, Foam/Sponge, Textiles, Rubber and Glass.

Site	Surface (m^2)	Unit	Material									Σ	AD	Total AD
			Pla	Pol	Wo	F/S	Tex	Mul	Rub	Gla	Met			
$1MO_U$	720	An	124	273	4	74	12	23	3	5	18	536	**0.52 ±0.35**	**1.06[4] ±0.74**
		AD	0.17 ±0.11	0.38 ±0.17	0.01 ±0.00	0.1 ±0.13	0.02 ±0.01	0.03 ±0.03	0	0.01 ±0.00	0.02 ±0.01	0.75		
		A%	23.09	50.84	0.81	13.72	2.30	4.35	0.62	0.93	3.35	100		
$1VE_U$	1487	An	210	31	2	0	19	306	54	0	423	1.045		
		AD	0.14 ±0.12	0.02 ±0.02	0	0	0.01 ±0.02	0.21 ±0.19	0.04 ±0.04	0	0.28 ±0.40	0.70		
		A%	20.12	2.97	0.14	0.00	1.82	29.28	5.17	0.00	40.49	100		
$1CO_U$	1890	An	109	11	0	1	4	22	54	4	38	243		
		AD	0.06 ±0.04	0.01 ±0.00	0	0	0	0.01 ±0.01	0.03 ±0.01	0	0.02 ±0.00	0.13		
		A%	45.51	4.38	0.00	0.21	1.46	8.98	22.34	1.46	15.66	100		
$2GA_{Uz}$	450	An	71	130	2	4	6	136	1	3	10	363	**1.05 ±0.81**	
		AD	0.11 ±0.11	0.29 ±0.37	0	0.07 ±0.10	0.01 ±0.00	0.01 ±0.00	0	0.01 ±0.00	0.01 ±0.01	0.56		
		A%	27.98	51.59	0.79	12.50	1.59	2.38	0.20	0.99	1.98	100		
$2AR_{Uz}$	510	An	283	629	2	64	7	9	0	2	15	1.011		
		AD	0.55 ±0.24	1.23 ±0.68	0	0.13 ±0.05	0.01 ±0.00	0.02 ±0.01	0	0	0.03 ±0.02	1.98		
		A%	27.99	62.28	0.17	6.34	0.69	0.89	0.03	0.17	1.45	100		
$2AL_{Uz}$	687.5	An	115	211	3	26	5	29	2	3	16	410		
		AD	0.17 ±0.13	0.31 ±0.27	0.00 ±0.01	0.04 ±0.04	0.01 ±0.00	0.04 ±0.06	0	0	0.02 ±0.03	0.60		
		A%	28.06	51.26	0.81	6.33	1.22	7.14	0.49	0.73	3.97	100		
$3VA_U$	1172	An	232	42	16	12	23	542	2	11	13	893	**0.76 ±0.49**	
		AD	0.30 ±0.17	0.04 ±0.02	0.01 ±0.01	0.01 ±0.00	0.01 ±0.02	0.23 ±0.33	0	0.01 ±0.00	0.01 ±0.01	0.76		
		A%	49.26	6.27	1.14	1.47	1.66	38.04	0.19	0.90	1.06	100		
$4FS_N$	3000	An	2.348	206	3	11	10	23	5	14	5	2.625	**1.50 ±0.32**	
		AD	1.35 ±0.90	0.08 ±0.10	0	0.01 ±0.00	0.01 ±0.00	0.01 ±0.00	0	0.01 ±0.00	0	1.47		
		A%	91.98	5.47	0.06	0.44	0.40	0.84	0.20	0.45	0.16	100		
$4MN_N$	620	An	554	48	1	7	1	6	1	5	4	627		
		AD	1.05 ±0.58	0.11 ±0.07	0	0.02 ±0.01	0	0.01 ±0.01	0	0.01 ±0.01	0.01 ±0.00	1.21		
		A%	86.21	9.35	0.12	1.30	0.27	1.01	0.22	0.80	0.73	0		
$4BM_N$	500	An	328	479	3	50	4	23	2	21	4	914		
		AD	0.66 ±0.33	0.96 ±0.83	0.01 ±0.01	0.10 ±0.05	0.01 ±0.01	0.05 ±0.06	0.00 ±0.01	0.04 ±0.06	0.01 ±0.00	1.8		
		Ab	35.93	52.50	0.27	5.43	0.38	2.50	0.25	2.33	0.41	100		
$5CG_{Uz}$	2336	An	1.413	106	4	25	10	11	8	4	5	1.586	**0.68 ±0.27**	
		AD	0.60 ±0.24	0.05 ±0.03	0	0.02 ±0.01	0.01 ±0.01	0	0	0	0	0.68		
		A%	89.10	6.69	0.27	1.58	0.63	0.66	0.50	0.24	0.33	100		
Notes	[4]Total number of items: 34.027 AMD (on a total monitored coastal area of 32.154 m^2).													

Table 3. Marine Litter Data for all Sites of present study. An - Average number of items (n); AD - Average Density of items (D=items/m2); Ab - Abundance of items (%)). Pla - Plastic; Pol - Polystyrene; Wo - Processed Wood; F/S - Foam/Sponge; Tex - Textiles; Mul - Multimaterial; Rub - Rubber; Gla - Glass; Met - Metal. For Sites abbreviations see Table1.

Figure 3 shows that Plastic is the prevailing Material in Area 4 (characterized by Natural beaches) and in Area 5 (an MPA with very low touristic pressure), with values of 71.37% and 89.10% respectively. Urban Beaches (Area 1 and 3) show, instead, an high percentage of Other Materials (i.e. the sum of Multimaterial, Metals, Processed Wood, Foam/Sponge, Textiles, Rubber and Glass) 51.03% and 44.47% respectively. High abundances of Polystyrene (greater than 55%) are recorder in Urbanized areas such as Area 2. A deeper insight (**Table 3**) in the Other Material category shows that: Multimaterial has a range between 0.66% and 38.04%; the highest percentage of Metals is in Area 1 (for example 40.49% in $1VE_U$); finally, Processed Wood, Foam/ Sponge, Textiles, Rubber and Glass are present with percentages that are lower than 22%.

In order to analyse density of beach litter along the sandy littoral, litter has been classified according to material. Shapiro-Wilk Test for testing normality gave back a W value 0.94 with $p_{normal} > 0.5$, so a normal distribution is assumed to be followed by our data. We assigned different features to Sites (geographical conditions, being part of Natural parks or MPAs, proximity of Harbours/Towns and River mouths) and we tested if there were significant variations of beach litter density between Sites and Areas. The Analysis of Variance (One-way ANOVA) for our data set allowed to verify the significance level with Fischer Test, leading to two conclusions:

1. differences between Areas do exist (df =4; F=2.717; $p_{empirical} = 0.0498 < p_{normal} = 0.05$)
2. differences between Sites do exist (df =10; F= 2.807; $p_{empirical} = 0.02087 < p_{normal} = 0.05$)

Average densities (items/m^2) for all the Areas and Sites are significantly heterogeneous, as confirmed by One-way ANOVA results. Principal Components Analysis (PCA) for Sites according AMD average density (**Figure 4**) can reveal some obvious similarities or unexpected differences between Sites belonging to the same Area. PCA analysis identifies, in fact, two main groupings of Urban and Urbanized Sites belonging to the Area 1 and 2 and some exceptions (i.e. 2ALuz geographically belongs to Area 2 but is instead very distant in the plot). In these two groups AMD average density is quite similar. An overlap with biplots - reporting the relationship between the Material categories of collected Beach Litter and the Sites - allows a better understanding of similarities and diversities between Sites, not only for AMD average density but also for Materials. We can, hence, see that Multi-Material, Rubber, Metals and Textiles, usually characterise Sites of the two groups. For what concerns the ungrouped sites, we can see that natural and some urbanized sites share common features: apart from similar high AMD density values, $4BM_N$ and $2AL_{Uz}$ have similar average density of Polystyrene items while on the other beaches of Area 4 ($4MN_N$ and $4FS_N$) and Area 5 ($5CG_{Uz}$) Plastic items predominate.

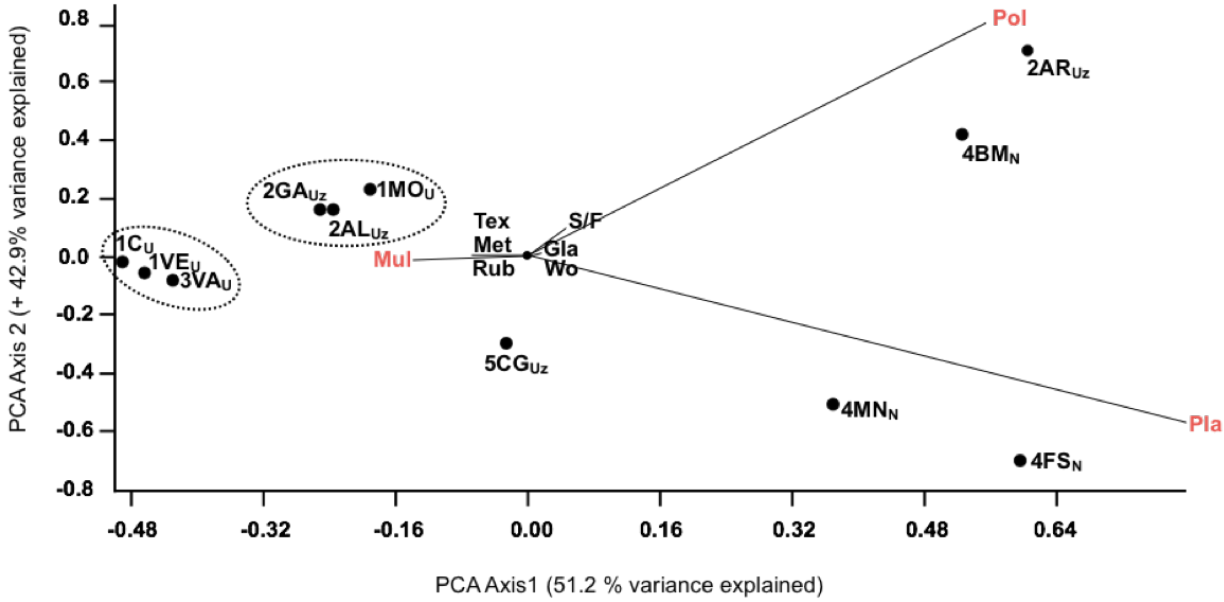

Figure 4. Plot of the principal component analysis of survey sites using group classification for the 11 Sites (black dots), according to the average density of AMD for each Material. Biplots have been overlapped to PCA, in order to add information for Materials. Small angles between arrows indicate positive high correlations between groups. For Sites abbreviations see Table1.

Cluster analysis has been performed, for AMD Size, using squared Euclidean distance similarity coefficient with Ward's method of clustering (**Figure 5**).

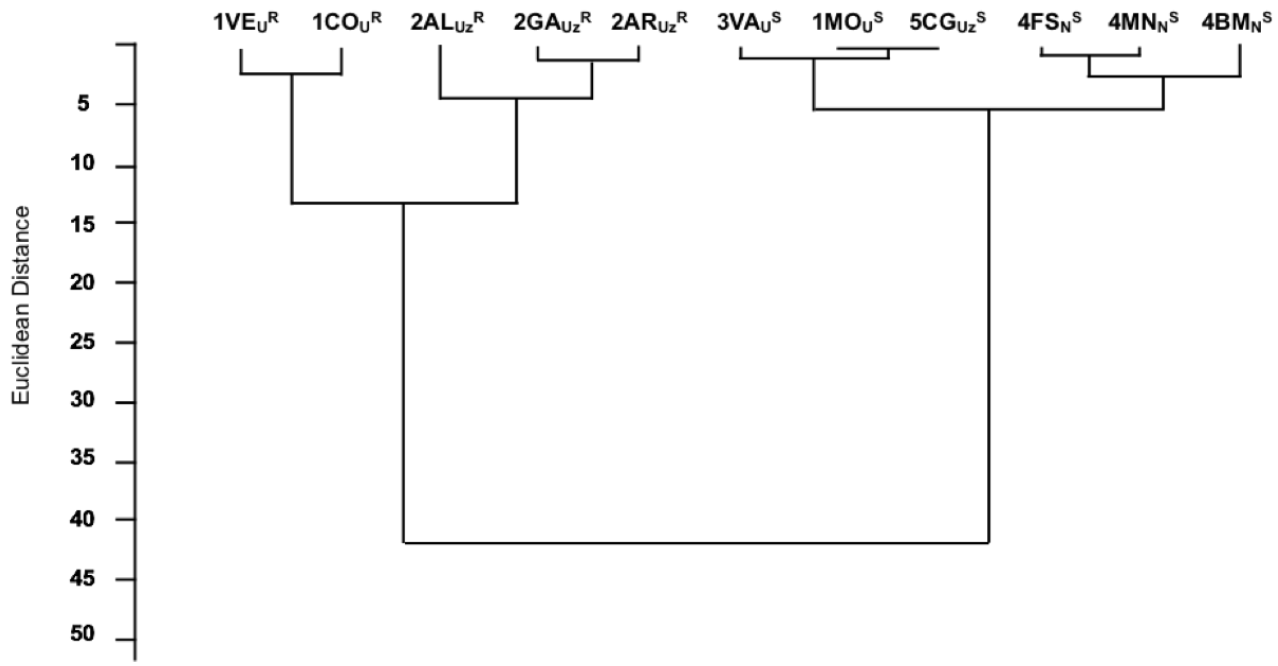

Figure 5 Cluster Analysis. Ward's Method for the 11 Sampling Sites according to the average size of AMD. For Sites abbreviations see Table1. Note: superscript letters on the beaches abbreviations indicate Sand (S) or Rocky beaches (R).

Two main clusters are evident: one includes the beaches characterised by a larger grain size ($1VE_U$, $1CO_U$, $2AL_{Uz}$, $2AR_{Uz}$ and $2GA_{Uz}$) and the other one includes the beaches with smaller with smaller granulometry ($3VA_U$, $1MO_U$, $5CG_{Uz}$, $4FS_N$, $4MN_N$ and $4BM_N$). Even if both clusters show a majority of small-sized items (75.76% and 93.97 %, respectively), in the first cluster medium and big AMD are more abundant compared to the second one (20.70% and 5.55 % medium AMD, 3.54% and 0.49% big AMD, respectively) as shown in **Table 4**.

Cluster	Site	Ab		
		S	M	B
1	$1VE_U$	69.46	23.57	6.97
	$1CO_U$	71.19	24.43	4.38
	$2GA_{Uz}$	81.15	16.87	1.98
	$2AR_{Uz}$	80.11	18.03	1.86
	$2AL_{Uz}$	76.89	20.60	2.51
	Average	75.76	20.70	3.54
2	$3VA_U$	95.40	4.60	0.00
	$4FS_N$	93.71	5.92	0.37
	$4MN_N$	93.18	6.60	0.22
	$4BM_N$	91.13	8.19	0.68
	$5CG_{Uz}$	95.21	3.98	0.81
	$1MO_U$	95.16	3.98	0.86
	Average	93.97	5.55	0.49

Table 4. Marine Litter Data on Size for all Sites belonging to the two clusters of Figure 6. AD - Average Density of items (D=items/m2); Ab - Abundance of items (%); S - Small (2,5 cm< Length <15 cm); M - Medium (15 cm < Length < 50 cm); B - Big (Length > 50 cm). For Sites abbreviations see Table 1.

Results of Beach Classification are shown in **Table 5** that compares the Schultz *et al.* (2013) method and an adapted version of the Clean Coast Index (CCI-Alkalay *et al.* 2007). Following the former author, only three positive exceptions are clear for urban beaches: $1MO_U$, $1CO_U$ and $3VA_U$. Generally, our monitored beaches score a mediocre environmental status. For example in $2GA_{Uz}$ this result is due to the prevalent presence of dangerous objects such as electrical wires with Plastic, Polystyrene, Foam Sponge fragments. Of course, these results are still preliminary, because in order to validate this method, protocol should be extended also to buried litter, while increasing the number of Sites and understand the actual (not estimated) damage caused to organisms by different types and amounts of items or materials. The CCI shows a more diverse situation, but quite coherent with the former method. Best ranking is attributed to two urban beaches ($1VE_U$ and $1CO_U$), and, as expected, worst ranking is given to all natural beaches ($4FS_N$, $4MN_N$, $4BM_N$).

	sensu Schultz *et al.* 2013		*sensu* Alkalay *et al.* (2006)	
Site	**Numeric Value**	**Qualitative Value**	**Numeric Value**	**Qualitative Value**
$1MO_U$	1	Good	11	D
$1VE_U$	2	Mediocre	3	C
$1CO_U$	1	Good	1	VC
$2GA_{Uz}$	2	Mediocre	9	M
$2AR_{Uz}$	2	Mediocre	36	ED
$2AL_{Uz}$	2	Mediocre	9	M
$3VA_U$	1	Good	5	M
$4FS_N$	2	Mediocre	29	ED
$4MN_N$	2	Mediocre	23	ED
$4BM_N$	2	Mediocre	32	ED
$5CG_{Uz}$	2	Mediocre	13	D
Average	2	Mediocre	17	D

Table 5. Environmental Status of Sites according qualitative evaluation sensu Schultz et al. (2013) and Alkalay et al. (2006). The former one follows a scale ranging from 1 to 4 where 1: Good, 2: Mediocre, 3: Unsatisfactory, 4: Bad. The latter ranges from Very Clean (VC; 0-2), Clean (C; 2-5), Moderate (M; 5-10) Dirty (D; 10-20) Extremely Dirty (ED; 20+).

Discussion and Conclusions

The study has provided additional data on the presence of beached AMD in an area that is still poorly studied and that needs urgently an implementation of the MSFD (e.g. definition/update of targets, development/implementation of a programme of measures designed to achieve or maintain GES). Many MPAs have been especially included, both to assess their environmental status and to understand the differences between continental (Area 4) and also isolated MPAs (Area 5): both cases represent a perfect place for registering accumulation driven by river and/or sea inputs in short time intervals (Smith and Markic 2013).

The average density highlighted by our study (1.06 items/m^2) is higher compared to the average results obtained from other studies in neighbouring italian areas (see **Table 6**), such as those carried out in the italian coasts by the NGO Legambiente (2014, 2015) that show an average value of 0.12 and 0.17 items/m^2 or Vlachogianni *et al.* (2017) with 0.28 items/m^2. The last surveys of Vlachogianni *et al.* (2017) in the Adriatic coast found AMD densities ranging from 0.11 to 0.55 items/m^2 (average 0.28), but also pointed out a possible underestimation, since sampling was performed only on the first 10 meters from the strandline (and not from the strandline all way back to the end of the beach as followed in present study). Just across the Adriatic border, on the Slovenian coasts, Laglbauer *et al.* (2014) found a higher value (1.51 items/m^2) for six beaches (three touristic and three non touristic - but sampling has been done in one month during summer season).

As shown in **Table 6**, our values for Urban, Urbanized and Natural beaches are higher compared to the studies carried out in Italy by Munari *et al.* (2016), Poeta *et al.* (2016) and Vlachogianni *et al.* (2017). Nevertheless, even if results are different, an increasing concentration of AMD from Urban (0.64 *vs* 0.11) to Urbanized (0.87 *vs* 0.29) and Natural (1.50 *vs* 0.55) is quite evident, thus revealing the absence of regular cleaning activities in natural or remote areas (unlike urban beaches) but also the fact that, despite being protected from direct inputs (i.e. beachgoers), these areas still receive important quantities of AMD from the sea. This is the case of Area 4 where the highest density (1.50 items/m^2) of AMD is due to objects coming from industries located all along the territory crossed by Arno River (such as textile factories, leather tanneries) and Serchio River or to others inexplicable sources (such as hazardous hospital or pharmaceutical waste whose management and disposal is supposed to be strictly regulated by national laws and rules). The importance of river contributions to beached solid waste is in line with what has been reported by Araújo and Costa (2007) and confirmed by several other studies (Moore *et al.* 2011; Rech *et al.* 2014).

Nation	Region | Macroarea	Number and kind of beach	Use	Sampling period	Followed Protocols	Average Value (items/m$^{2)}$	Reference
Slovenia	Slovene Littoral	6 sandy beaches	Touristic and non-touristic	July 2012 one sampling month	Beaches were cleaned on a monthly basis. One 50-m transect was placed randomly along the beach. parallel to the shoreline. All debris bigger than 2cm was collected in the area ranging from the shoreline to the upper beach limit within the 50-m transect.	1.51	Laglbauer *et al.* 2014
		sandy beach	Touristic			3.45	
		sandy beach	Non-touristic			0.81	
		3 sandy beaches	Semi-rural Semi-urban	From October 2014 to April 2016 at intervals of three months in the 4 seasons.	Two (2) sampling units (100 m * 10 m) were monitored on each beach, wherever possible, and were separated at least by a 50-metre stretch.	0.50	Vlachogianni *et al.* 2017
Italy	Tuscany, Liguria, Campania, Sicily, Apulia, Lazio, Basilicata, Marche.	24 beaches	U, Uz and N	May 2014: one sampling season	Transects 2 m apart from each other for a total length of 100 meters for the width of the beach. to the shoreline extending from the waterline to the backshore.	0.12[5]	Final Report Legambiente_Beach litter 2014
	Tuscany, Liguria, Campania, Sicily, Apulia, Lazio, Veneto, Friuli Venezia-Giulia.	29 beaches	U, Uz and N	April-May 2015		0.17[5]	Final Report Legambiente_Beach litter 2015
	Tuscany	Golfo di Talamone	Uz			1.34	
		Scarlino	U			1.32	
	Lazio	1 sandy beach with dunes	N	March 2014 to March 2015	3 equally distanced survey units. Each sampling unit is 100m long and is situated between the sea line and the back dune's woody vegetation.	0.86[6]	Poeta *et al.* 2016
	Adriatic italian coast (Veneto, Emilia-Romagna, Abruzzo)	7 sandy beaches	Remote/natural Semi-rural Semi-urban Urban	From October 2014 to April 2016 at intervals of three months in the 4 seasons.	Two (2) sampling units (100 m * 10 m) were monitored on each beach, wherever possible, and were separated at least by a 50-metre stretch.	0.28	Vlachogianni *et al.* 2017
			Urban			0.11	
			Semi-urban and semi-rural			0.29	
			Remote/natural			0.55	
	Emilia-Romagna	5 free access beaches included in the Po River Delta Parks and in the Natura 2000 Italian network.	N	May to June 2015.	Two 50-m transects were randomly placed along each beach parallel to the shoreline, and all litter greater than 2 cm was collected in the area ranging from the water edge to the back of the beach (determined by the presence of vegetation) within the 50-m transect.	0.02	Munari *et al.* 2016
	Tuscany and Liguria	11 sandy and pebbles beaches	U, Uz and N	January 2014 till December 2015 (in progress): trimestral survey (seasonal)	Transect length variating from 45 to 300 meters and width from 5 to 30 meters. AMD surveyed from the water's edge to the back of the beach.	1.06	***Present study***
			U			0.64	
			Uz			0.87	
			N			1.50	
Notes	[5]Average value deduced from the paper/report [6]Data in paper are expressed as items/linear meter. This value has been re-calculated as items/m^2 for this paper from Dr. Poeta.						

Table 6. Summary of Beached litter data and Surveys in Italian and neighbouring Slovenian areas.

Material found in our study highlight some peculiarities related to specific land-based sources or extraordinary events (more evident in protected areas because of the lack of regular cleaning activities), such as (1) rivers and streams floods, (2) storm surges (3) uncontrolled spills of civil and

industrial materials (discharges and runoffs) or to illegal dumping of waste at sea. This is the case of $2AR_{Uz}$, an urbanized beach that shows a higher density of litter compared to the other beaches of its same Area (1.98 items/m^2 with a prevalence of Polystyrene equivalent to 62.28% and 27.99 % of Plastic): this beach is located just between two of the major mussel farming in La Spezia and the majority of materials found in our survey for this beach were both polystyrene and oyster nets or mussel bags (used for commercial packaging). In another beach, $4BM_N$, which is quite close to $2AR_{Uz}$ in the PCA plot (even though is a Natural beach belonging to the MPA of Area 4), an anomalous presence of Polystyrene because of coastal fishing activities. Moreover, in the other beaches of the same Area 4, we found medical waste, spools from textile industries and shotgun cartridge related to hunting activities allowed in the nearby forest (**Figure 6**).

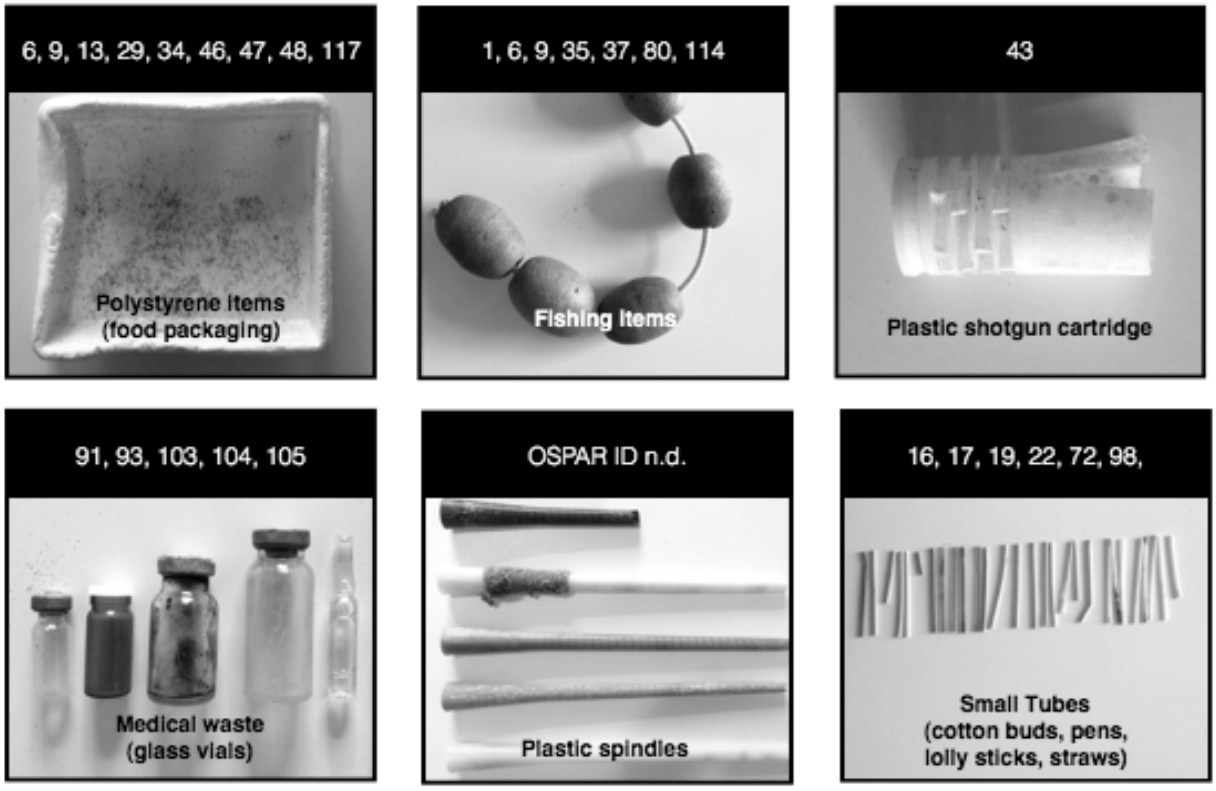

Figure 6. Examples of Articles that have been found in our study Macroarea during monitoring activities. White Numbers on black row indicate the OSPAR (2010) corresponding identification numbers used for marine litter characterisations.

Cluster analysis performed for Sites, taking into account Size of AMD lead to the following conclusion: fine and coarse sand beaches (such as $3VA_U$, $5CG_{Uz}$, $1MO_U$, $4BM_N$, $4FS_N$, $4MN_N$) show more than 90% small sized AMD, while in very coarse beaches (gravel and pebbles such as $1VE_U$, $1CO_U$, $2GA_{Uz}$, $2AR_{Uz}$ and $2AL_{Uz}$) abundance of small AMD drops to about 75%. These findings lead us to believe that lower densities in these urban and urbanized beaches may also be due to underestimation of small size objects that probably fit and hide in interstitial space available between pebble and pebble and that are not monitored by our protocol. Burial, is, hence, enhanced on gravel beaches, as already observed by other authors like Merrell (1980) and Williams and Tudor (2001a, 2001b) but, if we consider the several events that may occur on a coastline (such as extreme surges and waves, coastal erosion) exhumation of buried litter shouldn't be

underestimated, especially in totally protected areas, that not being constantly cleaned up may be considered - ‘paradoxically’ - an important source of pollution for the neighbouring areas. For example, in San Rossore Park, a deep mechanical beach cleaning would represent a huge damage for the Kentish plover (*Charadrius alexandrinus* Linnaeus, 1758), a small cosmopolitan shorebird protected by the Bird Directive (Bird Directive 2009/147/EC) that breeds on the shores of this protected area (Puglisi and Meschini 2015). This activity, would, in fact, eliminate useful shelters for chicks and adults to defend themselves from natural predators and remove the organisms these birds feed. The problem is, therefore, quite complex and implies for territorial managers also understanding how to deal with contradictory protection measures. In this specific case, the park allows occasional cleaning activities made by volunteers but without automated systems (such as sandbonis or raking and sifting devices): an intermediate solution that solves the problem of AMD only partially.

For what concerns the environmental status of the surveyed beaches, the system of assessment that has been build up, based on quantity and type of found Beach Litter, shows that beaches are mostly in a mediocre state regardless of kind (Urban, Urbanized, Natural), geographical location and cleaning strategies.

The present study is just the first step for assessing the state of such an important macroarea, intended as a whole. Its current state is, of course, far from being fully understood and the problem should continue to be analysed under several fronts: from rivers (banks and beds), to coasts (surface and buried litter, water column and open sea) in order to have a wide overview of accumulation dynamics and transport, but also in order to collect data on a larger spatial and temporal scale.

Nevertheless, understanding the problem is only part of our duty as researchers and educators: carrying out monitoring and clean up campaigns isn’t enough and “*litter cut off at source is the only real answer*” (Williams and Tudor 2001b). Marine pollution is everybody's problem and as such, there is a strong need to find different solutions that must involve all actors (civil society, academia and industry) with top-down and bottom-up approaches that must show that this environmental issue is not irrelevant for our survival on the planet. Raising awareness is, hence, fundamental and necessary: research activities carried out promoting a “citizen science” approach (Nelms *et al.* 2017) - such as our study - are, indeed, more effective for obtaining positive changes in behaviours, attitudes and proactivity towards environmental, economical and societal challenges.

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The authors declare that data supporting the findings of this study are available under request.

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