First characterization and impact assessment of beach litter in Sardinia (Western Mediterranean)

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Abstract

Marine litter entering the oceans has been estimated to be 4.8-12.7 millions tons per year. The presence of beach litter along the coast is due to the indirect input by waves, wind, rivers and currents and to the direct deposition by beach users. This study, conducted in Sardinia (West-Mediterranean Sea) aims to quantify and characterize beach litter all around the island and to define the main sources of impact. Seven beaches were monitored for 4 years (2013-2016) by means of 33 meters linear transects parallel to the shoreline in which all visible litter items were collected. Abundance evaluation and characterization of litter typologies were performed following the standardized protocol issued for the Marine Strategy. Uni-variate analysis of variance was performed to detect any difference in abundance and typology of marine litter according to time, exposure and site. The factor that better explains the distribution of litter in the study area was exposure: higher values were found on the "exposed" sites respect "non-exposed" ones ($p<0,05$). Moreover, on the most touristic beaches, direct litter deposition was higher. This work provides key information about litter sources, useful to suggest possible mitigation measures.

Keywords: marine litter, plastic, beaches, MSFD, Sardinia.

1. Introduction

Marine litter represents solid anthropogenic materials resulting from human activities that, after entering in the sea, negatively interact with the environment (Andrady, 2011). The origin of most of the litter is land-based and 60-80% of it is composed of plastic objects (Barnes *et al*., 2009; Poeta *et al*., 2014; Artuchelvi *et al*., 2008). Plastic pollution is considered one of the main issues of the last decades (Gregory, 2009), considering that about 4.8-12.7 millions tons per year are discharged in the marine environment (Jambeck *et al*., 2015).

Since plastic is mainly found on the sea surface (Moore *et al*., 2001; Thompson *et al*., 2004) and is subject to currents, wind and waves; coastal areas therefore represent a spot for plastic accumulation (Critchell *et al*., 2015; Martinez *et al*., 2009; Derraik, 2002). Most of the litter is washed ashore, making beaches a major sink for plastic (Van Cauwenberghe *et al*., 2015; GESAMP, 2015).

The Mediterranean Sea is considered one of the main polluted areas in the world since is a closed basin and therefore presents complex hydrodynamics, that need to be understood to determine the movement of plastic objects (Eriksen *et al*., 2014). Independently from the typology and density of the items, their movement is strongly determined by storms surges on the coastline, that make the accumulation rate vary over time (Imhof *et al*., 2017). Mechanical stress, UV radiation, chemical and biological action cause the constant degradation and break down of plastic objects into smaller fragments (Andrady, 2011). Therefore plastic items have been subdivided into different categories and sizes (Barnes *et al*., 2009). As a result the monitoring of beaches has been used worldwide as a primary tool for the evaluation of the amount of litter as well as considering the typologies of litter encountered in the marine environment (Gago *et al*., 2014).

The Marine Strategy Framework Directive (European Commission, 2008/56/EC) demands Member States to monitor descriptor 10 (Marine Litter). Therefore increasing knowledge on abundance, distribution and its impacts on the marine environment, in order to achieve or maintain the Good Environmental Status (GES) for the marine environment by 2020. Monitoring of beach litter has been assessed in the last decades (Debrot *et al*., 2013; OSPAR, 2007; Cheshire *et al*., 2009). In the North Seas guidelines have been released, which have led to the implementation of the MSFD (OSPAR, 2010; Galgani *et al*., 2013). There is still poor literature on the monitoring of beaches in the Mediterranean and particularly in the Western-Mediterranean sub-area (PNUE/PAM/MEDPOL, 2009). The present study is, to our knowledge, the first piece of work that assesses the amount and distribution of litter on the Sardinian coast. This has been done by applying the MSFD protocol (Galgani *et al*., 2013), which creates a characterization of the different typologies of marine debris. The interpretation of some of the categories is useful to understand the source of the plastic items washed ashore or directly deposited on land.

2. Materials and methods

2.1. Sampling design and study area

From 2013 to 2016 seven Sardinian sandy beaches (sites) were monitored in two different seasons (Autumn and Spring), during 5 monitoring campaigns (Autumn 2013; Spring 2014; Autumn 2015; Spring 2016; Autumn 2016) and 105 replicates were totally performed (Fig.1). The Island of Sardinia is located in the middle of the western Mediterranean area and prevalent winds are from West/North-West and they are able to wash ashore large quantities of litter floating in the sea. Fine-grained sandy beaches were selected around the Sardinian Island (Central Mediterranean sea, Italy) characterized by a mean slope value lower than 10 degrees.
According to the MSFD Guidelines, >1 Km beaches were selected. This allows to perform 3 spaced out fixed transects (100 m in total) positioned parallel to the shoreline and each one was geo-referenced (Garmin GPSmap 64ST). On each transect (33 m), a visual survey was performed to detect all litter items distributed on the sand surface going from the strandline to the base of the dune; in order to collect all the items the trained surveyors walked in an S shape manner. Of the chosen sites, 3 are "exposed" to the prevailing winds (E: Alghero, Is Arenas, San Giovanni di Sinis) and 4 are "non-exposed" (NE: La Cinta, Costa Rei, Poetto, Porto Pino).

2.2. Classification and analysis of samples

All the litter items were categorized and photographed (Nikon D40X); the items larger than 50 cm were left *in situ* while all the others were collected and afterwards cleaned and dried in the laboratory. As reported in the "Master list of Categories of litter items" (Galgani *et al*., 2013) the objects were classified into 165 categories included in 8 typologies: *Plastic*, *Rubber*, *Textile*, *Paper*, *Processed wood*, *Metal*, *Glass-Ceramic*, *Other materials*. Moreover the fragments were subdivided in three different sizes: Mega (>10 cm); Macro (>2 cm); Meso (>5mm) according to Barnes *et al*. (2009). Repeated measures permutational analysis of variance (RM-PERMANOVA) on litter abundance was carried out in order to test for any significant differences among the three factors considered: "time" (Three levels: Autumn 2015, Spring 2016, Autumn 2016), "exposure" (two levels: exposed, non-exposed) and "site" (seven levels: Alghero, Is Arenas, San Giovanni, La Cinta, Costa Rei, Poetto, Porto Pino) using PRIMER6 software (complete with PERMANOVA+ package).

Fig. 1. Map of the study area and sampling sites (N=7) distribution along the coast. "Exposed" sites are represented by black dots (3) and "non-exposed" ones by white dots (4).

3. Results

A total amount of 39972 litter items was recorded and classified during the entire monitoring activity.
As reported in Tab. 1, *Plastic* was the most abundant typology concerning 34551 items (86,43%), followed by *Metal* with 3330 items (8,33%), *Glass-Ceramic* with 755 items (1,89%), *Textile* with 452 items (1,13%), *Processed Wood* with 441 items (1,10%), *Paper* with 204 items (0,51%), *Rubber* with 201 (0,50%) and *Other Materials* with 38 items (0,10%).
Of the 165 categories reported on the MSFD protocol, here 146 were recorded. The most representative size classes of litter are "macro" (17792 items; 44,51%), followed by "meso" (12414 items; 31,06%) and "mega" (9766 items; 24,43%). Fifteen litter categories were identified as the most abundant on Sardinian beaches, listing 400 items: *small plastic fragments* (G78), *foam sponge* (G73), *other plastic fragments* (G79), *drink bottles caps* (G21), *cigarette filters* (G27), *wire* (G191), *cotton buds* (G95), *polystyrene items* (G83), *other plastic/polystyrene items* (G124), *plastic caps* (G22), *lolly sticks* (G31), *cups and cup lids* (G33), *strings and cords with diameter <1cm* (G50), *ropes with diameter >1cm* (G49), *small plastic bags* (G4).

Tab. 1. Marine litter typologies reported in the surveys carried out between 2013 and 2016, expressed as number of items (N°) and as percentage of items (%).

Litter typology	N° Items 2013-2016	% items 2013-2016
Plastic	34551	86,44
Rubber	201	0,50
Textile	452	1,13
Paper	204	0,51
Processed Wood	441	1,10
Metal	3330	8,33
Glass-Ceramic	755	1,89
Other materials	38	0,10

The comparison of the abundance of litter through the two seasons showed a higher accumulation in Autumn with a mean abundance of 1398±463,86 (items±SE) and a lower accumulation in Spring 758,14±205,11 items (Fig. 2). Litter abundance was significantly higher (p<0,05; Tab. 2) on "exposed" sites (Alghero, 1103,33±175,55 items; Is Arenas 2086,66±772,96 items; San Giovanni, 1899,66±150,72 items) respect to "non-exposed" ones (Porto Pino, 161±17,03 items; La Cinta, 392,66±180,04; Costa Rei, 703±424,44; Poetto, 425,33±28,29 items).

4. Discussion

This study provides for the first time a multi-annual assessment of marine litter on the Sardinian coast, in particular by describing the pollution state of the beaches through the monitoring of 7 representative sampling sites.

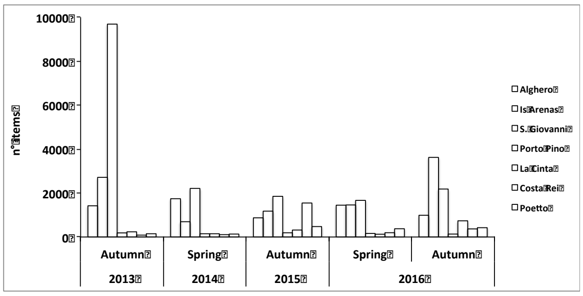

Fig. 2. Abundance of beach litter items in the 7 sampling sites during 4 years of surveys (2013-2016).

From the surveys conducted on Sardinian beaches litter resulted ubiquitous in all sites. The present study was carried out by using the MSFD protocol for the first time in Sardinia. Results will be easily comparable with the ones of monitoring campaigns carried out in the Member States areas of the North Sea as well as in the Western Mediterranean basin.

Tab. 2. Statistical analysis of beach litter. Results of Permanova on Time, Exposure, Site. df: Degree of freedom; SS: sum of squares; MS: mean square; pseudo-F: value of the pseudo-F statistic; P (perm): p-value of the PERMDISP analysis; perms: number of permutations; P(MC): p-value of Monte Carlo analysis.

Source	df	SS	MS	Pseudo-F	P(perm)	perms	P(MC)
Ti	2	17,289	8,6443	2,1904	0,2406	9986	0,2331
Ex	1	259,4	259,4	57,54	0,0287	35	**0,0089**
Si(Ex)	5	22,541	4,5082	9,3736	0,1089	9995	0,0814
TixEx	2	-6,2433	-3,1217	-0,791	0,6177	9987	0,6626
TixSi(Ex)	10	39,465	3,9465	8,2055	0,0785	9990	0,0638
Res	42	20,2	0,48095				
Total	62	354,55					

Of the 8 typologies of litter included by the MSFD protocol, plastic was the most abundant one (86,44%), thus confirming research from previous studies (Nelms *et al*., 2017; Smith and Markic, 2013). The data obtained which regard the Western Mediterranean area demonstrates the high plastic pollution concentration in a closed basin, which is determined by various anthropic factors. This confirms that the Mediterranean Sea is one of the most littered polluted areas in the world (Suaria and Aliani, 2014). Even if Sardinia has a very low population density (1.66 mil) and the only densely populated coastal city is Cagliari, it presents a high concentration of marine litter, exhibiting most of the categories described in the protocol. This datum, added together with the size class, further confirms the sea-based origin of the litter, which tends to accumulate along the coastline due to currents, waves and wind action (Van Cauwenberghe *et al*., 2015). Most of the plastic recorded were fragmented items (G78, small plastic fragments; G73, foam sponge; G79, other plastic fragments) less than 10 cm (Meso and Macro litter), resulting from the break down of larger pieces (Andrady, 2011).

The analysis of the exposure showed significant values in the abundance of litter on the beaches exposed to Mistral, which is the prevailing wind blowing in Sardinia and further confirming that the deployment of beached waste is due to the marine transport. Is Arenas, San Giovanni and Alghero showed high values of litter abundance, even if the tourist frequentation in these sites is lower than the others (La Cinta, Costa Rei, Poetto, Porto Pino). From the analysis of the categories we were able to determine that part of the litter had been directly trashed by the beach and sea users, due to their bad manners. As a result, the high density of cigarette filters (G27) recorded on touristic beaches outlines a low environmental consciousness although awareness campaigns are constantly carried out. Is remarkable the fact that most of the litter had originated from the activities of the fishing industry (Laglbauer *et al*., 2014) (G49, G50) and was reported in all sites (even far from marinas), thus calling for further and more specific mitigation actions.

Conclusions

To conclude, our study highlights the extended beach pollution around Sardinia, which negatively affects the island as a tourist destination.

It will be a priority to better control human activities and enhance the monitoring of the sources of pollution (Pasternak *et al*., 2017). Another focus point can be to intensify beach clean campaigns (OSPAR, 2009) in the highly impacted areas, thus increasing awareness to the local citizens.

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