Plastic litter in aquatic environments of Maremma Regional Park (Tyrrhenian Sea, Italy): Contribution by the Ombrone river and levels in marine sediments

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A B S T R A C T

During two surveys in 2015 and 2016, sediments samples were collected along the Ombrone river (Maremma Regional Park, province of Grosseto, Italy), in particular at its mouth and in the marine area in front of it, in order to quantify, identify and categorize plastic items (macro, *meso* and micro-plastics and colour, material etc.) and evaluate their potential sources. The Albegna and Osa rivers were identified as external areas of comparison. The results of the analysis showed different situations, especially as regards fluvial inputs, in addition to evidencing local provisions of plastic material derived from agricultural activities. The microplastics values per kg of sediment and the prevailing type of items found largely varied between the investigated sites (45–1069 items/kg dry sample).

1. Introduction

The presence of waste in the sea is an emerging issue of international concern, especially in relation to the ecological and biological consequences of the phenomenon (Alomar et al., 2016; Fossi et al., 2016). Marine litter is an important component of marine pollution; among the various types of wastes, plastics, mainly items smaller than 1 mm, are globally dominant, on the surface, the bottom of the sea and along the beaches (Derraik, 2002; Fossi et al., 2012, 2014; de Lucia et al., 2014; Fastelli et al., 2016; Blašković et al., 2017). In spite of the relatively recent diffusion of plastics, this type of litter has already invaded almost all marine habitats, such as freshwater ecosystems (Wagner et al., 2014; GESAMP, 2015) and including the most pristine environments, such as the deep Arctic Ocean (Bergmann and Klages, 2012) and Ross Sea (Antarctica) (Cincinelli et al., 2017).

Marine litter, which includes microplastics (MPs), is one of the eleven descriptors taken into account by the Marine Strategy Framework Directive (MSFD) and a potential source of contamination to the ecosystem and food web (Fossi et al., 2016). Contamination by plastics in aquatic environments is a problem whose extent is therefore only recently been recognized in many areas, including Italy, and that have not yet been characterized well; among these, also the area considered in this study, the Maremma Regional Park, that stretches, with a total surface area of 8902 ha protected, along 25 km of the coast of Tuscany. Considering that, while the research on marine MPs is more advanced, there are consistent gaps of knowledge regarding freshwater MPs and that the majority of marine plastics are considered to originate from land-based sources, including surface waters, the need for studies focused on freshwater ecosystems is evident (Wagner et al., 2014).

Under this premises, the overall objective of the research was a screening to evaluate/define the sediment's litter levels of the last stretch of the Ombrone river, of the transitional areas and of the river mouth, in the Maremma Regional Park, in order to establish a useful background knowledge on the impact of plastic litter, also in relation to the future possibility of extending the protection levels at sea. The Albegna and Osa rivers, near and outside the park, have been identified as comparison areas.

Sediments act as long-term deposits for MPs (Morét-Ferguson et al., 2010; Cozar et al., 2014) and therefore tend/have the ability to accumulate this type of waste (Fries et al., 2013; Nuelle et al., 2014), providing a significant sink, given the presence of microplastic in the whole ecosystem.

2. Materials and methods

2.1. Study area

The Ombrone River, the longest river in southern Tuscany (about 160 km), passes within the Maremma Regional Park for 12 km before

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flowing into the Tyrrhenian Sea at Bocca d'Ombrone (Grosseto, Italy). The Ombrone crosses natural areas and heavily populated districts: the Chianti area, the Crete Senesi area and the Grosseto plain. Along the rod and at the mouth of the Ombrone, 8 superficial sediment samples were collected, during two samplings; sampling sites were located as shown in Fig. 1.

The Osa river has a total length of 20 km; it flows in the province of Grosseto and emerges into Tyrrhenian Sea, about 17 km southernmost of the Ombrone. The sampling points selected for this study are also shown in Fig. 1, together with those of the Albegna river.

The Albegna is a 66 km river, which flows into the Tyrrhenian Sea in Albinia (about 4 km southernmost of the Osa, without entering in the Orbetello lagoon, and remaining North of few hundred meters. The "Middle Albegna" is a heritage site, which is both safeguarded as a Special Protection Area (SPA) and proposed as a Site of Community Importance (pSCI).

The sampling sites of the surface sediments selected for this study are shown in Fig. 1, together with those of the river Osa.

The coast is microtidal (tidal range = 30 cm) and exposed to south - south western storms (Cipriani et al., 2013). The climate in the study area is typically mediterranean, with summers characterized by moderate temperatures, mitigated by mistral and westerly marine breezes and winters not particularly cold, with rare episodes of night and morning frosts. Average annual rainfall varies from 419 to 650 mm; all locations record a minimum summer and a more or less accentuated fall spike (Giusti, 1993).

The main external critical elements of the environment monitored include water catchment and drawing in the basin, intensive farming practices in lowland areas and transformation of agro-ecosystems, with gradual increase of habitat fragmentation for the most sensitive species linked to these environments.

2.2. Sampling

Samples were collected in January 2015 and August 2016 from surface sediments of Ombrone (8 stations, 16 samples) and Osa/Albegna (6 stations, 12 samples) (exactly the same in both years), from different points on river course, including the mouth, the shore and the submerged beach.

A manual bucket 2 L volume has been used for the sampling. Samples were taken at a depth of 0–50 cm in submerged areas, and on the surface in those emerged, always in the first 10–15 cm. The sediment was then transferred to stainless steel trays in order to homogenize it, before being stored in glass jars.

After collection, samples were stored at 4 °C until analysis, performed in the Bioscience Research Center laboratories.

2.3. Analysis

The samples were processed according to the steps below, which refer to "DeFishGear Protocols for sea surface and beach sediment sampling and sample analysis" (http://mio-ecsde.org/wp-content/uploads/

Fig. 1. Sampling stations along the Ombrone river, the transitional area and the sea near the mouth (left). All the stations but OM_A and OM_B are in the Maremma Regional Park territory. Sampling stations along the Osa and Albegna rivers, the transitional area and the sea near the mouths (right). This areas are southern than the Maremma Regional Park and outside its territory.

Table 1
Plastic litter classification (from Fastelli et al., 2016).

Colour	Shape	Dimension
White (W)	Filament (FI)	>2.5 cm (MacroPs)
Clear (C)	Film (FILM)	2.5 cm–5.1 mm (MesoPs)
Red (R)	Fragment (FR)	≤5.0 mm (MicroPs)
Orange (O)	Granule (G)	
Blue (BE)	Pellet (P)	
Black (BK)	Foam (FO)	
Grey (GY)	Unrecognized plastic piece (UN)	
Brown (BN)		
Green (GN)		
Pink (P)		
Tan (T)		
Yellow (Y)		

2016/08/Beach-litter_monitoring-methodology.pdf), with some adaptation, already reported in Fastelli et al. (2016). In brief, each sample was dried in oven, broken up in a mortar, weighted and passed through a stack of sieves placed in descending sequence, with mesh diameter 4-2-1-0.063 ≤ 0.063 mm. Each passing fraction was collected from the sieve and weighed separately. The sediment fractions collected on 4-2-1 mm sieves were placed in Petri dishes and examined directly under a microscope (Nikon SMZ800N 10–80×), while fractions passing the sieve mesh from 63 μm and below were extracted with a saturated solution of water and NaCl and filtered through a Büchner funnel with a 4.7 cm diameter filter and pore size of 10 μm. The filters were dried in oven and examined under a microscope. The items unearthed were classified by assigning size classes and categories according to shape and colour, as proposed by Alomar et al. (2016) and Galgani et al. (2013), and reported by Fastelli et al. (2016) (Table 1). The total levels of plastic have been categorized by size (macro, *meso* and microplastic) and shape (filaments, fragments, foam etc.). In addition the colour frequency of each sample was signed up.

2.4. Statistics

t-Tests and ANOSIM Tests were carried out to identify possible differences between the study area and the controls, among different sections of the rivers and among samples taken in different seasons.

3. Results and discussion

Between plastic litter size classes, MPs were found to be the dominant size in the study area in all the stations and all the seasonal replicas made, although mesoplastics were fairly represented. Microplastics have never been detected. The maximum amount, as number of MPs for kilogram of dry sediment, was found in a sandy shore in Albinia (Giannella), (1069 items/kg), while the minimum in a sample from Albegna mouth, (57 items/kg). Table 2 reports the results achieved.

With regard to size classes, in most samples, plastic maximum size was 5–10 mm, except for two plastic samples which reached 20 mm size. The minimum measured dimensions were almost always between 0.5 and 1 mm, except for one sample in which the minimum measurement was 1.5 mm.

Among plastic litter shapes, filaments were predominant in all samples, while all the other shapes had not always been found. Fragments resulted the second most abundant shape category. In samples from the Maremma Park (Ombrone, Trappola and Marina di Alberese) all the shape categories of microplastics were found; whereas filaments, fragments and films were recorded in the samples from Albegna and Osa rivers.

A slight variability was observed in the colour dominance of plastic items; in particular, the black colour dominated items collected in the Ombrone river and its transition areas, while the prevalence of white and clear increased in samples from the marine environment. Very high levels of black items were recorded in the sandy shore at North of the transition zone, while high levels, but still lower than in the North, were found in the South. With regard to colour dominance, the site "Istia" (upstream of a dam on the Ombrone) is dominated by

Table 2
Plastic items recovered in single sampling points, in the two sampling campaigns.

Area	Description	Sampling	MPs items/Kg sediment	Mesoplastic items/kg sediment	Plastic items/kg sediment	Samples code
Albegna	River	Winter	305	12	317	AL_A_W
		Summer	253	16	269	AL_A_S
	End river	Winter	477	7	484	AL_B_W
		Summer	202	43	245	AL_B_S
	Mouth	Winter	395	13	408	AL_C_W
		Summer	57	0	57	AL_C_S
shore (near Albegna mouth)	North Giannella	Winter	882	0	882	AL_D_W
		Summer	181	16	196	AL_D_S
	South Giannella	Winter	1069	35	1104	AL_E_W
		Summer	134	7	141	AL_E_S
Osa	River	Winter	312	0	312	OS_A_W
		Summer	259	11	271	OS_A_S
Ombrone	River at Istia (before dam)	Winter	188	0	188	OM_A_W
		Summer	168	10	178	OM_A_S
	River at Steccaia (just after dam)	Winter	75	0	75	OM_B_W
		Summer	149	14	163	OM_B_S
	River (point "Canoe", after dam) (inside Maremma Park)	Winter	143	0	143	OM_C_W
		Summer	137	0	137	OM_C_S
	Mouth (inside Maremma Park)	Winter	118	0	118	OM_D_W
		Summer	99	0	99	OM_D_S
Shore (near Ombrone river mouth)	Trappola, emerged sandy shore (inside Maremma Park)	Winter	250	0	250	OM_E_W
		Summer	271	11	282	OM_E_S
	Trappola, submerged sediments (inside Maremma Park)	Winter	318	0	318	OM_F_W
		Summer	397	36	433	OM_F_S
	Marina di Alberese, emerged sandy shore (inside Maremma Park)	Winter	200	0	200	OM_G_W
		Summer	282	14	297	OM_G_S
	Marina di Alberese, submerged sediments (inside Maremma Park)	Winter	166	0	166	OM_H_W
		Summer	45	22	67	OM_H_W

Fig. 2. Plastic irrigation pipes piles along the Ombrone river (picture taken in summer 2016, near Steccaia sampling point, OM_B); these tubes were present also in other sampling stations along the river, and even in the riverbed vegetation (picture by C. Guerranti).

white and transparent plastic while the downstream of the dam sites were dominated by black colours. It is noteworthy that, at the time of sampling, in several points along the Ombrone river channel, black plastic irrigation pipes, abandoned and tangled to the riverbed vegetation, were detected in addition to several pipes, even over three meters high, placed at short distance from the embankment (Fig. 2); some samples of this plastic were collected, finely chopped, and, as a result of microscopic observation, they were compatible with the black colour microplastics found in the sediment. This leads to the hypothesis that the use, and subsequent abandonment, of plastic pipes for irrigation can be an important local source of (micro) plastics.

Multivariate statistical analysis was performed on micro and macroplastics sediment concentrations, divided in their main shape components to test the relevance of some factors potentially capable of interfering with the distribution of plastic. ANOSIM test performed on the entire database showed statistically significant difference for the "location" factor (Global $R = 0.237$; $p = 0.2\%$), due to the contribution of fluvial samples, while the transition area and the costs can be considered as homogeneous. ANOSIM test showed significant differences between the samples collected along fluvial and rods and those collected from the shore ($R = 0.373$, $p = 0.9\%$). The ANOSIM test performed on the entire database showed also no statistically significant difference for the factor "sample season/year". However, disaggregating the data by location, it emerges, in the case of Ombrone, a significant difference between samples (global $R = 0.341$; $p = 0.3\%$).

Regarding the Ombrone, the ANOSIM test showed significant differences between the samples taken in the auction river and those taken along the beach of Marina di Grosseto (global $R = 0.373$; $p = 0.2\%$). As for the two rivers Albegna and Osa, which showed no significant differences in pair wise tests in plastic items number, no differences related to the factors tested have been found, except the factor year that appears, however, able to affect the level of litter in the sediment analyzed. In fact, much higher levels of plastic have been found in 2015 compared to 2016. It was also verified that, in the case of Albegna river, there has been a significant difference between levels of litter in samples from shoreline and from river channel in the two samplings. In particular, in 2015 the levels of litter were much higher in samples from the shore than from the river. In 2016 the record/trend was reversed. This phenomenon was probably due to changes in river flows and dredging operations and handling of sediments carried out in spring 2014 at the mouth of the Albegna that may have determined changes in the litter content of surface sediments.

Table 3
Comparison of mean value of MPs/kg sediment reported internationally.

Site	Sediment origin	Mean	Reference
Italy, Venice	Lagoon	1445.2	Vianello et al. (2013)
Italy, Aeolian Archipelago	Sea	371.7	Fastelli et al. (2016)
Croatia	Sea	177.6	Blašković et al. (2017)
Slovenia	Beach	177.8	Laglbauer et al. (2014)
	Infralittoral	170.4	
Germany, Spiekeroog- Kachelotplate	Beach	671	Liebezeit and Dubaish (2012)
Germany, Norderney	Beach	1.45	Dekiff et al. (2014)
Belgium	Harbour	166.7	Claessens et al. (2011)
	Beach	92.8	
	Coast	91.9	
United Kingdom	Sub tidal	86	Thompson et al. (2004)
	Estuarine	31	
	Beach	8	
Malta	Harbour	4.37	Romeo et al. (2015)
Singapore	Mangrove	36.8	Nor and Obbard (2014)
	Beach	2.3	Ng and Obbard (2006)

There are several difficulties in comparing the obtained results with the available scientific literature, due to the adoption of different methodologies in data collection, classification and reporting of the marine litter (Strafella et al., 2015; Alomar et al., 2016). Nevertheless, in their entirety, the results obtained in this work fall within the wider international range reported for sediments all over the world (see Table 3, where an overview of international scientific literature on this topic is reported). As regards the sandy shore, overall, the levels measured in this study were similar to those found in beach transects in Germany (Spiekeroog and Kachelotplate, reported by Liebezeit and Dubaish, 2012), while they were significantly higher compared to all other. For what concerns samples from marine environments, the values found in this study are similar to what reported in literature. Finally, the amount of microplastic found in Talamone harbour were similar to those reported for comparable environments in Belgium (Claessens et al., 2011), but much higher than those of Malta (Romeo et al., 2015).

4. Conclusions

Given the general lack of information regarding plastic litter diffusion in freshwater ecosystems, this study aimed to give a first contribution to evaluate the extent of plastic pollution in river, transition, mouth ad shore areas, of great naturalistic interest.

Based on the results achieved, the investigated areas (rivers and shores) showed differences in amount of plastics present. Due to the presence of microplastic in coastal and transition areas, fluvial inputs may represent a significant plastic litter source and show considerable variations depending on factors related to the dynamics of the catchment. In the case of the study area, the use of irrigation plastic pipes, and their subsequent abandonment in the environment, was identified as a likely source of the local introduction of plastic litter in the last stretch of the river Ombrone, and thereafter, at sea.

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