Marine litter in sediments related to ecological features in impacted sites and marine protected areas (Croatia)

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ABSTRACT

This study estimates levels of marine litter including plastics (macro-, meso- and microplastics) in sediments collected in shallow marine water from Croatia (Central Adriatic Sea). Selected sampling areas are characterized by different human pressure: Silba is highly stressed by tourism while Grebena is listed as marine protected area (MPA) of future institution. Obtained results on marine litter in sediments are correlated to ecological features recorded in each sampling site. Marine litter in collected sediments ranged within 180–528 items/kg d.w. Macroplastics were not recorded while mesoplastics were 1.3–4.8%. On a general basis, fibres are higher than microplastics. In Južni Greben, level of fragments higher than fibres was recorded. A slight significance of the factor "water depth" was evidenced by the statistical analyses exploring relationships among marine litter and ecological features. Furthermore, Silba and Grebena Islands showed a significant different assessment of size, shape and colour features. These results suggest different sources/dynamics affecting marine litter recorded in marine areas stressed by tourism compared to MPA.

1. Note

In marine ecosystems different sources could affect plastic litter distribution and, in particular, the microplastic fraction (MPs) that could be originated from different sources as well as municipal wastewater effluents, cosmetic products (Mani et al., 2015; Eerkes-Medrano et al., 2015) but also by agriculture and many other human activities (Alomar et al., 2016). A recent research evidenced that rivers are important routes for plastic rubbish from inland towards marine coastal areas (Guerranti et al., 2017). In spite of that, local human impacts as well as illegal dumps could affect coastal areas representing a huge damage to the preservation of marine ecosystems. In fact, climate agents such as winds and waves could widespread dumps affecting larger areas than the dumping site. Mechanical stress and thermic excursions could drastically affect size easily reduce them in smaller fragments. At a smaller dimensional scale than the original one, microfragments persist in the marine environment even if in a not more visible size to the naked eye. This is the case of plastic litter that, in coastal rubbish deposits, could be reduced starting from large plastic-made objects to microplastics that accumulate in shallow-water marine sediments (Maynard, 2006). Guerranti et al. (2017) evidenced that illegal rubbish discharges by agriculture into riverine systems could represent a source of microplastics in sediments closed to the river delta. Once reached marine ecosystems, rubbish could be easily transferred through the trophic web affecting marine species (Setälä et al., 2014; Romeo et al., 2015b). Distribution routes in marine ecosystems from abiotic matrices towards the biota start from filter feeder species (Thompson et al., 2004; Graham and Thompson, 2009; Murray and Cowie, 2011; Fossi et al., 2016) and detritivores (Renzi et al., 2018a). Plastic litter could directly reduce the reproductive success of targeted species also by the release of chemicals both absorbed on from the environment on the plastic surfaces and released by the plastic material itself (*i.e.* plastic additives such as phthalates and bisphenol-A) (Rochman et al., 2013; Pedà et al., 2016).

Marine litter and plastic litter in particular, represent a significant potential risk for marine ecosystems and the definition of levels in different marine ecosystems is useful to produce in the next future well-sized monitoring and management actions as required by the Marine Strategy Framework Directive.

This study aims to define levels and principal features of marine litter (plastic litter in particular) in shallow coastal sediments collected around the Silba and Grebena Islands affected by different levels of human pressure (high impacted; low impacted, and marine protected area). Results collected in this study are compared to data reported by the literature for Telašćica MPA that is settled closed to the study area (Blašković et al., 2017). This research represents a first useful data

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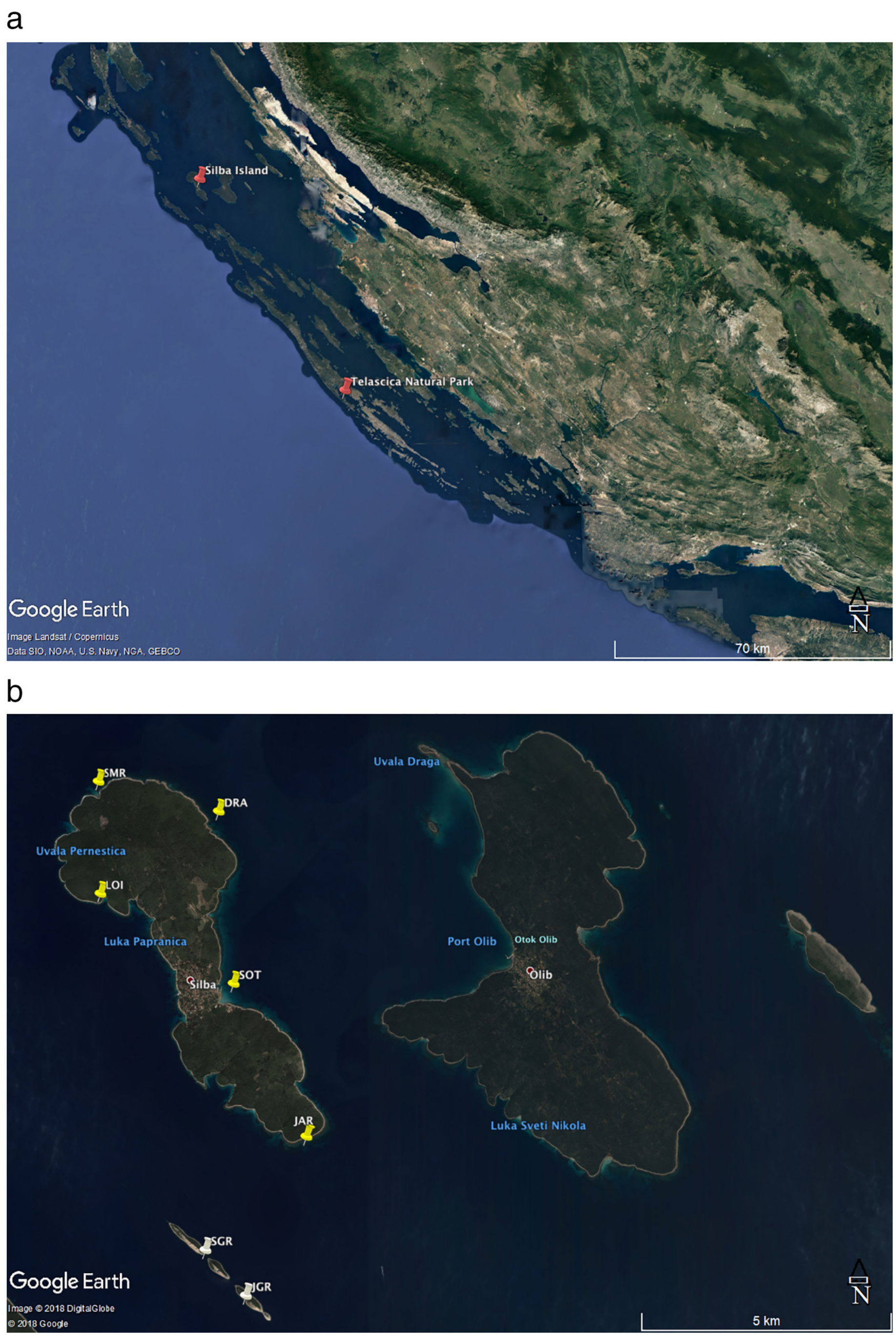

Fig. 1. Sampling sites are represented by georeferencing sampling stations on a Google Earth® picture. Replicates (n = 3) are not represented. Panel a. Telašćica MPA and Silba Island are represented. Panel b. Silba sampling sites are reported in yellow colour while Gerbena MPA (low impacted areas) is in withe. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

record to perform future temporal trend analyses in both highly impacted and MPA from the Croatian Archipelago (Central Adriatic Sea).

Silba and Grebena Islands are located in Central Adriatic Sea very closed together and near Telašćica bay. Sediment sampling was performed in October 2017 in seven sampling sites. Five sampling sites (named Dražice bay, Južni Arat, Loišće bay, Smrdeča bay, Sotorišće) were located all around the Silba Island while two sampling sites were located in Grebena MPA (Južni Greben, Sjeverni Greben). Grebena is a small archipelago settled closed to the Silba Island and as it represents a marine area of great ecological interest it is listed as MPA of future institution (Fig. 1). Samplings, samples collection, and samples conservation were performed according to the Guidance on Monitoring of Marine Litter in European Seas (Joint Research Centre, 2013) adapted as reported by Blašković et al. (2017) to allow us comparisons between this studies and previous researches performed in the same study area. Water depth ranged within 5–18 m. During samplings some factors defined *a priori* (*i.e.* number of inhabitants, water depth, wave current strength, sampling site orientation, % of bottom covered by *P. oceanica*) were recorded to check possible multivariate correlations among them and litter features. The extraction and analysis of marine litter were performed according to Blašković et al. (2017). Shape and colour categories were classified according to Galgani et al. (2013). Additionally, dimensional classes were structured according to Alomar et al. (2016). Sediment grain size analysis was performed according to Blašković

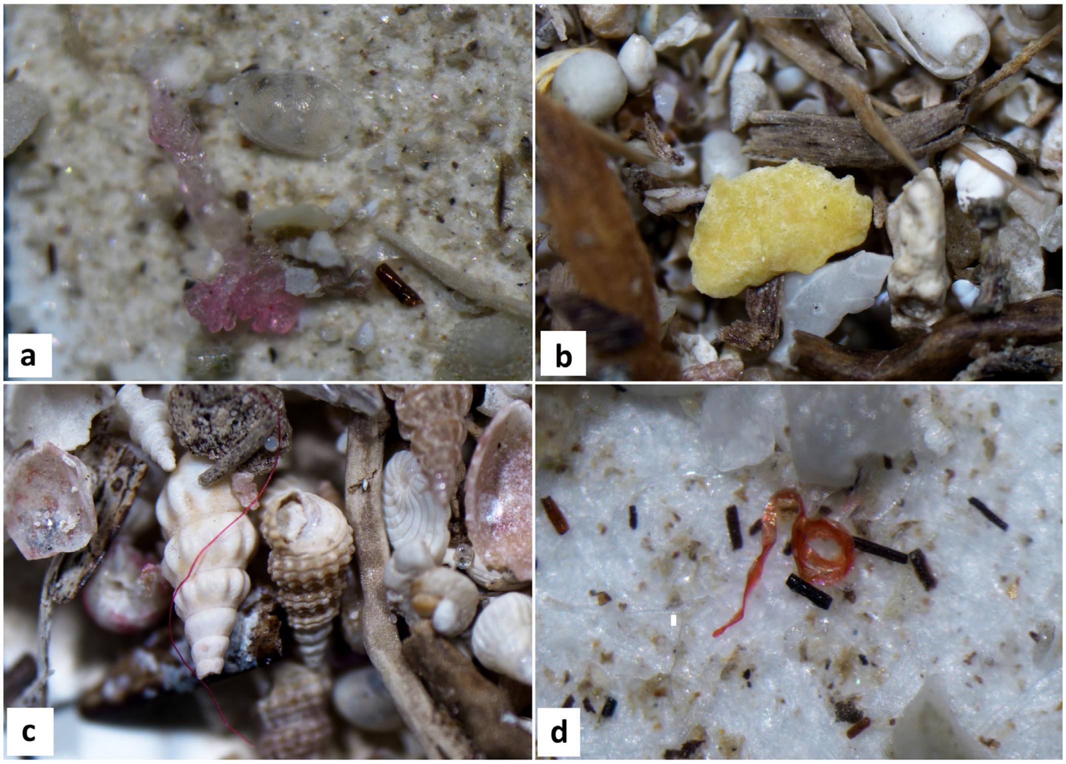

Fig. 2. Marine litter recovered in sediments form the study area. Pictures reported represent some of the recovered microplastics shapes in analyzed samples (40 ×): Films (a); fragment (b); fibres (c,d).

et al. (2017) and Udden-Wentworth grain size classifications. Macroplastics (macroPs, fragments diameter > 2.5 cm), mesoplastics (MesoPs, fragments diameter 2.5–0.5 cm), and microplastics (MPs, fragments diameter 5000–1 μm) were first of all determined and classified by stereomicroscopy (Nikon, mod. SMZ-800 N, ACT-1 software). All recovered items were collected and stored. A percentage (10%) of categories was checked by μFT-IR (Thermo Scientific, mod. Nicolet i-10 MX infrared imaging microscope). μFT-IR was equipped with liquid nitrogen cooled MCT-A detector operating within 7800–650 cm^{-1} spectral range and OMNIC Picta™ software interface to assess litter type. A representation of collected plastic litter items is reported in Fig. 2. Quality controls and quality assurance procedures were applied to ensure data quality as reported by literature (Fastelli et al., 2016; Renzi et al., 2018a). Glass materials and cotton dresses only were used by operators and during analyses. Tests were performed on blanks. Filters (n = 10) were left overnight exposed to the laboratory air, putting them on the desk on an opened glass Petri dish checking by the four-eyes approach to detect levels of undesired litter and microplastics.

Sands resulted the principal fraction of sediments collected in this study; silt percentages resulted always lower than 15%. Telašćica, an MPA settled closed to Silba and Grebena Islands (see Fig. 1), evidenced a grain-size distribution on average of 12.69% gravel, 72.57% sand, and 14.74% silt as reported in a recent paper. In the same study, Magrovica bay was the only site dominated by silt (50.1%) (Blašković et al., 2017). Results obtained in our study agree with previous records in Telašćica. As reported by the literature, litter is not correlated to silt dynamics; our results confirmed the absence of correlations among grain-size of sediments and marine litter recorded (Martins and Sobral, 2011; Romeo et al., 2015a; Fastelli et al., 2016).

Results obtained in this study on marine litter are summarized in Table 1. Concerning the abundance of marine litter, sediments from Silba Island ranged within 180 (SMR)–526.7 (SOT) items/kg d.w. Results obtained in this study evidenced that also sampling stations located in MPA (JGR and SGR, Grebena Islands) were polluted by marine litter resulting within 273.3–360.0 items/kg d.w. and showing values similar than others. Previous researches performed in Telašćica evidenced similar and quite lower levels (Blašković et al., 2017). In fact, on average 268 items/kg d.w. were recorded ranging within 27 (Magrovica)–428 (Mir) items/kg d.w. Compared to other Mediterranean sites, Croatian sediments resulted in a medium to high range of contamination by marine litter (Ng and Obbard, 2006; Claessens et al., 2011; Laglbauer et al., 2014; Liebezeit and Dubaish, 2012; Van Cauwenberghe et al., 2013; Vianello et al., 2013; Nor and Obbard, 2014; Romeo et al., 2015b). Recorded data are comparable to values observed in Malta harbour sites (Romeo et al., 2015a) and less contaminated than sediments from Venice (Vianello et al., 2013). Concerning plastic litter, macroplastics were not recorded at any location; while MesoPs were recorded at low percentages (1.3–4.8%) in DRA and SOT (closed to Silba harbour) but also inside the MPA of future institution (JRC). Literature evidenced that macroplastics were usually recorded in harbour sites rather than in shallow coastal marine sediments (Reddy et al., 2006; Romeo et al., 2015a). Plastic litter is characterized by the dominance of microplastics (MPs) in both Silba Island and Grebena. This result was also recorded in Telašćica characterized by the absence of recorded macroplastics and by 11.29% of MesoPs (Blašković et al., 2017). In Silba and Grebena Islands, litter items smaller than 100 μm represent a minor fraction of the total amount recovered resulting lower than 20% at any sampling sites. As regards as MPs size, the principal fraction (43.7–51.9%) is represented by items within 2000–500 μm in DRA, LOI, SMR, and SOT. Grebena and JAR showed higher percentages within 500–100 μm. Fibres represented, on average, the principal shape recorded. Nevertheless, sampling sites showed a different composition concerning shape of MPs. In particular, granules were recorded only in SOT, films and fragments showed similar percentages closed to 20% in DRA, JAR, SOT. On the contrary, in JRC, SGR, and LOI fragments were abundant and in JGR this shape resulted higher than fibres. Previous results performed by Blašković et al. (2017) in Telašćica MPA, evidenced that 90.07% of items were fibres, while films were 7.45%. As regards as colours, clear (25.13%), white (22.25%) and black (15.30%) items were more abundant than

Table 1
Results on marine litter analyzed.

	Meas. units	Silba					Grebena	
		DRA	JAR	LOI	SMR	SOT	JGR	SGR
Total items	n. items/kg	266.7	269.0	300.0	180.0	526.7	273.3	360.0
Fibres	%	57.5	65.0	80.0	70.4	49.4	39.0	53.7
Film	%	22.5	17.5	4.4	22.2	25.3	19.5	7.4
Fragment	%	20.0	17.5	15.6	7.4	24.1	41.5	38.9
Granule	%	0.0	0.0	0.0	0.0	1.3	0.0	0.0
MacroPS	> 2.5 cm	0	0	0	0	0	0	0
MesoPS	2.5–0.5 cm	4.8	0.0	0.0	0.0	1.3	2.4	0.0
MicroPS	5000–2000 μm	2.4	20.0	8.9	33.3	7.5	2.4	0.0
	2000–500 μm	50.0	32.5	51.1	51.9	43.7	33.3	33.3
	500–100 μm	38.1	45.0	33.3	11.1	32.5	45.3	55.6
	< 100 μm	4.8	2.5	6.7	3.7	15.0	16.7	11.1

DRA = Drazice, JAR = Južni Arat, JGR = Južni Greben, SGR = Sjeverni Greben, LOI = Loišće bay, SMR = Smrdeča bay, SOT = Sotorišće.

others while blue, red, and green were about 9–10% of the total. Yellow, tan and brown showed the lowest percentage (about 1 to 3%).

Principal component analyses (PCA) performed on data collected in this study, showed that the first two axes accounted for the 60.4% of the total variance recorded. Among *a priori* defined factors, the multivariate analysis performed evidenced a weak correlation of marine litter features (abundance, shape and colours) to water depth (Anosim test, p = 2.9%). This result should be improved by the acquisition of a larger number of field data to increase significance of observed relationships. PCA evidenced a significant and clear segregation of SGR and JGR from all the other sites due to a lower presence of items within 5000–1000 μm, fibres (PC2 −0.357), red (PC2 −0.334), tan (PC2 −0.298), and brown colours (PC2 −0.305) and a higher presence of yellow (PC2 0.334) items characterizing Grebena Islands.

Grebena Islands evidenced a composition of marine litter that was quite different compared both to Silba (this study) and Telašćica (Blašković et al., 2017). Nevertheless, any significant was recorded testing *a priori* factors selected in this study with the exclusion of the ANOSIM test performed on the factor "human exploitation level" (Silba, High; Grebena, Low; Telašćica, absent) let us to suppose that different levels human stress could be associated to the observed segregations. In fact, Telašćica sampling area was inside the marine protected area in the Natural Park of Telašćica bay. The MPA is visited by tourist mainly during the summer. On the contrary, Silba Island is a small human populated island with a long history. Sotorišće village is inhabited during the whole year (292 inhabitants; 2011 census) by local population which based their economy on agriculture and tourism. Grebena Islands are small and not inhabited Islands with summertime daily frequentation by touristic boat excursions.

Marine protected areas resulted efficient to preserve over-exploitation of species of some commercial interest (Lubchenco et al., 2003); nevertheless, some others human impacts are not efficiently faced by the establishment of MPA. Some examples of human impacts acting at a geographical scale level on which MPA are not effective are represented by hydrological changes, biological invasions by non-indigenous species (Allison et al., 1998), direct and indirect pollution (Renzi et al., 2010). MPA could be affected by pollution driven by small-scale global dynamics such as long-range run-off depositions (Lohmann et al., 2007), human activities along coastlines (Mille et al., 2007) or shipping activities (Renzi et al., 2010). Numerous studies reported that even at the highest level of protection (no-take, no-access zone) the prevention of MPA against chemical pollution is not efficient due to inputs coming from far sources (Shipp, 2003; Renzi et al., 2010; Perra et al., 2011). Marine litter and, in particular, plastics are considered as a new type of human-made pollutant that could not be efficiently faced by the institution of MPA. In fact, protection management based on local scale actions could be effective to prevent local direct sources (Costa et al., 2010), nevertheless, fragmentation of larger plastics and transport of smaller items from near marine areas (JRC EU, 2013; Browne et al., 2011) could not been avoided by MPA. Since 2004, when microplastics were documented for the very first time in marine sediments by Thompson et al. (2004), marine litter is recorded in almost all marine habitats form highly polluted as well as harbours (Reddy et al., 2006; Claessens et al., 2011; Romeo et al., 2015a) to MPA (Blašković et al., 2017). In spite of the inadequate action of MPA against marine litter pollution in sediments reported by the literature, a recent research evidenced that the presence of protected terrestrial areas (*i.e.* Natural Parks) and associated political actions finalized to manage and reduce costal wastes, could reduce local inputs of plastic debris and marine litter in coastal marine environments even closed to a riverine input (Blašković et al., 2018). The significant recorded in our study among marine litter features and human exploitation levels needs further statistical analyses on a larger dataset to weight the presence of other untested overlapping factors that could be responsible of the observed significance concerning segregations among sampling areas such as human pressure on the coastline.

Concerning some ecological and ecotoxicological aspects related to marine litter pollution, some recent researches evidenced as microplastics could represent a threat for marine species due to chemicals and microbes absorbed on their surface (Zettler et al., 2013; Thompson et al., 2004; Graham and Thompson, 2009; Murray and Cowie, 2011; Rochman et al., 2013; Romeo et al., 2015b; Pedà et al., 2016). A recent paper evidenced that microplastics are measurable in sediments from different marine habitats such as cliff, slopes and banks (Renzi et al., 2018a). In sediments from the Northern Adriatic Sea, microplastics are also present in different biocoenosis of particular ecological relevance such as *C. nodosa*, mäerl bed habitats, and amphioxus sands (Renzi et al., 2018b). In our research, any correlation was recorded between marine litter abundance, shape, and colour distributions in sediments from Silba and Grebena Islands to the percentage of bottom covered by *P. oceanica*. This result confirmed literature records for bottoms covered by *C. nodosa* (Renzi et al., 2018b) suggesting that microplastics could be considered a minor threat for phanerogam conservation in marine ecosystems. Nevertheless, other studies reported a positive correlation between the biotic diversity index and pollution levels by marine litter (Barnes, 2002; Romeo et al., 2015a; D'Alessanro et al., 2018) suggesting a possible use of the marine litter as a substrate by many benthic species. A recent research evidenced as benthic detritivores (holothurians) could be affected by microplastics and could transfer them from sediments towards the marine trophic web (Renzi et al., 2018a). Due to the great concern of these results, further studies should be performed to better evaluate risks associated to microplastics pollution for marine biota and trophic webs. Furthermore, as the removal of microplastics from contaminated marine sediments is actually impossible, prevention is the only weapon available to reduce microplastic levels in sediments in the near future. For this reason, a well-sized management plan on disposable plastic objects and wastes should be improved in Mediterranean Countries to reduce direct and indirect inputs in marine environments.

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