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Marine litter detection and correlation with the seabird nest content

Silvia Merlino[1] · Marinella Abbate[2] · Loris Pietrelli[3] · Paolo Canepa[4] · Paolo Varella[5,6]

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Abstract
A 3 year monitoring programme, realized in a citizen science context, from 2014 until 2016, allowed us to gather information on the prevalent quantities and qualities of anthropogenic waste in five Mediterranean coastal areas within the Pelagos Sanctuary, three of them located in Liguria, near La Spezia Gulf, and the other two in Tuscany. Here, we present results concerning the Polymeric Articles' abundances registered during the survey. Moreover, we show the results of the first study devoted to describe and quantify the anthropogenic content of the nest of a pair of Northern Gannets (*Morus bassanus*), a pelagic bird that, starting from some years, has been reproducing regularly in La Spezia Gulf. This breeding is atypical for this species, as is associated with artificial structures such as piers, floating docks, or boats; the material used in the construction of the nest reflects the "anthropogenic" link with the chosen location and objects of polymeric origin in particular abound. We detect the existence of a correlation between the most abundant types of Anthropogenic Marine Debris found in the Northern Gannet' nest (fragments of polypropylene nets) and one of the productive activities of the zones.

Keywords Marine litter survey · Polymeric AMD · Northern Gannets · Mussel nets · Aquaculture farms

1 Introduction

Sea-based sources of litter were found to be significant in certain countries as Italy and Greece (Vlachogianni et al. 2017), related to the main economic sectors, such as fisheries and aquaculture, as mentioned in the other studies (Poeta et al. 2016a, b). In Italy, a 3 year monitoring programme, realized in a citizen science context (SEACleaner Monitoring programme, Merlino et al. 2015, Merlino 2016), was devoted to estimate quantity, typology, and distribution of Anthropogenic Marine Debris (AMDs) within a Tyrrhenian coastal area. First, results concerning the spatial distribution of different Material categories (as plastic, expanded polystyrene, glass, textiles, etc.) have been published (Giovacchini et al. 2018), confirming that the objects of polymeric origin represent the largest percentage in each of the studied areas. The importance of river contributions to beached solid waste for this Macro-Area is in line with what has been reported by several studies (Araújo and Costa 2007; Moore et al. 2011; Rech et al. 2014). Moreover, we highlight peculiarities related to specific land-based sources and productive activities of the territory. It is the case of the dispersion and accumulation of special objects ("mussel nets", used in mussel and oyster farms) in the Ligurian Area, contained within the Macro-Area (M-Area) studied during the SEACleaner project. In this Area, in fact, abounds historical productive activities of aquaculture (Marino et al. 2005; Cataudella and Spagnolo 2011), and the incorrect disposal of polypropylene (PP) nets used during the mussel/oyster

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✉ Silvia Merlino
silvia.merlino@sp.ismar.cnr.it

[1] CNR-ISMAR, U.O.S. di Pozzuolo di Lerici, C/O Forte Santa Teresa, Loc. Pozzuolo di Lerici, Lerici, 19032 La Spezia, Italy

[2] ENEA SSPT PROTER BES, Pozzuolo di Lerici, Via S. Teresa, Lerici, 19032 La Spezia, Italy

[3] ENEA Centro Ricerche Casaccia, Via Anguillarese, 301, 00123 Santa Maria Di Galeria (RM), Italy

[4] LIPU La Spezia, Via Trezzo 65, Loc. Corvara, 19020 La Spezia, Beverino, Italy

[5] Cooperativa Mitilicoltori Spezzini Scrl, Via S. Teresa, 11, SP6, 19032 Lerici, Italy

[6] Legambiente, La Spezia, Via Paleocapa 19, 19122 La Spezia, Italy

production process probably have led to a dispersion and accumulation of this kind of material, that turned out to be particularly suitable to be used by some seabirds for the construction of their nests. It is the case of the Mediterranean breeding of Northern Gannets (*Morus bassanus*), a pelagic bird that generally nests in the colonies (gannetries) ranged on cliffs or skerries. Only two nesting cases of Northern Gannets in the Mediterranean are currently known and studied: the Italian one, in the little harbor of Portovenere, inside the La Spezia Gulf (Giagnoni et al. 2015) in the Ligurian Area, and the French one, in Carry-Le-Rouet, a small harbor in South France (Deideri et al. 2014). Both breeding cases are in close association with harbors and man-made structures such as jetties, floating docks, and boats (Giagnoni et al. 2015; Merlino et al. 2017), in a highly anthropized environment, a behavior noted also in a few other non-Mediterranean cases (Palmer 2001; Lyngs 2015).

This implies a large availability of plastic dispersed material, whose lightness and flexibility make it particularly attracting to birds for the construction of nests, but that, especially in the form of laces and filaments, can easily twist around the body of newborns or even of adults, damaging them and sometimes causing their death (Deideri et al. 2014; Merlino et al. 2017).

As SEACleaner beach surveys period overlaps the time laps of Northern Gannets colonization in Portovenere, started in 2013, we decided to compare results from the monitoring programmes, concerning the abundances of P-Articles in the different surveyed areas, and especially in the Ligurian one, with the results of the analysis of the Italian nest of 2017.

2 Materials and methods

2.1 The study area

The monitored areas and sites, within the Pelagos sanctuary (http://www.sanctuaire-pelagos.org/en/), are reported in Fig. 1. The Sites, within Liguria and Tuscan regions, have been selected according to the most general SEACleaner monitoring planning (Merlino et al. 2015; Giovacchini et al. 2018) to monitor and estimate contribution of urban, riverine, or marine inputs to coastal litter pollution, in compliance with indications of the Marine Strategy Framework directive (Galgani et al. 2013). In

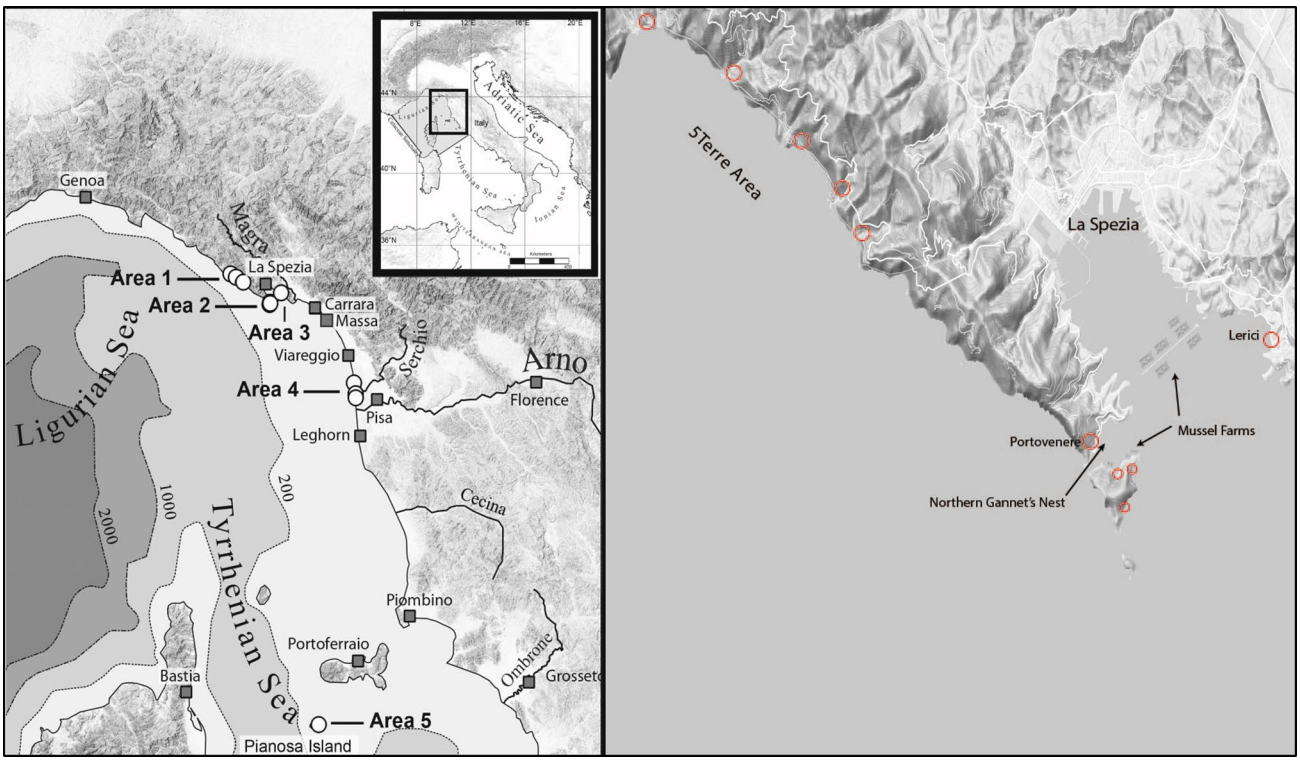

Fig. 1 Macro-Area of SeaCleaner monitoring programme for beach litter, on the left, described in Giovacchini et al. (2018); Pelagos Sanctuary region is evidenced in the small upper box (Area 1 = 5 Terre, Area 2 = Portovenere, Area 3 = Lerici, Area 4 = San Rossore, Area 5 = Pianosa). On the right, the La Spezia region, with the three Ligurian Areas, the location of the Northern Gannet breeding site and that of the aquaculture farms (color figure online)

particular, the chosen sites were: Portovenere and Palmaria; Tino and Tinetto Islands belong to a Natural Regional Park and two areas inside the Macro-Area of the Pelagos Sanctuary (San Rossore Park and Pianosa island, in National Tuscan Archipelagos Park).

Monitoring campaigns of macro beach litters have been carried out with teams of researchers, volunteers, and students. The adopted survey protocol is the result of the integration of direct observations with all guidelines and methodological instructions identified in the literature (Cheshire et al. 2009; OSPAR 2010). To minimizing the bias of a wrong classification, only predominant AMDs were taken into account, and the number of materials was reduced from 12 to 9 (plastic, foamed plastic, textiles, and the number of lass and ceramic, metal, paper and cardboard, rubber, wood, and others, following Cheshire et al. 2009), while the number of kind of Articles was reduced from 121 to 34. Items have been collected following a standardized approach starting from the seaside line to the beginning of the back-dune vegetation, or other back constraints, both for sandy and linear beaches (Cheshire et al. 2009) than for "pocket beaches" (Williams and Tudor 2001a, b). Beach surveyed dimension range from 450 to 3000 m^2 for the surface and from 45 to 300 m for the total length. Litter with dimension bigger than 2.5 cm has been removed and brought to laboratory for sorting and counting, and so properly thrown away. The initial and final points of the chosen beaches have been geo-referenced using a GPS (Garmin GPSMAP® 64st) to repeat survey in the same stretch of beach. Taking into account the time required for AMDs to accumulate, we considered a minimum of 2/3 months between replicates in the same Site (Ryan et al. 2009).

2.2 Data analysis

Statistical analysis of collected data on beach litter has been performed with the PAST 3.12 software for Windows (Hammer et al. 2001). We assume that data followed a normal distribution as Shapiro–Wilk test for testing normality gave back a W value 0.94. Average density values (items/m^2) of considered sites and areas, both for Materials and for Articles, have been calculated considering all the available replicas. Categories of litter that were primarily responsible of the differences between areas have been identified using similarity percentage analysis (SIMPER). Materials withdrawn in the Northern Gannets' nest have been separated, classified, and weighed with a scale KERN (Kern and Sohn GmbH D-72,336). The analysis of the polymeric component was carried out in the ENEA laboratories of Centro Ricerche Casaccia, through Fourier transform infrared spectroscopy (FT-IR) measurements. The used instrument was an IRAffinity-1 FT-IR Shimadzu apparatus. The spectrum peaks (range 4000–600 cm^{-1}) were compared with spectra database and instrument libraries.

3 Results

3.1 Marine litter coastal survey

We report a resume of the principal outputs emerging from this survey in Table 1. Data set agreed well with the previous one (Giovacchini et al. 2018), confirming the goodness of the data collection and elaboration. Monitored Sites have been classified in different class of Urbanization (Ariza et al. 2008). We note that, in the present data set, the Tuscan San Rossore Site (Natural) present the higher density of the total Macro-Area (M-Area), followed by

Table 1 Values of mean density of AMDs found for each studied area (items/m^2) and abundances in percentage (calculated over the total amount of materials) for the five areas surveyed during SEACleaner project, calculated considering all the replicas

Name of the area	Lerici		5 Terre		Portovenere		San Rossore		Pianosa	
Beach type	U		U		Uz		N		Uz	
Material	AD	Ab	AD	Ab	AD	Ab	AD	Ab	AD	Ab
P-Articles[a]	0.243 ± 0.200	47	0.324 ± 0.212	54	0.980 ± 0.503	95	1.444 ± 0.960	95	0.609 ± 0.288	96
Multi-material	0.245 ± 0.330	46	0.083 ± 0.077	15	0.022 ± 0.023	2	0.023 ± 0.023	2	0.010 ± 0.007	2
textiles	0.010 ± 0.020	2	0.01 ± 0.010	1	0.007 ± 0.007	1	0.007 ± 0.007	2	0.010 ± 0.007	2
Processed wood	0.007 ± 0.009	2	0.003 ± 0.003	1	0	0	0.003 ± 0.003	0	0.001 ± 0.001	0
glass	0.005 ± 0.009	1	0.003 ± 0.003	1	0.003 ± 0.003	1	0.020 ± 0.023	2	0.001 ± 0.001	0
Metal	0.007 ± 0.009	2	0.106 ± 0.014	18	0.017 ± 0.018	1	0.007 ± 0.007	1	0.001 ± 0.001	0
Total AMDs	0.517 ± 0.380	100	0.595 ± 0.450	100	1.029 ± 0.810	100	1.504 ± 0.320	100	0.632 ± 0.290	100

Lerici: 4 replicas; 5 Terre: three sites × 2 replicas; Portovenere: 3 sites × 3 replicas; San Rossore: 3 sites × 4 replicas; Pianosa: 4 replicas

[a]P-articles include objects of polymeric material, as expanded polystyrene, foam, sponge, rubber, and other plastic types in PET, PE, PP, etc

AD average density of items (items/m^2), *Ab* abundance of items (%)

the two Urbanized Areas Portovenere and Pianosa, and so by the two Ligurian Areas classified as Urban. This fact confirms and strengthens the hypothesis, already proposed in Giovacchini et al. (2018), of the existence of a trend relating the Urbanization degree of the beaches with the total density of litter.

Table 1 also emerges a trend that relate the polymeric material (P-Article) abundance to the Urbanization class, with the two Tuscan Areas and Portovenere Area having the higher values, and the Ligurian Areas of five Terre and of Lerici showing the lowest values. A plausible explication is that these two urban areas present a major abundance of the trash categories related with a high touristic presence, as multi-material, textile, glass, and metal. Natural areas (forbidden to tourism, as San Rossore Park Area) or Urbanized areas with, especially in winter, a lower touristic pressure (as Palmaria Island in Portovenere Area and Pianosa Island Area) show, instead, a predominance of polymeric objects, i.e., objects that, for their lower specific weight, are more easily moved by sea currents and deposited on beaches, even far from the place of entry. This leads us to think that, in trying to identify the potential sources of beach litter on a broad scale, we should consider multiple factors, such as rivers presence, sea currents, and the role of urban areas and beach users (Poeta et al. 2016b).

Table 2 highlights the differences among the different areas, in terms of polymeric materials density and abundances, these last calculated over the total amount of polymeric material. The categories EPS, fragments, FNS, and caps account, together, for more than 80% of the total amount of P-Articles for the M-Area. Comparison with other marine litter surveys, performed in Italian coasts, (Legambiente 2015, 2016; Munari et al. 2016; Poeta et al. 2016a, b; Vlachogianni et al. 2017), confirm that these are among the most common Articles found during these monitoring programmes, and, so, that a few litter items categories constitute the majority of the total amount of items collected. Pie charts of Fig. 2 display the occurrences of the different P-Article in respect to the total P-AMD content. The similarity percentage analysis (SIMPER) identifies four categories, among P-Articles, responsible for the 79% of the differences between the five areas: EPS, FNS, bottles, and fragments. The densities of these categories in the different areas are reported in Fig. 3, together with the ones for the other article categories, plotted for the different areas, and for the Macro-Area.

As concern the category "Filaments/nets/sticks", when split in the three sub-categories (see Table 2, gray lines), the "Cotton buds" are particularly abundant in Tuscan Areas, probably as a consequence of proximity of river mouth and incorrect disposal of sewage systems (Poeta et al. 2016a, b; Giovacchini et al. 2018). On the contrary, the "Mussel nets", absent in Tuscan monitored areas, have a high occurrence in Portovenere and Lerici Areas, probably as a consequence of incorrect waste management of aquaculture material.

3.2 Results from nests analysis

Identification of nest material reveals the presence of very few natural objects in comparison with the anthropogenic (AMDs) ones (Fig. 4). The AMDs items coincide with objects of polymeric origin as reported in Table 3. In particular, these items are almost exclusively fragments of nets made with polypropylene (95%) and polyethylene (5%) that, currently, are used for aquaculture (mussel) farming (http://www.intermasgroup.com/en/aquaculture/dossier/mussel-farming.html).

4 Discussion

Differences in P-article composition among areas can be related to the urbanization class, to the geographical position, the proximity with pollution sources, such as wastewater treatment plants or fishing industries, and the differences in the specific buoyancy of the article category (Poeta et al. 2016a, b). In a similar way to what we found for the Material category of AMDs, which resulted distributed differently within the M-Area monitored during the SEACleaner project (Giovacchini et al. 2018), also the P-articles seem to have a spatial distribution strongly influenced both by local sources of pollution (as evidenced by the cotton buds' occurrences in Tuscan Areas) and by the buoyancy of the materials themselves and, therefore, by their ability to spread far from local sources of pollution. The already mentioned importance of the buoyancy of Article category (Poeta et al. 2016a) explains, in fact, the different occurrences of P-Articles found in the surveyed areas (Table 2): EPS pieces, floating above the surface, are easily transported by marine current and spread also far from primary pollution source, accounting for its presence in almost all the monitored areas. The particularly high occurrence of EPS in Portovenere Area can, anyway, be explained with the proximity of a pollution source of this material. In fact, the very short distance from Portovenere beaches and local aquaculture farms, together with the low frequency of the beach-cleaning actions, can account for the high occurrence of floating and beached expanded polystyrene, and for the high occurrence of plastic bottles registered in this area, too. Both these P-Articles are, like mussel nets, used in aquaculture farms: polystyrene containers are used to pack mussels ready for sale; plastic bottles are used as a buoy, to signal the presence of the poles used in these types of marine farms.

The data collected, relating to a single Northern Gannets nest, cannot be considered a quantitatively relevant statistical sample, but they show that the anthropogenic component of

Table 2 Calculated mean density (items/m^2) and abundance (in percentage, calculated over the total amount of polymeric material) for the 13 categories of articles of polymeric origin (P-Articles) for the three South Liguria and the two Tuscan Areas surveyed. Averaged values for the Macro-Area (M-Area) are also reported

Name of the area	Ligurian Area						Tuscan area				M-area	
	Lerici		Cinque terre		Portovenere		San Rossore		Pianosa			
Beach classification	U		U		Uz		N		Uz			
P-Articles type	AD	Ab	AD	Ab	AD	Ab	AD	Ab	AD	Ab	AD	Ab
Bottles	0.0047 ± 0.0018	2	0.0043 ± 0.0072	1	0.1014 ± 0.1325	10	0.0231 ± 0.0258	2	0.0051 ± 0.0044	1	0.0277 ± 0.0343	4
Plastic bags	0.0132 ± 0.0114	5	0.0104 ± 0.0181	3	0.0438 ± 0.0429	4	0.0700 ± 0.0764	5	0.0277 ± 0.0125	5	0.0330 ± 0.0323	5
Toys	0.0051 ± 0.0012	2	0.0033 ± 0.0074	1	0.0022 ± 0.0027	0	0.0116 ± 0.0085	1	0.0017 ± 0.0010	0	0.0048 ± 0.0042	1
Fragments	0.1352 ± 0.1236	56	0.0714 ± 0.0635	23	0.0347 ± 0.0121	4	0.4613 ± 0.3114	32	0.2085 ± 0.0886	34	0.1822 ± 0.1198	24
Containers	0.0059 ± 0.0036	2	0.0120 ± 0.0128	4	0.0197 ± 0.0126	2	0.0479 ± 0.0299	3	0.0083 ± 0.0047	1	0.0187 ± 0.0127	3
Mussel nets	0.0152 ± 0.0093	6	0.0019 ± 0.0032	1	0.0296 ± 0.0130	3	0	0	0	0	0.0093 ± 0.0051	1
Cotton buds	0	0	0.0014 ± 0.0020	0	0.0032 ± 0.0012	0	0.1700 ± 0.1847	12	0.1868 ± 0.0734	31	0.0723 ± 0.0523	10
Other types of FNS	0.0065 ± 0.0034	3	0.0063 ± 0.0047	2	0.0063 ± 0.0045	1	0.0494 ± 0.0239	3	0.0231 ± 0.0190	4	0.0183 ± 0.0127	3
Filaments/Nets/ Sticks (FNS)	0.0217 ± 0.0127	9	0.0096 ± 0.0099	3	0.0391 ± 0.0186	4	0.2194 ± 0.2086	15	0.2099 ± 0.0924	35	0.0999 ± 0.0701	14
Caps	0.0115 ± 0.0090	5	0.0077 ± 0.0137	2	0.0530 ± 0.0888	5	0.1756 ± 0.1384	11	0.0742 ± 0.0199	12	0.0644 ± 0.0539	9
Tubes	0.0004 ± 0.0006	0	0.0031 ± 0.0033	2	0.0073 ± 0.0055	2	0.0089 ± 0.0065	1	0.0040 ± 0.0025	1	0.0047 ± 0.0037	1
foam/ sponge	0.0092 ± 0.0090	4	0.0331 ± 0.0436	11	0.0682 ± 0.0639	7	0.0433 ± 0.0235	3	0.0204 ± 0.0106	3	0.0348 ± 0.0301	5
rubber	0.0010 ± 0.0027	0	0.0231 ± 0.0174	7	0	0	0	0	0.0043 ± 0.0035	1	0.0057 ± 0.0047	1
EPS (*)	0.0354 ± 0.0259	15	0.1351 ± 0.1200	43	0.6108 ± 0.6077	62	0.3836 ± 0.3110	27	0.0453 ± 0.0303	7	0.2420 ± 0.2190	33
Total P-Articles	0.2432 ± 0.2004	100	0.3244 ± 0212	100	0.9803 ± 0.5035	100	1444 ± 0960	100	0.6091 ± 0.2883	100	0.7181 ± 0.4328	100

AD average density of items (items/m^2), *Ab* abundance of items (%)

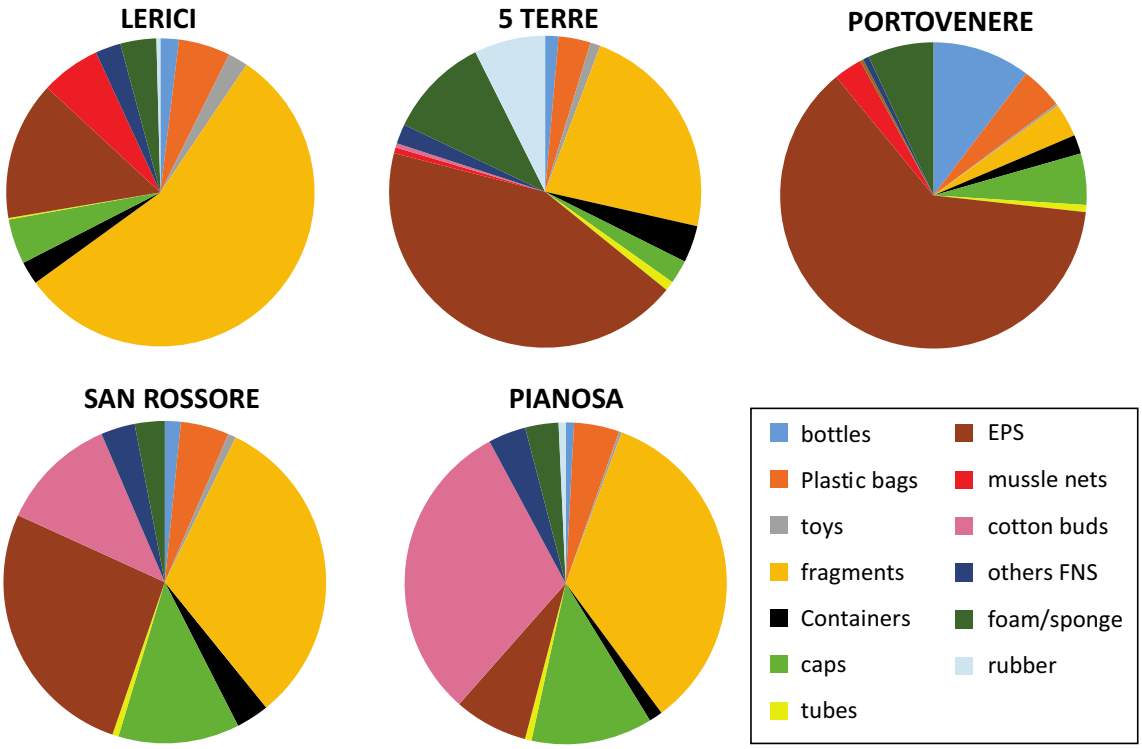

Fig. 2 Pie charts report the occurrences of the different P-Article in respect to the total P-AMD content. Here, the Article category "Filaments/Nets/Sticks" (FNS) is split in the three sub-categories: "Cotton buds", "Mussle nets", and "other FNS" (color figure online)

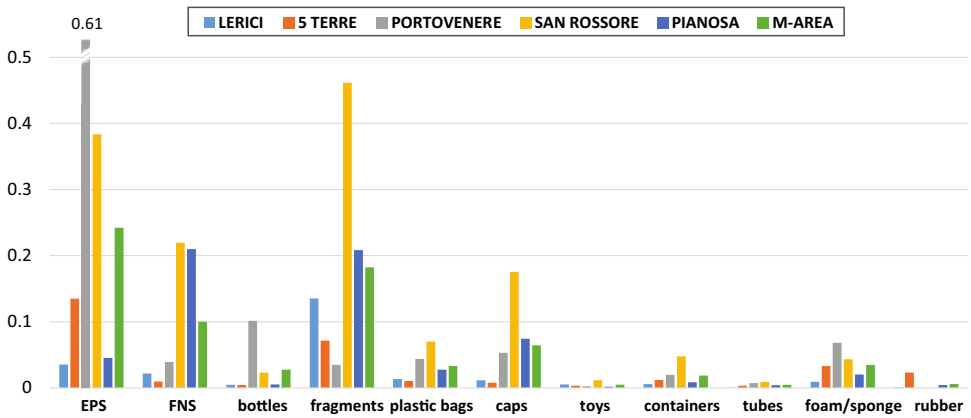

Fig. 3 Frequencies of the P-Article categories, for the five areas and for the Macro-Area (M-Area). *EPS* expanded polyethylene, *FNS* article "filaments/nets/sticks" (color figure online)

the material used by birds for the construction of the nest is much greater than the natural one. In particular, 90% type of material used is mainly of polymeric origin (by the mussel farmers) confirming, therefore, relating the prevalent productive activities of this area with the problem of marine and coastal pollution and with the dangers, for the local fauna, that derive from it. We tried to measure non-biological diversity for the sample of object found in the Gannet' nest, on line with how suggested by Battisti et al. (Battisti et al. 2017), using more diversity indices. For sake of simplicity, we used univariate indices: Shannon–Wiener diversity indices (H) and Simpson diversity indices (1-D), this lasts ranging since 0 to 1. Applying to sample containing specific marine litter categories (species), they can provide information on diversity of sources of material collected (Battisti et al. 2017; Galgani et al. 2000). In our case, considering all the categories (species), both natural than anthropogenic, presents in our sample, we obtain, for Simpson Index, a value of 0.39. H diversity indices range from 0 to 5 and generally have typical values between 1.5 and 3.5, in our case results 0.69. As H increases as both the richness and the evenness of the community increase, its low value highlights that, in our sample, the richness is low and, moreover, some categories of objects are much

Fig. 4 On the left, the Northern Gannets nest of Portovenere, built over the deck of a boat. On the right, the nest content, cleaned up by the remains of feathers, mud, and compacted excreta (color figure online)

Table 3 Data of anthropogenic (AMDs) and natural objects found in the nest. *P-Articles* polymeric articles

	Items number	Items (%)	Weight (Kg)	Weight (%)
Total items	46	100	0.466 ± 0005	100
Natural items	8	17	0.146 ± 0005	31
Total AMDs	38	83	0.320 ± 0005	69
P-Articles	38	83	0.320 ± 0005	69
Mussel nets	35	76	–	–
Fragments	3	7	–	–

P-Articles are the sum of the different plastic typologies that we found in the nest, as reported in the last two rows. No single weight has been taken for each one of these categories. Nest content is characterized by the presence of only a few categories of material. Among the Natural Items only one category is accounted, that is "wood stick". Anthropogenic content (AMDs) in this case coincide with P-Articles content, lacking other types of man-made objects (textile, metals etc.). Finally, among P-Articles only the "mussle nets" category stands out for abundance

better represented than others ("mussel nets", see Table 3). This fact has strong implication in the removal strategy of anthropogenic objects from the environment where the nest is located. Natural items are under-represented inside the nest, being very few (see Table 3) and all belonging to the same "species" (category "wood stick"), as it lacks a lot of other natural components, typically roots and leaves of *Posidonia oceanica*, normally presents in Gannet nests (Merlino et al. 2017, 2018). The analysis of the polymeric articles collected within the monitored areas confirm the fact that the mussel nets abounds particularly in areas where the Gannets are supposed to retrieve the building material for the nest. Both Portovenere and Lerici areas present a relevant occurrence of "Mussel nets" among the different types of P-Articles collected and cataloged (Table 1). Portovenere area shows the higher marine litter density (Table 2), probably due to the rather isolated position of the beaches, accessible almost exclusively from the sea. These lead to a major availability, for birds, to find material for the construction of the nest among the AMDs lying on the beaches or floating in the surrounding waters, especially during the end of winter and the beginning of spring (nesting period). Not only "Mussel nets" but, more generally, plastic object of the Article category "Filaments/nets/sticks", are suitable to be used by Northern Gannets to build their nest (Merlino et al. 2017). Usually, the species built up its nest using compacted mud, grass, and feathers cemented together with excreta (Cramp and Simmons 1983). In Portovenere, instead, the highly prevalent type of objects used by Norther Gannets for nest setup seems to be related to the presence of aquaculture activities that represents an important source of income for local aquaculture workers, with a total turnover that last year was over 6 million Euros. Mussel farmers use nets made in polypropylene (or in polyethylene), that are used to contain the mussel from the very beginning of their life to the moment of their withdrawal to be put on sale. When the nets are replaced, they are cut and, therefore, cannot be used anymore contributing to the marine litter in particular if the waste management is inappropriate.

5 Conclusion

The monitoring surveys on marine litter, performed in the Portovenere and Neighbor Areas, shows that a relevant quantity of peculiar polymeric objects found in these areas, i.e., "Mussel nets", is related with local aquaculture production activities, in line with already mentioned for other Italian and Greek regions (Vlachogianni et al. 2017). This fact leads to the availability, inside the nesting area of a

pair of Mediterranean Northern Gannets, of a large quantity of polymeric objects flexible, light, and also eye-catching, so particularly suitable for the construction of their nest. The predilection shown by these birds for this type of AMD has caused harmful consequences, including the death of newborns, and this suggests that drastic measures should be undertaken to mitigate the AMDs dispersion, especially in an almost enclosed area as Portovenere hosting a rare case of Northern Gannet breeding' pair. Recently, some efforts in this sense have been undertaken, as proposal of projects devoted to promote *blue process chain* for collecting and recycling the polypropylene mussel nets once used, with the double advantage of having less of this type of material dispersed in the area and, moreover, of being able to reuse it (Pietrelli et al. 2017). One of these proposed projects, named ECOMUSSLE, involves also the local farmers in trying to the restore old aquaculture methodologies that do not use polymeric mussel nets, and to experiment mussel nets build with new material with a lower environmental impact.

Finally, the fact that the largest proportion of the total amount of P-Articles collected in the five areas is consistently made of a limited number of litter item categories (Vlachogianni et al. 2017; Poeta et al. 2016a) supports the approach of prioritizing the implementation of measures to tackle a set of priority litter items, thus, attaining greater impact towards achieving good environmental status.

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