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Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy)

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ABSTRACT

Marine debris is a recognized global ecological concern. Little is known about the extent of the problem in the Mediterranean Sea regarding litter distribution and its influence on deep rocky habitats. A quantitative assessment of debris present in the deep seafloor (30–300 m depth) was carried out in 26 areas off the coast of three Italian regions in the Tyrrhenian Sea, using a Remotely Operated Vehicle (ROV). The dominant type of debris (89%) was represented by fishing gears, mainly lines, while plastic objects were recorded only occasionally. Abundant quantities of gears were found on rocky banks in Sicily and Campania (0.09–0.12 debris m^{-2}), proving intense fishing activity. Fifty-four percent of the recorded debris directly impacted benthic organisms, primarily gorgonians, followed by black corals and sponges. This work provides a first insight on the impact of marine debris in Mediterranean deep ecosystems and a valuable baseline for future comparisons.

1. Introduction

In the past, deep-sea ecosystems were among the least studied and explored marine regions of the world, due to logistical difficulties in sampling deeper waters (Menza et al., 2008; Danovaro et al., 2010; Ramirez-Llodra et al., 2011). Recently, thanks to the availability of several technical devices (mainly Remote Operating Vehicles – ROVs), the interest of the marine scientific community has increasingly focused on these particular environments, which support high levels of habitat diversity, species longevity and provide a wealth of resources (Buhl-Mortensen et al., 2010; Ramirez-Llodra et al., 2011; Fabri et al., 2014).

The Mediterranean Sea, intensely studied over the past centuries, is considered a marine biodiversity hotspot, characterized by high levels of endemism (Bianchi and Morri, 2000). Most of the investigations carried out in this basin were conducted above 50 m depth. Only in recent times, several studies have focused on deeper assemblages characterized by a great variety and abundance of habitat-forming taxa, such as sponges and corals, providing high biomasses and structural complexity (e.g. Aguiliar et al., 2009; Bo et al., 2009; 2012a,b; Freiwald et al., 2009; Bongiorni et al., 2010; Cerrano et al., 2010; Salvati et al., 2010; Gori et al., 2011; Fabri et al., 2014).

A common assumption is that deep sea areas are less impacted by anthropogenic disturbances (e.g., trawling, human litter, pollution, mining, oil drilling) (Hinderstein et al., 2010), whereas recent research has shown that this environment is more subjected to and affected by human and natural impacts than previously thought (Davies et al., 2007; Jones et al., 2007; Bongaerts et al., 2010).

The Mediterranean Sea is located among some of the most densely populated and highly industrialized regions of the world and it is affected by intense shipping activity. The pollution of this sea has been recognized internationally as a serious problem (Galil et al.,

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1995), raising concerns regarding threats to the conservation of the rich Mediterranean biodiversity (Coll et al., 2010).

Among the sources of marine pollution, litter is an ecological and social concern and an increasing issue worldwide (Galil et al., 1995; Galgani et al., 2000; Bauer et al., 2008; UNEP, 2009). Marine debris is defined as a solid or persistent material of human origin either discarded or abandoned in the marine and coastal environment (National Academy of Sciences, 1975). It represents a significant and persistent threat to wildlife due to its low biodegradability and its potential to be ingested by or to entangle marine organisms (Laist, 1987, 1997; Bavestrello et al., 1997; Yoshikawa and Asoh, 2004; Lee et al., 2006; Bo et al., 2014). Moreover, it can serve as means of transport and habitat for alien species, altering the natural community composition (Katsanevakis et al., 2007)

Since the 1970s, several studies have faced the problem of debris in marine environments (Galgani et al., 1996; Matsuoka et al., 2005; Katsanevakis et al., 2007; Spengler and Costa, 2008; UNEP, 2009; Keller et al., 2010). In particular, beach and floating litter has been recognized as an important social problem due to its esthetic impact and its influence on public health (Hess et al., 1999; UNEP, 2009). Whereas, little information is available regarding the composition and distribution of submerged marine debris and its influence on the benthic organisms (Galgani et al., 2000; Spengler and Costa, 2008; Watters et al., 2010; Miyake et al., 2011). Once settled on the seabed, marine debris alters the habitat by providing a previously absent hard substrate that organisms can eventually cover. Moreover, the debris covering the sediment prevents gas exchange and interferes with life on the seabed (UNEP, 2009). Finally, lost fishing gears, such as lines and nets, and anchors may cause direct physical damage to benthic organisms (Donohue et al., 2001; Yoshikawa and Asoh, 2004; Bauer et al., 2008; Heifetz et al., 2009; Bo et al., 2013, 2014), since abrasive actions cause the progressive removal of tissues from sessile organisms (Bavestrello et al., 1997).

Various methods have been employed to quantify marine debris on the sea floor and the ones currently used in deep sea environments include: bottom trawlers, sonar, submersibles and ROVs (Spengler and Costa, 2008). In particular, submersibles and ROVs have been used to investigate benthic litter on the continental slope and the abyssal plain (Galgani et al., 1996, 2000; Freese, 2001; Fosså et al., 2002; Heifetz et al., 2009; Watters et al., 2010; Miyake et al., 2011; Mordecai et al., 2011; Bergmann and Klages, 2012; Fabri et al., 2014). Visual data, in form of videos and pictures, have been demonstrated to be useful in obtaining quantitative data on deep-sea litter; even if debris cannot be directly inspected and measured (Spengler and Costa, 2008; Watters et al., 2010). The most important feature of these methods is that they can be effectively applied to all sea bottom types, including complex rocky habitats, where some debris (especially fishing gears) may be found in abundance (Watters et al., 2010). Moreover, these methods do not cause any impact on the explored environments; whereas the bottom trawling gear method can affect the seafloor (Gage et al., 2005).

In the last decade, there has been an increased interest from the scientific communities on how commercial fisheries and the presence of debris have affected the sea bottom. However, the majority of studies have investigated the impact of mobile gears, such as trawls and dredges, on soft bottom community structure (e.g. Kaiser et al., 2000; Freese, 2001; Koslow et al., 2001; Cryer et al., 2002; Fosså et al., 2002; Maynou and Cartes, 2011; Mangano et al., 2013) or the effect of ghost fishing (e.g. Matsuoka et al., 2005; Ayaz et al., 2006; Baeta et al., 2009). While, the impact of lost fishing gears on sessile organisms are less documented (Bavestrello et al., 1997; Eno et al., 2001; Freese, 2001; Chiappone et al., 2002, 2005; Asoh et al., 2004; Yoshikawa and Asoh, 2004; Heifetz et al., 2009; Bo et al., 2013, 2014), and little research has been focused on the impact of debris on rocky environments (e.g. Watters et al., 2010; Mordecai et al., 2011; Fabri et al., 2014).

Although, the Mediterranean basin is considered a particularly sensitive ecosystem (Bianchi and Morri, 2000; Coll et al., 2010), at present little is known about the extent of litter, especially in rocky areas deeper than 100 m (Galgani et al., 1996, 2000; Orejas et al., 2009; Madurell et al., 2012; Watremez, 2012; Bo et al., 2013, 2014; Fabri et al., 2014).

The aim of this study is to draw a baseline quantitative picture, by means of ROV, on the marine debris in three Italian regions (Tyrrhenian Sea, NW Mediterranean). This work attempts to evaluate, through a large number of observations, the occurrence and abundance of different types of debris and their potential impacts on benthic fauna. The study has been carried out in a marine area where there is a high level of tourism, commercial fishing and coastal urban population with respect to other areas of the Mediterranean basin.

2. Material and methods

2.1. Study areas

The data on marine debris were collected during three different surveys financed respectively by the Italian Ministry for Environment, Land and Sea (MATTM) and by Sardinian Regional Council aimed to explore rocky coral assemblages and to study red coral (*Corallium rubrum*) deep-dwelling populations. The cruises were carried out on-board the R/V *Astrea* of ISPRA along the south Tyrrhenian coast (NW Mediterranean Sea, Italy), respectively in June-July 2010 in Campania and September–October 2011 in Sicily and Sardinia (Fig. 1).

Along the north coast of Campania six areas were explored (Fig. 1A), located in the Gulf of Naples and in the Sorrentine Peninsula. The Gulf of Naples is a SW oriented coastal embayment with an average depth of 170 m and a continental shelf with variable width ranging between 2.5 and 10–15 km offshore (Ribera d'Alcalà et al., 2004). The seafloor is characterized by a rough morphology, influencing hydrological features of the gulf, characterized by both oligotrophic and eutrophic systems and exhibiting a strong seasonal variability. The outer part of the Gulf of Naples is more directly influenced by offshore Tyrrhenian oligotrophic waters (Cianelli et al., 2011), that when move inside the gulf, creates a basin-scale cyclonic gyre transporting offshore the land runoff. On the contrary, when the Tyrrhenian current moves southeastward, the inner part remains separated forming anticyclonic gyres (De Maio et al., 1985; Cianelli et al., 2011). This condition prevents the renovation of the coastal waters, thus favoring stagnation and consequently pollution and high sedimentation rate (De Maio et al., 1985; Cianelli et al., 2011). The Gulf of Naples is among the most densely inhabited Italian areas and it is heavily influenced by the land runoff. Along its coasts approximately 30 ports and more than 300 maritime constructions are located (Uttieri et al., 2011). The intense anthropic pressures determine a strong impact on the marine ecosystem and its waters present hydrographic and biological properties reflecting anthropic stress (Ribera d'Alcalà et al., 1989; Zingone et al., 2010).

In Sardinia, eleven areas located in the southern part of the island (Fig. 1B), and distributed through the Sardinia Channel and the Tyrrhenian Sea were explored. The seafloor morphology is different from the south eastern coast westwards; on the western side, a wide shelf area characterized by volcanic outcrops extends from the San Pietro Island to the Gulf of Cagliari, while a smaller shelf area (2 km of extension on average) with several canyon heads occurs along the south eastern shelf margin (Sulli, 2000;

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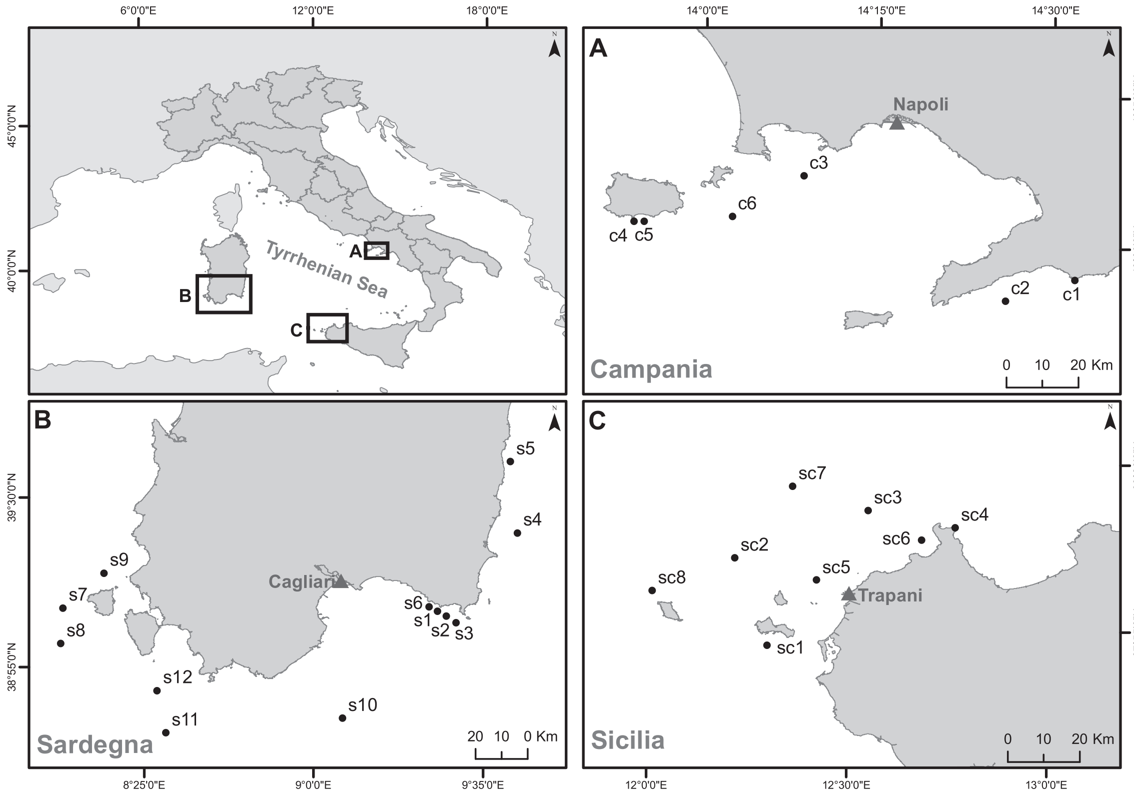

Fig. 1. Distribution of the study areas along the three explored Tyrrhenian regions (solid black borders) off southern Italy: (A) Campania, (B) Sardinia and (C) Sicily. The black dots denoted the dive sampling areas and the codes (ID) correspond to the list provided in Table 1.

Mascle et al., 2001). The Sardinia channel is a wide opening between Tunisia and Sardinia with a sill at about 1900 m that allows exchanges of deep waters between the western Mediterranean and the Tyrrhenian Sea. The surface layer is occupied by Modified Atlantic Water (MAW) directly coming from Gibraltar. On the opposite side, a significant flow of Levantine Intermediate Water (LIW) coming from Tyrrhenian Sea and extending from Sardinia slope to the centre of the channel leaves this region to the west (Send et al., 1999). Along south Sardinian coast, the westward Algerian current is reported to be dominant: this current merges with the southward currents forming the quasi-permanent South Eastern Sardinian gyre (Sorgente et al., 2011). South Sardinia hosts a wide range of ports, from small touristic (mostly located in the east/south eastern coast) and industrialized areas as Cagliari (southern coast) and Porto Scuso (south western coast). Moreover, the south-western coast is also renewed for intense tuna fishing activities (Addis et al., 2013).

The eight studied areas in Sicily were located in the NW portion of the island and around the Egadi Archipelago (Fig. 1C), positioned between the strait of Sicily and the Tyrrhenian Sea. This zone represents the shallowest part of a wide submarine canyon that connects the Sicilian continental shelf to the Tyrrhenian Sea abyssal plane (Colantoni et al., 1993). The Sicilian continental shelf is very broad in front of Trapani coastlines and narrower between Levanzo and Marettimo Islands (Brugnano et al., 2008). The strait of Sicily can be considerate a small intermediate basin that subdivides the Mediterranean into western and eastern sub-basins and it is a topographically complex region. The surface circulation is mainly characterized by the flow of Atlantic Water (AW) flowing eastward from the Sardinia Channel into the Tyrrhenian Sea (Astraldi et al., 1999) and a deeper Levantine Intermediate Water (LIW), coming from the eastern Mediterranean to west, forming a two-layer system with a 100 m thick transitional layer. The topographic constrains lead the LIW flows to turn eastwards and enter the Tyrrhenian Sea across a section offshore the Egadi Islands (Brugnano et al., 2008). The strait plays an important role in hydrodynamic and biological exchanges between the two principal sub-basins, acting as a transitional basin and as reservoir for deep water (Millot, 2005). This Sicilian zone hosts several touristic and commercial ports and the professional fishery represents one of the most important activities. Moreover, a rising number of recreational boats increase the fishing pressure on these areas.

2.2. Data acquisition

Surveys were conducted first mapping the seabed of the study areas using Multibeam echo sounders (RESON 8125 and Kongsberg Em 3002), and then carrying out exploratory video transect along the seafloor by means of a ROV 'Pollux' (Global Electric Italiana). The ROV was equipped with a digital camera (Nikon D80, 10 megapixels), an underwater strobe (Nikon SB 400), and 3 jaw grabbers (SeaBotix) to take samples. In addition, three laser beams, at a distance of 10 cm each other, provided a scale of the photos.

The ROV had a depth sensor, a compass and an underwater acoustic tracking position system (Tracklink 1500 MA, LinkQuest), providing detailed records of the tracks along the seabed. Geographical positions and depth were registered from the beginning to the end of each transect, every 1 s. The ROV moved ~1.5 m above the seabed, at constant speed (approximately 0.5 knots).

Along each transect, high-resolution photo-sampling units were acquired every ≈30 s in order to identify and quantify the marine benthic litter. Litter was divided into 5 categories: fishing lines; nets; pots; plastic (bags, bottles, other objects, etc.); other items (glass, metal, etc.). The presence of debris was evaluated both by occurrence (frequency of debris types) and relative abundance (debris items m^{-2}), assessed by counting the number of debris respect to the photo area.

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Photos were analyzed by means of Image J software (http://rsbweb.nih.gov/nih-image), using laser beams as a scale. In order to assess the differences among the three studied regions, relative abundance (with a not normal distribution) was verified by the non-parametric Kruskal–Wallis H test and the post hoc Nemenyi-Damico-Wolfe-Dunn test.

The distance of each area from the nearest coast was also measured.

The impact of benthic debris was assessed and classified in 4 levels: (i) covering, when debris covered the organisms; (ii) abrasion, when the tissues of the organisms were injured; (iii) hanging, when debris was under tension between rocky obstacles but apparently did not injure any organism; (iv) lying, when debris was sitting on the bottom and did not impact the organisms.

The eventual fouling on marine debris by macro-benthic organisms was examined and the most common colonizing taxa were recognized. Thus, based on the number of taxa growing on debris items, three degrees of colonization were identified: none (0 taxa), moderate colonization (1–3 taxa), heavy colonization (>3 taxa).

The number of dead sessile organisms, not directly impacted by debris, was also recorded.

In order to evaluate the impact of debris, logistic models with mixed effects were used. The outcome was the presence or absence of a certain impact. Therefore, the probability of observing an impact of some kind was modeled. The logarithm of the odds of this probability was assumed to be a linear function of fixed effects associated with debris and other predictors, with a dive-specific intercept. The latter was used to take into account the effects of unobserved factors, and capture the dependence among the observations realized within the same dive. The dive-specific intercept was assumed to arise from a zero-centered Gaussian distribution, as in usual generalized linear mixed models. Bivariate association models were estimated at first, and then the final linear multivariate model with mixed effects was obtained through forward stepwise selection. Bivariate logistic models were also used to analyze the region specific effects of marine debris impacts. All logistic models are used to estimate predictor's effects. These are summarized as odds-ratios. The odds ratio is a measure of effect which can be interpreted as the fold change in probability of a presence when estimated with and without the predictor of interest. Consequently, an OR > 1 indicates that the presence of the predictor of interest increases the probability of observing a certain damage; while an OR < 1 indicates that the presence of the predictor decreases the probability of observing a certain damage.

The effect of depth and distance from the coast on the number of marine debris items was also analyzed using a Poisson regression model with mixed effects and with adjusted coefficients. The number of items observed can be naturally assumed to arise from a Poisson distribution. The logarithm of the expectation of this Poisson distribution was once again assumed to be a linear function of predictors (i.e., depth and distance from the coast), associated with fixed effects, and to have a Gaussian distributed dive-specific intercept.

The software R version 2.14 was used to carry out this analysis, in combination with package lme4, which is an R package for fitting and analyzing linear, nonlinear and generalized linear mixed models.

3. Results

3.1. Abundance and distribution of debris

6.03 km^2 of rocky bottom were explored by means of 69 video transects in 26 areas of the three regions (Table 1). The initial and final depth of each transect varied between 30 and 300 m, depending on the geographical characteristic of each location. The length of each transect varied between 100 and 900 m.

A total of 3018 photos were analyzed and 368 benthic marine debris items were recorded. The number of areas without any sign of debris was negligible.

The highest median value of debris abundance was found in Campania (0.12 debris m^{-2}, ranging from 0.02 to 0.16 debris m^{-2}), while the lowest value was recorded in Sardinia (0.03 debris m^{-2}, 0.01–0.09 debris m^{-2}). Sicily showed the widest range of debris abundance (0–0.3 debris m^{-2}) and the median value of abundance was 0.09 debris m^{-2} (Figs. 2A and 3). Significant differences of debris abundance were recorded between Sardinia and the other two regions (Kruskal–Wallis $H = 8.9487$, $p < 0.05$; post hoc Nemenyi test $p < 0.05$; Fig. 2A). Similar results were obtained considering only the lines (post hoc Nemenyi test $p < 0.01$) (Fig. 2B).

The distance of the surveyed sites from the coast ranged from 0.065 to 16 NM. Bivariate Poisson regression models showed that only the presence of lines was function of the distance from the coast ($p < 0.001$ and O.R. = 1.2), while the presence of plastic was related to the depth ($p < 0.001$ and O.R. = 2.48).

Overall, fishing gears were the dominant source of debris (89%): lines made up the most significant portion (62.5%), followed by nets (24.4%) and pots (2.1%). Plastic and other debris were occasionally found, representing respectively 5% and 6% of the samples. In particular, Sicily showed a higher occurrence of fishing lines (79% of analyzed debris), while in Campania and Sardinia this value was 57% and 55% respectively (Fig. 4).

3.2. Impact of debris

More than half of debris (54.5%) was observed in contact with sessile invertebrates, either covering them (17.2%) or causing abrasion (37.3%). The remaining portion of debris (45.5%) was recorded lying on the bottom (26.2%) or hanging from the rocks (19.3%) without producing any apparent injury to sessile organisms.

The results of logistic model showed that lines and nets carried out the most significant abrasive action (Table 2; Fig. 5B–F), producing the progressive removal of the tissues of entangled organisms. Nets and plastic carried out mainly a covering action (odds ratio value was 1200). Nets, for example, were found snagged on rocks, entangling or covering benthic organisms (Fig. 5B and C), while plastic bags were observed enveloping some organisms. Hanging debris was represented only by nets and lines (odds ratio value 444) (Fig. 5I), while lying debris was made up mainly of glass bottles, cans, tires or rigid sacks (odds ratio value 3156) that generally do not impact the organisms (Fig. 5G and H), but provide a secondary substrate or a refuge for others (e.g. Fig. 5J and K).

The effects of the models estimated for Campania and Sicily were not significantly different, while both were significantly different from the ones found in Sardinia for all the impact typologies, in particular for hanging debris (Table 3).

Ischia site (c5) in Campania and other three banks (sc3, sc5, sc7) in Sicily were the areas with the greatest relative abundance of debris determining a heavy impact (covering and abrasion action) on the organisms, as showed in Fig. 3.

Gorgonians were the most commonly affected organisms (53.0%), followed by red coral (23.5%), antipatharians (14.3%), sponges (6.0%) and other invertebrates (3.2%). This pattern was similar, but with a specific composition for the three regions (Table 4). The areas explored in Campania were characterized by coralligenous outcrops. Here, the large amount of debris, mainly lines and nets, abraded and covered especially the common gorgonians *Paramuricea clavata* (Risso, 1826) and *Eunicella cavolinii* (Koch, 1887) (≈73%) (Fig. 5B). In Sardinia, a greater number of different taxa were affected (Table 4). In Sicily, the most impacted

Table 1
Areas assessed for the presence and effects of debris to rocky benthic communities of the Tyrrhenian Sea. Location, number of transect, geographical position and depth range.

Region (year)	Area	ID	No. transects	Lat	Long	Depth range (m)
Campania (2010)	Amalfi	c1	4	40° 36.4′ N	14° 31.5′ E	30–180
	Li Galli	c2	2	40° 34.6′ N	14° 25.7′ E	50–115
	Nisida	c3	2	40° 45.3′ N	14° 08.3′ E	40–110
	Ischia AMP	c4	2	40° 41.5′ N	13° 53.6′ E	40–120
	Ischia	c5	3	40° 41.3′ N	13° 53.6′ E	60–150
	Procida	c6	2	40° 41.8′ N	14° 02.2′ E	200–300
Sardinia (2011)	Capo Boi	s1	3	39° 06.6′ N	9° 25.7′ E	70–290
	SW Cavoli	s2	4	39° 04.1′ N	9° 29.4′ E	90–150
	Villasimius	s3	2	39° 05.4′ N	9° 28.3′ E	50–150
	Porto corallo	s4	6	39° 22.7′ N	9° 41.2′ E	70–275
	Capo Palmeri	s5	2	39° 37.4′ N	9° 40.8′ E	90–150
	Torre delle Stelle	s6	2	39° 07.3′ N	9° 23.9′ E	40–130
	Carloforte	s7	5	39° 07.1′ N	8° 08.2′ E	70–130
	Stella Maris	s8	2	38° 59.8′ N	8° 07.7′ E	150–200
	Punta delle Oche	s9	2	39° 14.3 N	8° 16.7′ E	60–90
	Secca di Capo Teulada	s10	1	39° 44.3′ N	9° 06.1′ E	80–100
	Bancotto	s11	3	38° 41.3′ N	8° 29.5′ E	130–140
	Isola del Toro	s12	5	38° 50.9′ N	8° 21.6′ E	70–130
Sicily (2011)	Favignana	sc1	1	37° 53.1′ N	12° 18.2′ E	50–60
	Banco dei Pesci	sc2	2	38° 06.2′ N	12° 13.3′ E	80–120
	BancoScuso	sc3	2	38° 13.2′ N	12° 33.3′ E	70–140
	Zingaro	sc4	3	38° 11.4′ N	12° 46.2′ E	30–140
	Porcelli	sc5	2	38° 02.8′ N	12° 25.3′ E	80–120
	P.ta San Vito lo Capo	sc6	4	38° 10.6′ N	12° 42.4′ E	100–250
	Banco Marco	sc7	2	38° 16.9′ N	12° 21.9′ E	200–270
	Banco Marettimo	sc8	1	38° 01.3′ N	12° 00.9′ E	70–110

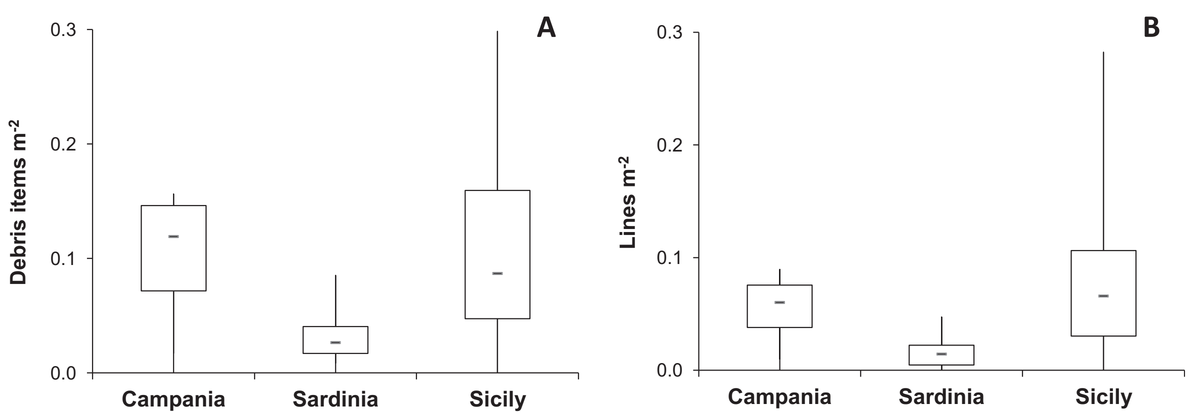

Fig. 2. (A) Debris relative abundance (debris items m^{-2}) and (B) Line relative abundance (lines m^{-2}) in the three investigated regions. Black rectangles indicate median values, boxes indicate first and third quartiles and lines indicate the range between minimum and maximum values.

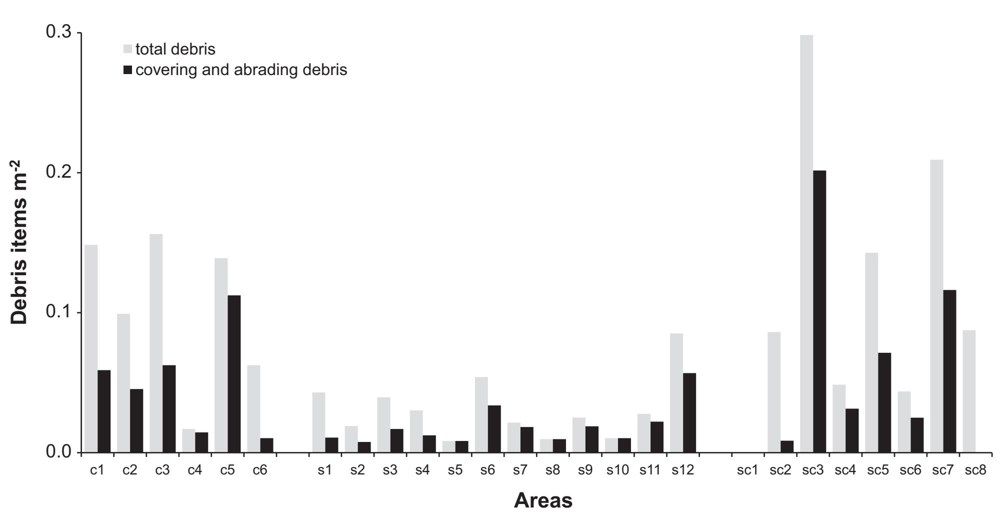

Fig. 3. Relative abundance (debris items m^{-2}) of total debris items (grey) and relative abundance of covering and abrading items (dark), in each investigated area of the three regions.

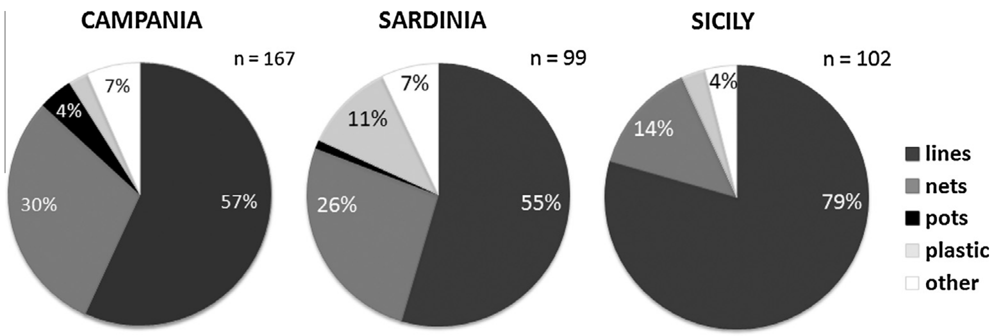

Fig. 4. Frequency of occurrence of marine debris items found in each region by debris category. "n" refers to the total number of debris items recorded in each region.

Table 2
Results of mixed logistic models for presence/absence of damages in each sampling unit. Results are grouped by damage (outcomes) and the relationship with debris types is investigated. The larger the Odd Ratio (OR), the stronger the impact of the debris type on the specific damage. For all tests, $p < 0.0001$.

Damage	Debris types	OR	C.I. 95%	
Abrasion	(Intercept)	0.0011	0.0004	0.0030
	Lines	846.6	303.3	2362.8
	Nets	38.7	10.5	142.9
Covering	(Intercept)	0.0008	0.0003	0.0027
	Nets	1756.1	505.7	6097.5
	Plastic	128.8	22.3	743.9
Hanging	(Intercept)	0.0002	1.68E-05	0.0017
	Lines	1200	120	12043
	Nets	444	42	4717
Lying	(Intercept)	0.0011	0.0004	0.0030
	Lines	126.4	48.4	329.9
	Nets	98.0	31.3	307.1
	Plastic	393.4	77.3	2002.0
	Others	3156	556	17911

species was the black coral *Antipathella subpinnata* (Ellis & Solander, 1896) (52%) (Fig. 5F), such as wide meadows of this species were recorded in some areas.

Several epibionts settled on the bare branches of impacted corals, forming large aggregates. Hydroids were the most common taxa (29%), followed by serpulids (17%), sponges (16%), other anthozoans (13%) and bryozoans (7%). The anthozoan *Alcyonium coralloides* (Pallas, 1766) was often observed forming large colonies mainly on *E. cavolinii*.

Debris items also represented a substrate for other organisms. The majority of debris (80%), in fact, was covered by colonial organisms. Fishing lines showed predominantly moderate colonization (59%), while considerable amount of taxa were observed on nets (Table 5). Sometimes, lost nets still standing in their operative position and potentially still fishing were observed covered by organisms (Fig. 5A). 40% of other debris types showed no colonization.

The most frequent recorded taxa on debris were hydroids (31%), sponges (22%) and polychaetes (16%), followed by bryozoans, anthozoans and ascidians. Polychaetes such as Serpulidae species (*Protula* sp., *Sabella* sp.) were often observed growing on metal cans, pots, or sacks (Fig. 5J, K). Among anthozoans, various alcyonaceans (*Alcyonium acaule* Marion, 1878, *Alcyonium palmatum* Pallas, 1766, *A. coralloides*), actiniarians, scleractinians were commonly observed in association to lost gears. Some gorgonians, as *P. macrospina*, and more rarely *P. clavata* or *E. cavolinii*, were also recorded growing as epibiotic organisms on abandoned waste (nets or hard debris) or on dead portions of other corals. The basket star *Astrospartus mediterraneus* (Risso, 1826) was also observed on lost nets (Fig. 5C). Differences among regions were observed in the percentage of occurrence of epibiont taxa and species composition.

Besides sessile species, debris was utilized as habitat by numerous fish (e.g. *Anthias anthias* (Linnaeus, 1758), *Callanthias ruber* (Rafinesque, 1810), *Muraena helena* Linnaeus, 1758, *Scorpaena elongata* Cadenat, 1943, *Scorpaena scrofa* Linnaeus, 1758) and vagile benthic species (such as crustaceans, sea-urchins and octopuses) which used their cavities as a refuge or dug in the sediment underneath them.

The logistic model revealed a significant relationship between dead specimens of benthic species and fishing gears as nets ($p = 0.019$ and O.R. = 3.13) and lines ($p < 0.001$ and O.R. = 2.76), while no significant relationship was found with other types of debris (Table 6). Dead specimens were mainly corals, found broken, detached or buried in the sediments. Others were still anchored to the substratum but deprived of branches. Others were observed bare, with patches of living tissue or completely covered by epibiont species. Very few dead specimens were recorded in Sicily. In Campania, dead specimens mainly belonging to *P. clavata* and *E. cavolinii*, were recorded in 67% of the explored areas, particularly in Ischia (c5) and Amalfi (c1). Sardinia showed the highest incidence of dead specimens, belonging to several species such as *P. clavata, E. cavolinii, C. rubrum, V. flagellum* and *C. verticillata*, and recorded in 90% of the explored areas.

4. Discussion

This study highlights a massive and widespread occurrence of anthropogenic debris in the deep rocky environment of the Tyrrhenian Sea, with a substantial inter-regional variability. The lowest abundance of marine debris, recorded in Sardinia is likely related to the small human population living in this region, representing a minor potential source of litter in comparison to more populated regions, such as Campania. This point supports the hypothesis that the occurrence of high concentrations of debris, in proximity to coastal urban areas, is correlated to the size of the surrounding human population (Galgani et al., 1996, 2000; Hess et al., 1999; Mordecai et al., 2011).

In fact, it is possible to observe a positive relationship of debris abundance with the average density of human population in the three surveyed regions (429, 196, 68 inhabitants per km^{-2}, respectively for Campania, Sicily and Sardinia), suggesting a main landbase origin of the recorded debris.

Moreover, the debris abundance estimated in this study are comparable to the ones determined by other authors from urbanized areas (Galgani et al., 2000; Watters et al., 2010; Mordecai et al., 2011; Pham et al., 2013, 2014). Very low values of debris abundance were found only in the Artic region, likely due to the remote nature of this environment (Bergmann and Klages, 2012).

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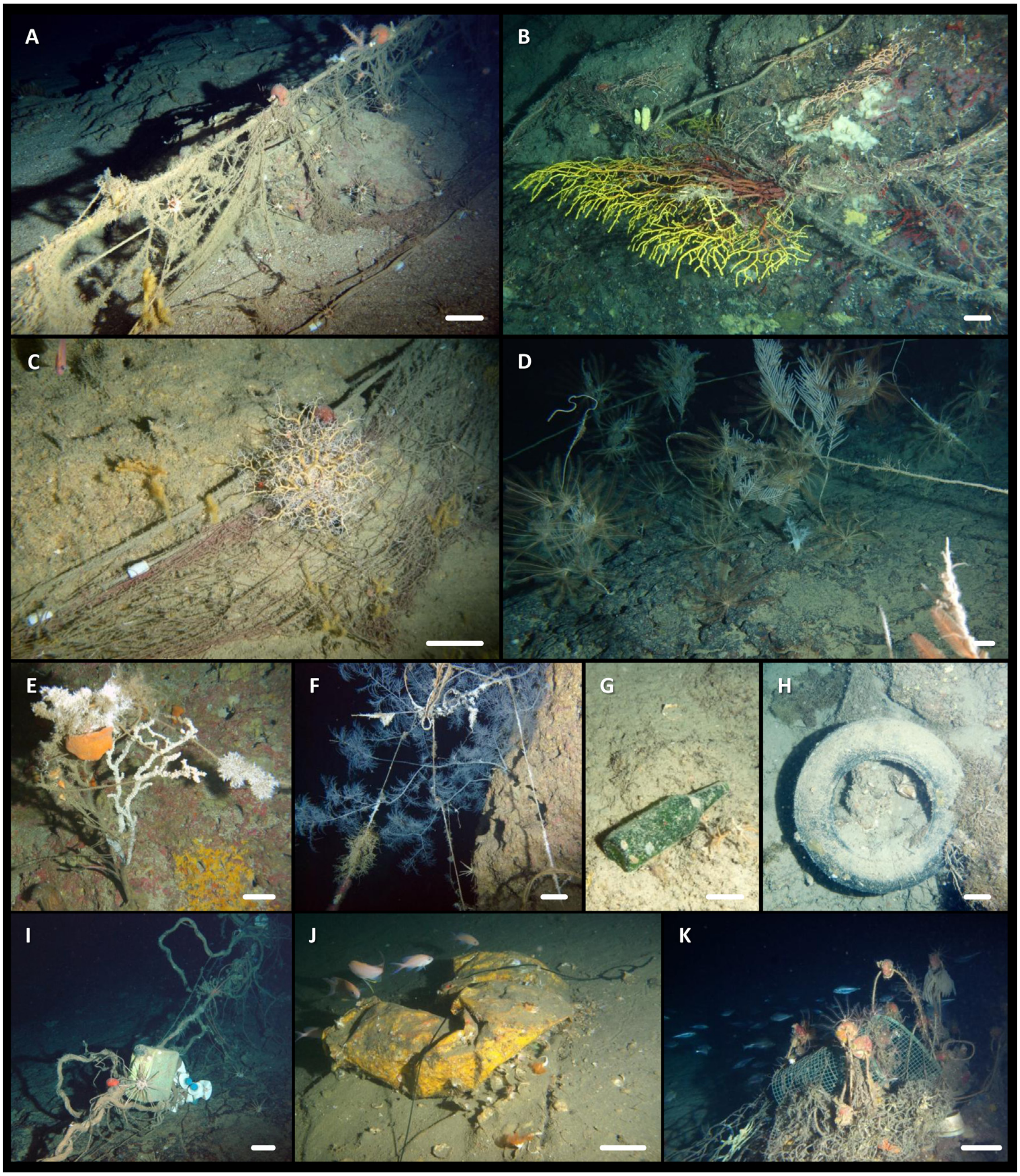

Fig. 5. Impacts of debris and fishing litter on the rocky bottom of the Tyrrhenian Sea. (A) Ghost net covered in various epibionts such as sertulariid hydroids, *Paramuricea macrospina*, *Alcyonium palmatum* and Cidaridae sea urchins (Banco Scuso – sc3, 140 m). (B) An old lost net entangled on a colony of *Paramuricea clavata* and stretching over a mixed assemblage of *Eunicella cavolinii* and *Corallium rubrum* (Ischia – c5, 118 m). (C) Lost net, hosting the basket star *Astrospartus mediterraneus*, entirely wrapping a rocky boulder and stretched over a population of *Paramuricea macrospina* (Banco Scuso – sc3, 120 m). (D) Colonies of *Viminella flagellum* and *Callogorgia verticillata*, hosting the crinoids *Leptometra phalangium*, entangled and pulled by lines (Banco Marco – sc7, 270 m). (E) Old long line entangling a colony of *Savalia savaglia*, peeling off the tissue of the gold coral. *Filograna implexa*, *Poecillastra compressa* and gastropods occurring on its dead parts (Porto corallo – s4, 90 m). (F) Fishing lines entangled on the black coral *Antipathella subpinnata* (Banco Scuso – sc3, 140 m). (G) Encrusted glass bottle (Amalfi – c1, 94 m). (H) Discarded tire and net (Amalfi – c1, 84 m). (I) A hanging rope hosting some specimens of Cidaridae (Banco Marco – sc7, 270 m). (J) A sack laid on the seafloor attracting *Anthias anthias* and other benthic species (Nisida – c3, 77 m). (K) Epibionted net and other litter snagged on a rock (Isola del Toro -s12, 97 m). Scale bar: 10 cm. For interpretation of the references to the areas, the reader is referred to Table 1 and Fig. 1.

A pattern of decreasing debris density is not always correlated with distance from the coast (Watters et al., 2010). Bo et al. (2014) suggested a negative relationship between the density of lost lines and the distance to the coast. A higher number of sites investigated in this study indicates, inside a distance range of 16 NM, a more complex situation. In fact, the presence of rocky banks, which are exploited by commercial fisheries, drive the fishing efforts which result in the presence of fishing debris, mainly lost line, being found far from the coastline. Moreover, differences in the structurally complex rocky habitat of the explored areas affect the probability to find snagged lines (Chiappone et al., 2005; Watters et al., 2010).

Instead, the observed plastic items (bags, bottles, other objects, etc.) show a significant positive relation to depth. In most of the investigated areas, the slope of rocky walls were very steep and high depths were reached relatively close the coast. In this situation, the increase of plastic debris found in the deep habitat could originate by both land-based sources and maritime activities.

Table 3
Results of mixed logistic models for presence/absence of damages in each sampling unit. Results are grouped by damage (outcomes) and the relationship with region of sampling is investigated. For each outcome, regions with larger Odd Ratio (OR) are at higher risk of showing the specific kind of damage with respect to regions with a smaller OR.

Damage	Region	OR	C.I. 95%		*P* value
Abrasion	Campania	0.053	0.025	0.112	<0.001
	Sardinia	0.228	0.087	0.600	0.003
	Sicily	0.845	0.281	2.540	0.765
Covering	Campania	0.029	0.015	0.058	<0.001
	Sardinia	0.289	0.115	0.726	0.008
	Sicily	0.576	0.191	1.740	0.328
Hanging	Campania	0.038	0.019	0.076	<0.001
	Sardinia	0.111	0.039	0.318	<0.001
	Sicily	0.613	0.211	1.782	0.368
Lying	Campania	0.035	0.017	0.070	<0.001
	Sardinia	0.299	0.119	0.750	0.010
	Sicily	1.510	0.565	4.039	0.412

Table 4
Percent frequency (%) of taxa impacted by debris (T) and taxa occurrence (frequency of taxa respect to the total regional frames, F) in each investigated region.

Taxa	Campania (%)		Sardinia (%)		Sicily (%)	
	TI	F	TI	F	TI	F
PORIFERA						
Aplysina cavernicola	4.7	6	–	–	–	–
Poecillastra compressa	–		14.5	7.9	–	–
ANTHOZOA						
Chironephthya mediterranea	–		–	0.6	3.6	0.8
Acanthogorgia hirsuta	–		–	1.3	–	5.2
Corallium rubrum	22.7	56	47.3	38	1.8	5.6
Eunicella cavolinii	41.5	64	5.4	16	3.6	11
Eunicella verrucosa	–	0.4	–	1.9	1.8	0.1
Viminella flagellum	–	–	5.5	4	–	0.4
Bebryce mollis	–	–	3.6	1.8	–	2
Paramuricea clavata	30.2	24	7.3	1.9	12.5	11
Paramuricea macrospina	–	4	–	0.8	7.1	14
Callogorgia verticillata	–	0.3	9.1	12	14.3	7.5
Antipathes dichotoma	–	–	1.8	1.5	–	–
Leiopathes glaberrima	–	–	1.8	6.1	–	–
Antipathella subpinnata	–	0.1	–	3.7	51.8	13
Ceriantharia	0.9	0.3	–	–	3.5	3
Dendrophyllia cornigera	–	0.4	1.8	2.6	–	–
Savalia savaglia	–	0.1	1.9	0.3	–	–

However, the extensive spatial variation of waste may be related to hydrographical factors as well as to geomorphologic factors (Galgani et al., 2000; Mordecai et al., 2011), which are likely responsible for the transportation and accumulation of marine debris at greater depths (Galgani et al., 1996).

On the basis of previous studies, plastic items are generally considered the most diffused marine debris (Galil et al., 1995; Galgani et al., 1996, 2000; Law et al., 2010; Miyake et al., 2011). The data in this study indicate that the evidence of these type of debris can be biased on the kind of explored sea bottom and the employed methods (Watters et al., 2010) such as the selective exploration of bottoms exploited by trawling nets (Galgani et al., 1996). On the contrary, the use of alternative investigative methods (e.g. submersibles, ROVs), allow researchers to assess the abundance and type of general debris found on structurally complex rocky banks (Chiappone et al., 2005; Keller et al., 2010; Watters et al., 2010; Mordecai et al., 2011), that are particularly subjected and impacted by recreational and professional fishing pressure (Bo et al., 2013).

In this study, in fact, the occurrence of debris is mainly caused by fishing gears, particularly lost lines, which represent about a half of all debris found in Campania and Sardinia. While in Sicily, this value reached about 80%. The explored off-shore deep rocky banks in Sicily host numerous commercially relevant fishing stocks, that attract local recreational and professional fishing boats (Bo et al., 2013), likely responsible for the great abundance of lines found in this area. However, this pattern of debris composition is comparable with ones recorded by other authors. For example, Chiappone et al. (2002, 2004, 2005) studied shallow areas of Florida, where fishing gears, mainly lines, contributed to up to 90% of the total quantified litter. In deep areas, similar results were obtained by Watters et al. (2010) off the coasts of California, and by Bo et al. (2014) in five Tyrrhenian banks. The above findings highlight that fishing litter may be predominant in areas characterized by intense fishing activities, such as the western Mediterranean Sea (Mordecai et al., 2011). Moreover, it can take up to six hundred years to decompose a nylon line (Bianchi et al., 2004). Consequently, dangerous synthetic debris appears to be fishing gears, which can cause entanglement and also break down over time into dangerous fragments that can be ingested by organisms (Laist, 1987). Therefore, the wide distribution of this debris represents an important source of perturbation on the Mediterranean sensitive ecosystem.

All the explored sites hosted coral and sponge aggregations that have now been internationally identified as special ecological features that require protection under the Convention of Biological Diversity (Aguiliar and Marín, 2013). Fishing litter in the studied areas had a major impact on these benthic communities, mainly on the arborescent large coral colonies, that are easily snagged by derelict gears. More than half of the recorded debris seriously impacted the benthic organisms by covering and abrading their tissues (Fig. 4). These results are consistent with Bo et al. (2013, 2014) findings, indicating that lost lines affect 30% of arborescent corals found in the deep Tyrrhenian rocky banks. Chiappone et al. (2005) have found that lost lines were responsible for damaging 84% of all sponges and benthic cnidarians in the Florida Keys National Marine Sanctuary.

Yoshikawa and Asoh (2004) have demonstrated that older cauliflower coral colonies, with large surface areas have a greater risk of entanglement compared to smaller younger colonies. Some of the most damaged specimens in this study were erect filter feeders composed of tall and branched colonies (as the octocorals *P. clavata*, *E. cavolinii*, *C. verticillata*, *C. rubrum* and the antipatharians *A. subpinnata, Antipathes dichotoma* and *Leiopathes glaberrima*). Coral skeletal characteristics, such as stiffness and flexibility of a colony, are known to play an important role in the resistance of friction, which explains the different responses of protein-based gorgonians or chitinous-based antipatharians to mechanical impacts (Bo et al., 2013). Due to their elastic skeletons, *E. cavolinii* gorgo-

Table 5
Percent frequency (%) of colonization degree on different debris types (lines, nets and other debris) and on all debris (tot) by macro-benthic invertebrates in each surveyed region.

Fishing gear	Campania (%)				Sardinia (%)				Sicily (%)			
Colonization	Line	Net	Other	Tot	Line	Net	Other	Tot	Line	Net	Other	Tot
None	9.5	0.0	35.0	9.7	33.3	3.8	46.7	27.4	34.6	0.0	50.0	30.7
Moderate	44.2	34.0	25.0	38.8	42.6	30.8	46.7	40.0	44.4	50.0	50.0	45.5
Heavy	46.3	66.0	40.0	51.5	24.1	65.4	6.6	32.6	21.0	50.0	0.0	23.8

Table 6
Results of mixed Poisson regression models for the number of dead specimens in each sampling unit as a function of the debris type detected. The coefficients can be interpreted as the expected additional number of dead specimens that are due to each debris type. For all tests, $p < 0.0001$.

Debris types	Coefficient	C.I. 95%	
(Intercept)	0.016	0.011	0.024
Line	3.13	1.72	5.69
Net	2.76	1.18	6.46
Plastic	2.75	0.28	26.86

nian colonies were rarely broken but were found to be covered by epibionts (mainly the fast-growing parasitic alcyonacean *A. coralloides*). Colonies of *P. clavata* were recorded as being detached and buried in the sediment; thus, showing the typical arborescent morphology, and were rarely found with broken branches. The resistant skeleton of black coral allows this taxa to hold out against mechanical friction that normally only scrapes the soft tissue of the branches. As a consequence, these corals were frequently observed partially covered by epibionts, but were rarely found having broken branches or being completely overgrown. On the contrary, numerous branching fragments of *C. verticillata*, known as being very breakable (Bo et al., 2013), were often observed lying on the sea bottom, as also reported by Fabri et al. (2014).

In this study, 30% of the observed coral colonies in contact with debris, showed traces of epibiosis of up to nine different taxa of sessile invertebrates. Opportunistic fast growing species, such as hydroids, polychaetes, sponges and bryozoans were widely found on dead coral branches. Corals are capable of rapidly healing small lesions. But in cases of more extensive damage or under the frequent occurrence of physical stress, recovery may be difficult (Bavestrello et al., 1997; Yoshikawa and Asoh, 2004) and the development of aggregates of epibionts can lead to the death of colony portions (Mistri, 1994). Then, once caught by a fishing gear, the probability of death of a colony can be very high (Yoshikawa and Asoh, 2004). The positive correlation between the number of dead colonies and the presence of lost gears in the habitat indicates the destructive effects of fishing activities. This point is particularly relevant considering the longevity and slow growing rate of these coral species, which make them more susceptible and vulnerable.

Other ROV surveys in the western Mediterranean (Orejas et al., 2009; Madurell et al., 2012; Watremez, 2012; Bo et al., 2013, 2014; Fabri et al., 2014) have highlighted the widespread presence of how fishing has impacted all the investigated areas, which reduces the coverage of these habitat-forming taxa and lastly the diversity and abundance of associated invertebrates and fish. The decline in these communities may lead to the significant modification in the structure and functioning of deep ecosystems whose consequences are still not clear.

Despite debris is harmful to biota altering the seafloor, these anthropogenic materials can also provide artificial substratum for sessile organisms (Watters et al., 2010; Miyake et al., 2011). In this study, the majority of debris (80%) was colonized quite heavily by encrusting invertebrates. Nets, usually occurring as large agglomerates, showed the highest frequency of epibiosis (66%), probably due to their greater surface with respect to single strands of nylon or other debris.

Hydroids, as well as encrusting sponges, observed growing on all types of debris were the most frequent fouling taxa, as already recorded by De Palma (1983) and Montanari et al. (1990). It is known that, due to their fast growth rates, they are among the pioneering species, capable to completely colonize artificial substrates and enhance the settlement of other organisms (Ardizzone et al., 1989), incorporating debris items into the habitat matrix.

Few debris, which did not show any sign of colonization, may have been discarded or lost relatively recently. The fouling extent may give an indication to the age of lost gear (Saldanha et al., 2003), considering that the most heavily encrusted debris is presumably of older origin (Donohue et al., 2001). However, debris may show different species-specific variations in abundance of fouling organisms, depending on material, geography, depth and/or season (Saldanha et al., 2003).

The presence of marine litter, used as substratum or as refuge by organisms, can increase both the number of species and the total abundance of individuals in a specific habitat (Katsanevakis et al., 2007) altering the natural community structure, modifying the spatial heterogeneity (Saldanha et al., 2003) and in some cases enhancing the settlement of non-indigenous species (Mordecai et al., 2011). Therefore, although apparently the presence of marine litter can increase diversity, this alteration contrasts with the principle of habitat and biodiversity conservation and sustainability (Katsanevakis et al., 2007).

The results here presented can provide a baseline for future monitoring efforts, as well as a quantitative assessment, useful to motivate adequate managerial actions. Further studies are necessary to reach a more comprehensive and precise understanding of litter distributions. Moreover, mapping the abundance of coral communities remains a necessary step in order to quantify the threats to which these characteristic environments are exposed.

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