MARINE LITTER POLLUTION ASSOCIATED WITH HYDROTHERMAL SITES IN THE AEOLIAN ARCHIPELAGO (WESTERN MEDITERRANEAN SEA)

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Abstract

The Aeolian Archipelago, in the western Mediterranean Sea, is an active volcanic arc hosting several hydrothermal sites. This area, considered a Vulnerable Marine Ecosystem by The Food and Agriculture Organization because of its ecological importance and biodiversity value, is affected by various pressures and threats that may act as sources of marine litter. The aim of this paper was to analyse the composition and distribution of marine litter on the seafloor of this archipelago with a specific focus on the hydrothermal areas, using almost 60 hours of remotely operated vehicle footage collected at depths of 15 to 411 m. Derelict fishing gear represented the main source of marine debris (71.9% of the overall litter); nevertheless, the observed mean litter density was quite low (0.57 items/100 m^2) when compared with other Mediterranean areas, probably because fisheries in the area mainly use pelagic gear that has a low impact on the seabed. No differences were found in litter densities between hydrothermal and non-hydrothermal zones. The occurrence of benthic fauna impacted by debris was rarely recorded (only 10.6% of litter items showed interactions with species) and entanglement was the most commonly observed impact. However, both the density of synthetic fishing gear and its impact on habitats and species are bound to increase over time. Overall, plastics constituted most of the marine litter (79.7%). So, prevention and mitigation measures are needed in order to protect this sensitive ecosystem. To this end, the most effective strategy could be the establishment of a Marine Protected Area or a Site of Community Importance, due to the presence of habitats ("submarine structures made by leaking gases" and "reefs") listed in Annex I of the European Habitats Directive, where all fishing activities could be strictly regulated.

Graphical Abstract

Seafloor marine litter composition in hydrothermal sites

Litter density ranged from 0 to 2.6 items/100 m^2 (mean = 0.57 (±0.08) items/100m^2)

Highlights

- The Aeolian Archipelago hosts important hydrothermal vents and sites.
- Litter density ranged from 0 to 2.6 items/100 m^2 with a mean of 0.57 items/100 m^2.
- Derelict fishing gear represented 71.9% of the overall litter density.
- Prevention and mitigation measures are needed to protect this vulnerable ecosystem.

Keywords: Seafloor marine litter; Hydrothermal habitat; ROV; Derelict fishing gear; Plastics; Aeolian archipelago

1. Introduction

Pollution by anthropogenic litter represents one of the most worrying threats to the marine ecosystem of recent decades (Galgani et al., 2015; Ryan, 2015; Thompson, 2015; Rangel-Buitrago et al., 2020). The marine ecosystem is particularly vulnerable owing to direct pollution from sea-based activities and indirect pollution from land-based sources through estuaries, sewage discharge, tides, currents, winds, waves and in any case as a consequence of inadequate human actions and improper debris management (Coe and Rogers, 1996; GESAMP, 2019; Stachowitsch, 2019; UN, 2019).

When debris reaches the sea, a large part inevitably sinks to the seafloor, the ultimate site for the accumulation of most global marine litter (FAO, 2010; Courtene-Jones et al., 2017), which has serious impacts on the surrounding ecosystem. These impacts include covering, smothering, and entangling sponge grounds and coral gardens (Kühn et al., 2015; Sheehan et al., 2017; Hinz, 2017; Galgani et al., 2018; Consoli et al., 2019, 2020a), providing an artificial substrate that may lead to a change in the diversity of benthic fauna (Mordecai et al., 2011), limiting gas exchange and producing anoxia (Moore, 2008), being ingested by organisms (Bellas et al., 2016; Fossi et al., 2018) and transferring toxic compounds (Teuten et al., 2007; Tanaka et al., 2013).

Litter of any size (at nano, micro, and macro scales) can reach all marine compartments, from shorelines to pelagic and benthic habitats, even those that are most remote and inaccessible such as the Arctic and Antarctic (Bergmann and Klages, 2012; Bergmann et al., 2017; Munari et al., 2017), or deep canyons and abysses (Chiba et al., 2018; Pierdomenico et al., 2019). The Mediterranean Sea, being a semi-closed basin, is one of the most impacted marine areas in the world, recording the greatest densities of marine litter on the seafloor (Bergmann et al., 2015; Cózar et al., 2015; UNEP/MAP, 2015), which may reach values of 43.55 items/100 m^2 (Consoli et al., 2020b).

Recently, thanks to the use of underwater visual techniques (performed by remotely operated vehicles (ROVs), towed cameras, submersibles, scuba diving), it has become possible to document the impact of benthic litter at sensitive sites such as Ecologically or Biologically Significant Area (EBSAs) and Marine Protected Areas (MPAs) (Consoli et al., 2018b, 2019, 2020a; Vlachogianni, 2019), although there is no information yet on this kind of pollution in other sensitive marine ecosystems, such as shallow or deep hydrothermal vents.

Active hydrothermal vents are valued worldwide because of their biodiversity and are considered Vulnerable Marine Ecosystems (VMEs) by the Food and Agriculture Organization and Regional Fisheries Management Organisations (FAO, 2019). Many hydrothermal vents around the world, especially deep-sea ones, are subjected to Area-Based Management Tools (ABMTs) defined as spatial closures that offer a degree of protection greater than that of the surrounding area (e.g., MPAs, Sites of Community Importance/Special Areas of Conservation - SCI/SACs; Marine Parks; Menini and Van Dover, 2019). Canada, Mexico, Portugal, Japan, New Zealand, the United States and others have created MPAs to protect deep-sea vent ecosystems. For example, some Azorean deep-sea thermal areas have been identified as SACs under Annex I of the European Habitats Directive (European Commission, 1992) due to the presence of ‘Submarine structures made by leaking gases’ (habitat code 1180) or Reefs (habitat code 1170). The extraction of minerals and other geological disturbances are forbidden, while tourist activities are limited to scuba diving under specific conditions (Aguiar and Costa, 2010).

The only protected hydrothermal site in the Mediterranean Sea, is represented by the Thalassia Periochi Koloumvo SCI (Greece), which is characterized by chimneys and vents (with fluids up to 220°C).

The Aeolian Archipelago, located in the central Mediterranean Sea, consists of seven volcanic island-building (Lipari, Alicudi, Salina, Vulcano, Panarea, Filicudi and Stromboli) and five islets (Dattilo, Lisca Nera, Lisca Bianca, Basiluzzo and Bottaro). The archipelago is a volcanic arc located about 10 miles from the northern coast of Sicily (south Tyrrhenian Sea - western Mediterranean Sea) and represents one of the largest areas in the whole Mediterranean where this type of gas seep is active (Esposito et al., 2018). The Aeolian archipelago was formally identified under Italian law as a site of a future MPA in 1982, due to its high diversity of species and habitats (Álvarez et al., 2019). Moreover, in 2000, the Aeolian Islands were declared as a World Heritage Site by UNESCO for their outstanding universal value, based on their vulcanological characteristics. As a result of volcanic activity, the seafloor, especially around the islands of Panarea and Vulcano, hosts hydrothermal vents that play an essential role in several processes occurring on the seabed.

However, the entire area is affected by several pressures and threats such as shipping, fishing activities, and high volume of tourism (Andaloro, 2005; Battaglia et al., 2010) that may act as sources of marine litter (Sheavly et al., 2007), threatening species and habitats.

The presence of marine microplastic' pollution has recently been reported in sediments and benthic species (sea cucumbers) sampled at several rocky habitats off Salina island (Fastelli et al., 2016; Renzi et al., 2020), while Blasi et al. (2016) studied the occurrence of floating marine litter related to the use of Fishing Aggregating Devices (FADs), which are well known as a source of floating and seafloor marine litter (Consoli et al., 2020a; Sinopoli et al., 2020).

According to the European Marine Strategy Framework Directive 2008/56/EC (MSFD European Commission, 2008), the marine environments of all member states should have attained Good Environmental Status (GES) by 2020, evaluated using 11 descriptors. Within Descriptor 10, marine litter, criterion D10C1 focuses attention on the amount, composition, spatial distribution, and sources of litter deposited and accumulated on the sea bottom.

In light of this, the present study aims to respond to the MSFD by analysing the amount, composition, and distribution of marine debris on the seafloor of the Aeolian Archipelago with a specific focus on the hydrothermal area, using large amounts of ROV footage. This research also provides some management suggestions for measures and mitigating actions to assure the protection and preservation of this important environment.

2. Material And Methods

2.1 Study area

The surveyed area included the seafloor surrounding four Aeolian Islands (Panarea, Vulcano, Salina, and Alicudi). The area that was most extensively explored was the seabed of Panarea and surrounding islets, in the eastern sector of the archipelago (Fig. 1).

Panarea is an asymmetric volcanic edifice, almost flat at its summit, while sloping at a steep angle on the south-eastern flank and more gently on the others sides (Anzidei et al., 2005). The entire area is characterized by active tectonic structures, such as a NNE-SSW, NE-SW trending graben, with gas venting commonly observed at the base and the top of the related faults (Gamberi et al., 1997).

The swath bathymetry acquired and the ROV video footage showed different geomorphological and volcanic features. In the north-eastern continental shelf and slope, separated by a volcanic rock edge (90-95 m depth), the bottom (from 85 to 150 m deep) is almost totally covered by volcanoclastic sedimentation, usually in the form of Fe-rich crusts (Gamberi et al., 1997). These crusts are widely colonized by the tubicolous *Ampelisca ledoyeri* (Fig. 2a; Esposito et al., 2015) and interrupted by large assemblages of ostreomorph molluscs (*Neopycnodonte cochlear*) or outcropping rocks and vertical walls hosting precoralligenous and coralligenous biocenosis (A.A.A., 2016). According to Bortoluzzi et al. (2017), along the steep slope, dissected by gullies and channels and largely dismantled by erosion, sulfide deposits, fields of small relict and collapsed chimneys and Diffusive Ferruginous Seeps (DFS; Fig. 2b and 2c) can be observed. The seabed south of the islet of Basiluzzo is characterized by the presence of gas venting from big chimneys in the “Smoking land”, at a depth of 70-80 m, (Esposito et al., 2018), and by the coarse sediments of the shallower areas surrounding the archipelago of the islets of the Panarea caldera (Fig. 2d). Finally, the “Secca dei Pesci” shoal, located on the south-eastern margin of the Panarea platform, shows strong exhalative activity on the top and a rocky edge colonized by facies at *Eunicella singularis*.

Regarding Vulcano and Salina islands, in the central area of the archipelago, two bays located along the North-eastern coast of Vulcano (depths of 26 to 135 m) and the shoal “Secca del capo”, located to the north-east of Salina (Fig. 1), were explored. The seafloor of the Vulcano bays is a detritic bottom with bio-concreted outcropping rocks on the continental shelf, becoming steep and rocky all along the slope, where colonies of gorgonians and antipatharians were observed. The “Secca del capo” is a submarine shoal comprising two cones of volcanic origin with flat-tops that rise to 250 m (western cone) and 27 m (eastern cone) (Gamberi et al., 1997). The ROV images showed large boulders colonized by Cidaridae and somewhere concreted by *N. cochlear*, interrupted by detritic bottoms and rhodolith associations. Coralligenous biocenoses and sulfur deposits of hydrothermal origin could also be observed along the steep slope.

Finally, the western coast of Alicudi was explored, in the western sector of the Aeolian archipelago (Fig 1). Bathymetries from 30 to 160 m are characterized by a biodetritic seafloor with rhodolith associations and volcanic pinnacles widely colonized by sponges, gorgonians, and antipatharians. At the deepest bathymetries explored (to 290 m) the silty fraction increased, and rocky bottoms of lava flow origin were also observed.

2.2 Field sampling methods

Quali-quantitative assessment of the abundance of marine macro-litter (>25 mm in the longest dimension) on the seafloor of the Aeolian Archipelago was carried out using an opportunistic approach (Galgani et al., 2018): we used a large amount of ROV footage, collected during several expeditions carried out in the area (from 2010 to 2015) and originally aimed at investigating the biodiversity associated with these hydrothermal sites, to evaluate also litter abundance. All surveys were conducted with the same research vessel, "Astrea", belonging to the Italian National Institute for Environmental Protection and Research. Underwater observations were performed by the same equipment and operator. The ROV ("Pollux III" Global Electric Italiana) was equipped with several instruments, as previously described by Consoli et al. (2019).

2.3 Video and data analysis

The ROV track data were handled using ArcGIS 10.3 software: before estimating the transect length, all XY points were converted to track lines that were smoothed using the PAEK (Polynomial Approximation with Exponential Kernel) algorithm. The width, corresponding to the visual field of the ROV 1.5 m above the seafloor, was calculated through the metric scale provided by the laser pointers. The area of the explored surface was calculated by multiplying the length by a width of 2 m, as already defined by Consoli et al. (2019), and the debris abundance was standardized to 100 m^2 (n. debris items/100 m^2) in order to obtain the density values. Photos and video footage were examined to identify all litter items within this surface.

2.4 Statistical analysis

Non-parametric multivariate analysis was applied to the litter density matrix (n. debris items/100m^2) to assess differences in distribution between hydrothermal and non-hydrothermal areas, taking into account all the explored sites. A one-way PERMANOVA analysis was performed, initially considering all the twelve debris categories identified and then merging litter items into two main groups as previously described by Consoli et al. (2019): fishing gear (FG), including all the debris that could be related to fishing gear, and general waste (GW), which included all the other identified debris categories. Data were square-root transformed and analysed based on Gower distance, with 4999 permutations used. Gower distance was deemed the most suitable for data which are generally skewed and contain many zeros (Gower, 1971; Anderson et al., 2008). The same analysis was performed on the densities data matrix of litter recorded in hydrothermal areas only, to assess differences in the bathymetric distribution, considering four strata (0-50 m; 51-100 m; 101-150 m; >151 m). In addition, pair-wise comparisons were performed when significant differences ($p<0.05$) among levels of factor "depth" were found. Finally, SIMPER (SIMilarityPERcentange) test was used to reveal which debris category most contributed to variations in the spatial and bathymetric distribution. All analysis was performed using the statistical software applications PRIMER6 & PERMANOVA+ (Clarke and Warwick, 2001; Anderson et al., 2008).

3. Results

Overall, 53 video transects with lengths of between 59 and 2070 m, were recorded on the Aeolian Islands seafloor, at depths from 15 to 411 m. The ROV covered a total distance of approximately 24 km and recorded 59:18 h of video footage. The density of marine debris fluctuated from 0 to 2.6 items/100 m^2 (Dive 51) with a mean density (±standard error, SE) of 0.57 (±0.08) items/100 m^2. The characteristic of each transect with debris density values are shown in Supplementary Table S1.

3.1 Percentage composition of marine litter

A total of 320 litter objects were observed and identified in the whole area. Overall, the marine debris was mainly composed of the plastics/polymers category (fishing gear, beverage bottles, etc.), which represented 79.7% of the total number of overall observed items, followed by metal (9.1%), and glass/ceramics (6.6%; Fig. 3).

Fishing activities represented the major cause of debris in the archipelago, with 71.9% of litter items being related to fishing, whereas GW represented the remaining part. Among items of “fishery-related debris”, or ALDFG (Abandoned, Lost or otherwise Discarded Fishing Gear), “fishing line” was the most abundant category (52.2%), followed by “fishing rope” (12.8%). The category “GW” was mostly composed of plastic objects (8.44%), such as beverage bottles, cleaner bottles, buckets and jerrycans, and metal objects (9.06%) that were mostly represented by beverage cans (Tables 1 and 2).

The top ten marine litter items identified, listed in Table 2, represented about 80% of the overall observed debris. Among plastics, Single-Use Items (SUPs) represented 6.6% of the total observed debris and, among these, plastic beverage bottles made of polyethylene terephthalate (PET) were the most abundant (38.1%; Table 2).

3.2 Statistical analysis

PERMANOVA analysis showed no significant differences between hydrothermal and non-hydrothermal areas when taking into account both the densities of all the debris categories identified and that of the litter items merged into the two macro-categories FG (average density = 0.59 and 0.56 items /100 m^2, respectively, in hydrothermal and non-hydrothermal areas) and GW (average density = 0.19 and 0.22 items /100 m^2, respectively, in hydrothermal and non-hydrothermal areas). The same results were found in respect of the bathymetric distribution of the twelve debris categories observed in the hydrothermal areas only. However, PERMANOVA indicated significant differences in FG and GW distribution for factor “depth” ($F_{3,35} = 2.4009$; $p > 0.05$). Pair-wise comparisons revealed the stratum “51-100 m deep” differed from the strata “101-150 m” and “> 151 m”, mainly ascribable to the density of FG, which showed the highest values at depth of 51-100 m (FG average density: 0.58; SIMPER).

3.3 Litter-fauna interactions

Litter-fauna interactions were encountered rarely, since only 10.6% of litter items (34 items) showed interactions (at least one contact) with species of the benthic fauna. Entanglement was the most commonly observed impact, and in one case a lost net, still in good conditions (ghost fishing), caused a specimen of *Calappa granulata* to be caught (Fig. 4 b). In another case, a derelict trawl net covered a large patch of coralligenous biocenosis and associated species (Table 3).

The organisms most commonly observed to colonize litter objects included hydroids, algae and ophiuroids (*Astrospartu mediterraneus*). However, some small assemblages of *N. cochlear* were also found, as well as specimens of polychaetes (*Filograna/Salmacina* spp. and serpulids) and some ascidiaceans (Fig. 4).

4. Discussion

The present study evaluated, for the first time, the seafloor marine litter in the Aeolian Archipelago using a ROV.

Fishing constituted the main source of marine litter, since more than 70% of the observed litter items (mainly fishing lines/longlines and ropes) belonged to the category of ALDFG. High percentages of ALDFG (above 70%) were also found in other sites in the Mediterranean basin that are heavy influenced by local fishing activities (Table 4). According to Battaglia et al. (2010), bottom long-lines (LLS) are used in the area by professional, recreational, and illegal fishers to catch demersal species such as the European hake, porgies, or blackspot seabream (*Pagellus bogaraveo*). Moreover, the occurrence of a fair percentages of ropes (and anchoring ballasts) indicates that FAD fishing, targeting the dolphinfish (*Coryphaena* *hippurus*), is practised in the area (Blasi et al., 2016). FADs are generally composed of palm leaves, which provide shade for the dolphinfish, plastic floaters and ropes anchored to large stones (Consoli et al., 2020a; Sinopoli et al., 2020). As observed in many studies (Galgani et al., 2018; Consoli et al., 2018a; 2019; 2020a), ALDFGs are found in abundance on hard or mixed substrates, where the presence of rocky outcrops, usually colonized by sessile organisms with three-dimensional and arborescent structures, can facilitate the loss of gear through entanglement. In particular, corals and gorgonians are vulnerable to harm generated by entangled longlines which can cause skin abrasions, tissue damage, fractures and breakages, and also, ultimately, the death of colonies (Angiolillo and Canese, 2017; Rodríguez and Pham, 2017; Consoli et al., 2018b; Galgani et al., 2018; Figueroa-Pico et al., 2020; Du Preez et al., 2020).

However, the average litter density (0.57 items/100m^2) observed in the Aeolian Archipelago is quite low compared with that recorded, also by means of ROVs, in other areas of the Mediterranean basin (Table 4). In truth, fishing in the archipelago, is mainly carried out with pelagic gear (mainly using long lines and lines, targeting tunnids and squid, respectively), which has a lower impact on the seabed than demersal fishing gear. Moreover, in the area, the seafloor rapidly reaches high depth and the neritic zone (where the coastal activities are more concentrated) is very narrow.

Overall, taking all synthetic items into consideration (i.e. most of the ALDFG and GW plastic objects), the marine litter was dominated by plastics, which represented nearly 80% of the total litter: high percentages have also been reported in other environmental compartments, such as surface waters (Castro-Jiménez et al., 2019; Constantino et al., 2019), beaches (Constant et al., 2019), and sediments (Fastelli et al., 2016; Filgueiras et al., 2019; Enrichetti et al., 2020).

Moreover, although fish have been observed to use gas plumes as feeding stations (Cardigos et al., 2005) and the hydrothermal structures located in some of the areas explored were up to 4 m high (Esposito et al., 2018), no differences were found in litter density between hydrothermal and non-hydrothermal zones. A possible explanation of these results is the similarities between the geomorphologies of most of the hydrothermal habitats and those of the non-hydrothermal areas of the explored Aeolian islands, both of which are exploited by fishers and tourists.

Fishing gear is mostly composed of non-biodegradable long-lasting synthetic polymers, which is why, despite the low abundance of litter, it is easy to assume an inevitable increase in density over time and a consequent escalation of impacts on these habitats and the associated species.

The various plastic polymers comprising fishing gear, such as polyethylene (PE), polypropylene (PP) and nylon, can act as vectors for contaminants and break up to form microplastics (Bellas et al., 2016; Lusher et al., 2017; Song et al., 2017; Xue et al., 2020). Chemical compounds such as PE and PP have recently been recorded in sediments and benthic organisms collected around Salina island (Renzi et al., 2020).

According to Macfadyen et al. (2009), it is possible to put in place specific prevention and mitigation measures, widely recognized worldwide, aimed at reducing ALDFG in the marine environment. Such measures include the gear marking, on-board equipment to localize the lost fishing gear, spatial and temporal bans to reduce fishing effort, ABMT, and the use of biodegradable materials. Among the preventive measures it would also be appropriate to emphasize environmental education in the fisheries sector in order to raise awareness of the risks associated with loss of biodiversity and ecosystem services. In the medium and long term, increasing awareness could lead to a reduction of ALDFG in the marine environment.

In this regard, the main aim of the European Strategy for Plastics in a Circular Economy, adopted in January 2018, was also to tackle the leakage of plastics into the environment, increase recycling and re-use, and boost innovation in the European Union. In particular, both the Single-Use Plastic (SUP; European Commission, 2019b) and revised Port Reception Facilities (PRF; European Commission, 2019a) Directives, adopted in 2019, set out a package of measures to lessen the impact of plastic materials such as ALDFG on the marine ecosystem and human health. The priority of the legislation was to prevent fishing gear ending up as waste in the marine environment and to capture this resource, making it part of the circular economy.

As an alternative to prevention and mitigation measures it is also possible to adopt remedial measures, such as the retrieval of fishing gear. However, in the study area derelict fishing gear could only be retrieved by divers only in shallow waters, but this would not be possible in deep waters for safety reasons.

The Aeolian Archipelago is an area rich in hydrothermal habitats: several terrestrial and marine hot springs are spread throughout, but are mainly located around the islands of Panarea and Vulcano (Álvarez et al., 2019). The hydrothermal activity of these areas is characterized by the presence of intense degasification with typical bubble plumes that can be easily observed at the surface of the water (Panarea-Bottaro crater; Vulcano-Baia di Levante) and by the presence of sulfide deposits, relict chimneys, bacterial mats or DFS (eg: Gamberi et al., 1997; Italiano, 2009; Bortoluzzi et al., 2017). However, the most peculiar site explored to date, is the "Smoking land" located in the Panarea Volcanic Complex off the south-western coast of Basiluzzo islet and composed of more than 200 chimneys that are observed to host higher biodiversity than the areas without vents (Esposito et al., 2018).

Although fishing activities, through abandoned fishing gear, constitute the main source of marine litter and therefore impact, other commercial activities (tourism, mineral exploration) and scientific activities (deposit and structure sampling) (Esposito et al., 2018) may have negative impacts on these sensitive habitats and their associated biodiversity, as well as on their geochemical cycles.

Unlike other sites worldwide, the Aeolian hydrothermal sites do not enjoy a protected status. Therefore, considering the uniqueness of these habitats, the intense pressure of seasonal tourism, and the presence of an important small-scale fishing fleet (Battaglia et al., 2010), some restrictions could help protect and conserve this ecosystem, as reported by Esposito et al. (2018). To this end, a possible solution could be the creation of an MPA (according to Italian Law 979/82, Art. 31), characterized by some no-take/no-access zones (an integral reserve) at these hydrothermal sites, where all fishing activities, both commercial and recreational, could be strictly regulated.

Furthermore, the presence of ‘Submarine structures made by leaking gases’ (habitat code 1180) and Reefs (habitat code 1170), as listed in Annex I of the European Habitats Directive (European Commission, 1992), could represent reasons to designate these sites as SCIs. According to this directive, each Member State should designate SCIs as SACs within six years of the adoption of the European list of SCIs and then to define conservation objectives and conservation measures. Among these measures, given the abundance of fishing-related litter, it would be useful to prohibit the use of professional or recreational fishing gear at least in the most sensitive hydrothermal sites. This kind of protection status has been adopted for Azorean and Greek deep-sea thermal sites.

The underwater thermal resources of the Aeolian Islands could be used as a driver to encourage the development of sustainable tourism in the area through a special management plan that emphasizes maintaining the equilibrium of the hydrothermal ecosystem. After all, some thermal waters located in Vulcano Island are already used for therapeutic purposes. For example, tourism operators could offer dives within the shallowest hydrothermal sites, taking into account the conservation measures set out in the management plan. However, whereas on one hand these activities may increase people's awareness of the importance of these peculiar sites, on the other hand it will inevitably increase human impact at the sites. In these circumstances it would be crucial to foster best practice among diving operators in order to facilitate both habitat conservation and the sustainable exploitation of ecosystem services. In addition, it would be necessary to define the carrying capacity of each hydrothermal area in order to tailor management measures and minimize impact. Before that, however, there is an urgent need to publish georeferenced maps with general ecosystem information for all shallow and deep vent sites within the Aeolian Archipelago.

Acknowledgments

We are thankful to Captain Massimo Colorito and the crew of R/V Astrea for their professional support in the field work.

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Figure captions

Fig. 1. Study area with sampling sites. Other information on the survey points can be found in Appendix 1.

Fig. 2. Images of the most characteristic hydrothermal features observed in the Panarea Volcanic Complex: a) Fe-rich crust widely colonized by the tubicolous amphipods *Ampelisca ledoyeri*; b-c) Diffusive Ferruginous Seep; d) bacterial mats associated to hydrothermal fluid emissions. Scale bars: 10 cm for foreground.

Fig. 3. Seafloor marine litter composition for the whole study area. The numerical abundance is expressed as the percentage over the total number of litter items.

Fig. 4. Marine litter ROV images: a) A lost trap providing new artificial substrata for encrusting or sessile organisms; b) A ghost fishing net entangling a shamefaced crab (*Calappa granulata*); c) A small colonial ascidian (*Diazona violacea*) colonizing a lost rope; d) A set net covering the sessile fauna. e) A chimney entangled by a lost line; f) An encrusted ceramic item. Scale bars: 10 cm for foreground.

Tables

Table 1. Percent composition of each litter category. 'Fishing gear' is separated per metier and 'General waste' is separated per material.

Fishing gears	**n**	**%**	**General waste**	**n**	**%**
Fishing lines	167	52.19	Metal	29	9.06
Rope	41	12.81	Plastic objects	27	8.44
Set net	8	2.50	Glass/ceramic	21	6.56
Trawl net	7	2.19	Rubber	3	0.94
Trap	5	1.56	Textile	1	0.31
FAD anchoring ballast	2	0.63	Other	9	2.81
Tot	**230**	**71.88**	**Tot**	**90**	**28.13**

Table 2. Percentage contribution (%) of each litter item found on the seafloor of the Mediterranean Sea. In grey the top ten marine litter items.

Litter categories	**Litter materials**	**Debris items**	**n.**	**%**
Fishing gears	Plastics/polymers	Fishing lines	167	52.19
		Rope	41	12.81
		Set net	8	2.50
		Trawl net	7	2.19
		Trap	5	1.56
Fishing gears	Other	FAD anchoring ballast	2	0.63
General waste	Metal	beverage cans	28	8.75
		pipe	1	0.31
General waste	Glass/ceramic	beverage bottles	18	5.63
		ancient amphora	2	0.63
		toilet bowl	1	0.31
General waste	Plastics/polymers	beverage bottles*	8	2.50
		bottles: bleach, cleaner*	4	1.25
		buckets & jerrycans*	4	1.25
		cups, plates, forks, knives, spoons*	3	0.94
		undefined	2	0.63
		boat fender	1	0.31
		bags: grocery/retail*	1	0.31
		caps & lids*	1	0.31
		rope	1	0.31
		sheet	1	0.31
		pipes (plastic/PVC)	1	0.31
General waste	Rubber	tyre	3	0.94
General waste	Textile	bag	1	0.31
General waste	Other	old scientific devices	4	1.25
		anchoring ballast	3	0.94
		piece of boat	1	0.31
		chair metal/plastic	1	0.31

* single-use plastic item (SUPs)

Tab. 3. List of species impacted by marine debris in the Aeolian Archipelago.

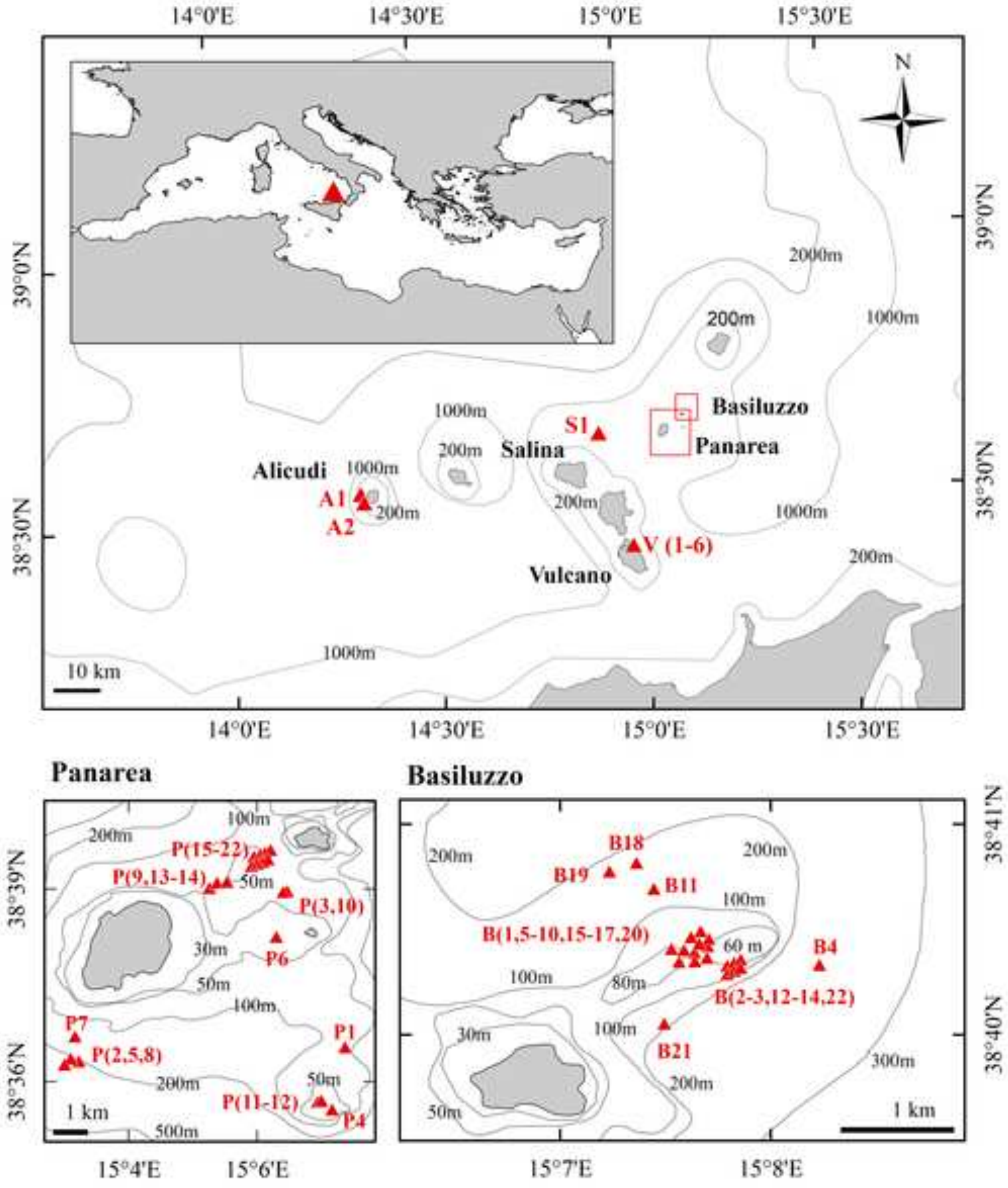
Fishing gear	**n. of litter items interacting with fauna**	**interaction categories**	**impacted species**
Fishing lines	16	entanglement	*Ampelisca ledoyeri (facies)*
		entanglement	*Anthipatella subpinnata**
		entanglement	*Eunicella cavolini**
		entanglement	*Eunicella singularis**
		entanglement	*Myriapora truncata*
		entanglement	*Neopycnodonte cochlear*
		entanglement	*Paramuricea clavata**
Rope	15	entanglement	*Ampelisca ledoyeri (facies)*
		entanglement	*Halocyntha papillosa*
		entanglement	*Neopycnodonte cochlear*
		entanglement	*Cerianthus membranaceus*
		entanglement	*Diazona violacea*
Set net	2	entanglement	*Antipathella subpinnata**
		entanglement	*Neopycnodonte cochlear*
		ghost fishing	*Calappa granulata*
Trawl net	1	coverage	*Adeonella calveti*
		coverage	*Paralcyonium spinulosum*
		coverage	*Myriapora truncata*
		coverage	*Centrostephanus longispinus**
		coverage	*Reteporella grimaldii*

*protected species.

Table 4. Seafloor debris abundance (items/100 m2) and percentage (%) of ALDFG and plastics recorded by ROV surveys from several locations in the Mediterranean Sea.

Area	Substrate	Depth range (m)	Mean abundance (n/100m^2)	ALDFG (%)	Plastics (%)	REF.
Aeolian Islands, Sicily, IT	**mixed**	**15-411**	**0.57**	**71.9**	**79.7**	**Present study**
Straits of Sicily, Malta	rocky	250-400	4.63	96.2	97	Consoli et al., 2020a
Adriatic Sea, IT	rocky	21-23	3.3	69	-	Melli et al., 2017
Tyrrhenian Sea, Campania, IT	rocky	30-300	0.95	91	2	Angiolillo et al., 2015
S-W Tyrrhenian Sea, Sicily, IT	rocky	30-300	1.49	93	3	Angiolillo et al., 2015
Sardinia Channel, IT	rocky	30-300	0.44	82	11	Angiolillo et al., 2015
Straits of Sicily, IT	mixed	20-200	2.13	98	96	Consoli et al., 2018a
Straits of Sicily, IT	soft	5-30	0.11	32	73	Consoli et al., 2018b
S Tyrrhenian Sea, Sicily, IT	mixed	20-240	3.49	78	84	Consoli et al., 2019

Figure 1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Panarea
S1
Salina
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Alicudi
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A1
A2
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V (1-6)
Vulcano
1000m
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Panarea
100m
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P(15-22)
P(9,13-14)
50m
P(3,10)
30m
P6
50m
100m
P7
P(2,5,8)
P1
200m
50m
P(11-12)
P4
1 km
500m
38°39'N
38°36'N
15°4'E
15°6'E
Basiluzzo
B18
200m
200m
B19
B11
100m
B(1,5-10,15-17,20)
60 m
B4
100m
80m
B(2-3,12-14,22)
30m
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B21
300m
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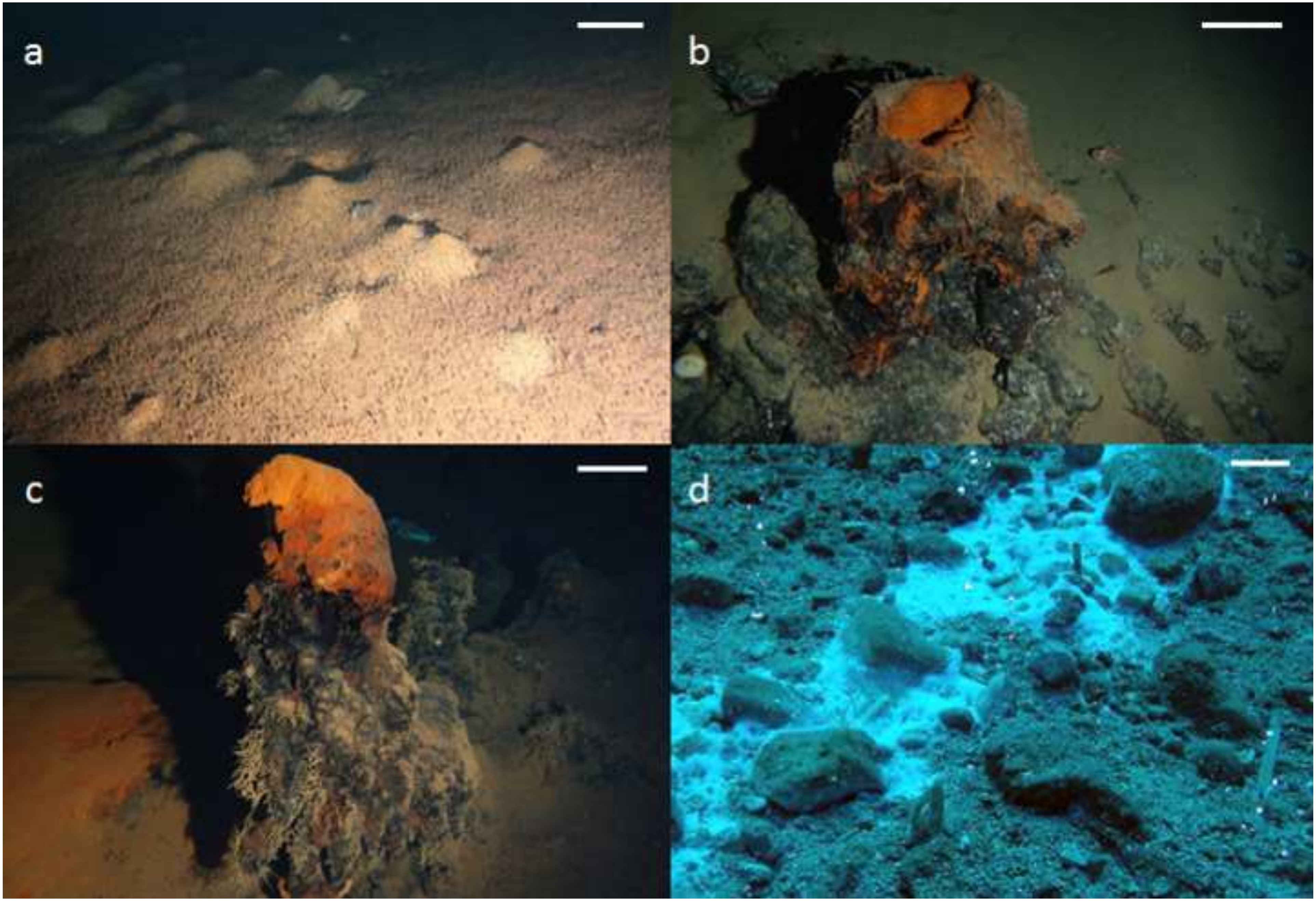
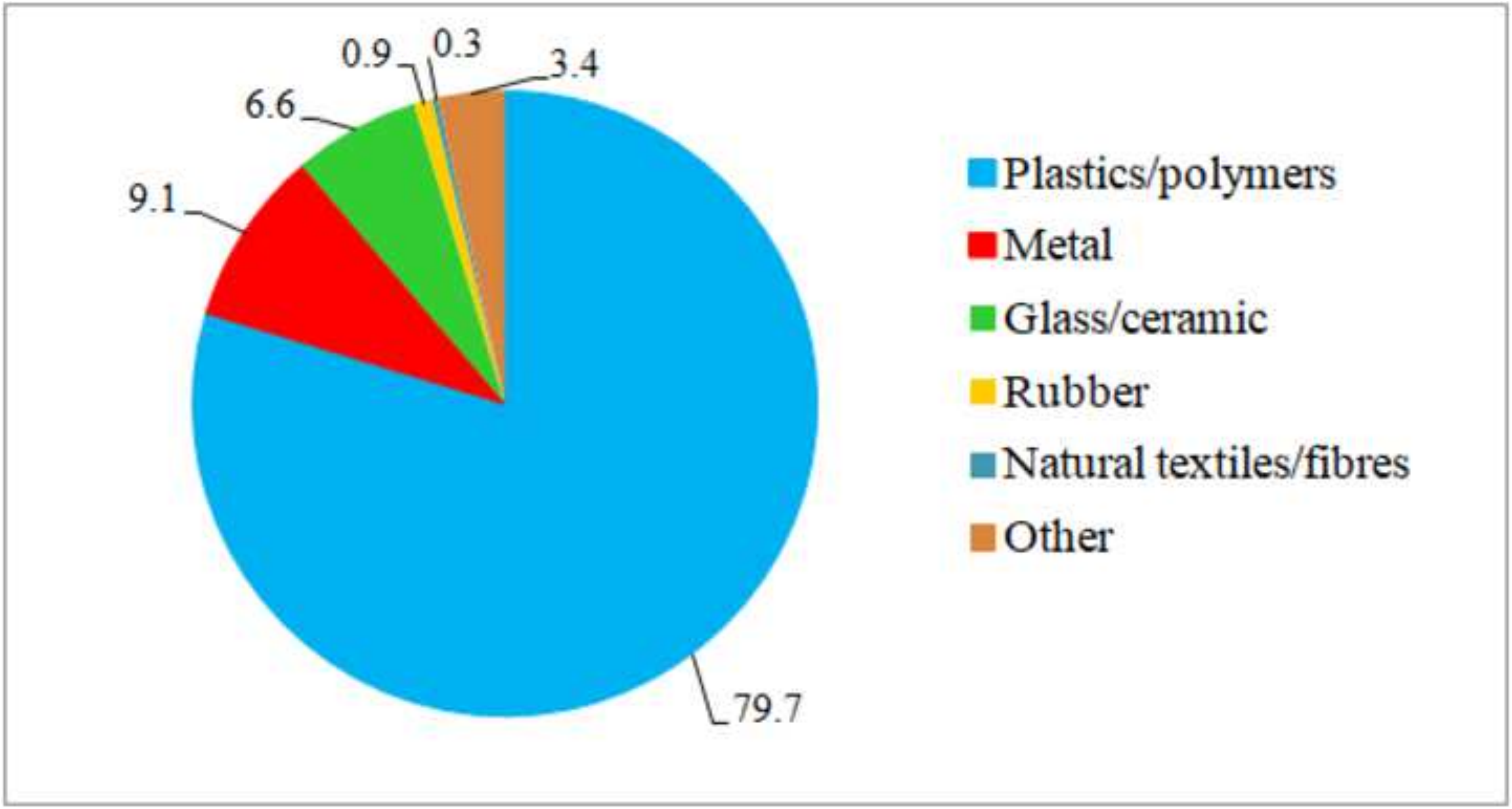
38°40'N
15°7'E
15°8'E

Figure 2

Click here to access/download;Figure;Fig. 2.tif




0.9
0.3
3.4
6.6
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79.7
Plastics/polymers
Metal
Glass/ceramic
Rubber
Natural textiles/fibres
Other


a
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