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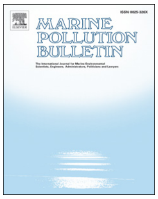

Marine litter disrupts ecological processes in reef systems

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ABSTRACT

Marine litter (ML) contaminates essentially all global coastal and marine environments and drives multiple ecosystem-level effects. Although deleterious effects of ML on several organisms have been investigated in the last years, this information tends to be dispersed or underreported, even in marine biodiversity hotspots such as reef ecosystems. Two are the main goals of this paper: (i) to integrate and synthesize current knowledge on the interactions of ML and reef organisms, and (ii) to evaluate the multiple disruptions on the ecological processes in reef systems. We report here ML-driven ecological disruptions on 418 species across eight reef taxa, including interactions that were previously not addressed in detail, and evaluate their major conservation implications. These results can help raise awareness of global impacts on the world's reefs by highlighting ML associations in different reef systems around the world, and can aid in ML input reduction and marine management.

1. Introduction

Marine litter (ML), also known as “anthropogenic marine debris”, is widely recognized as a global environmental problem (Ryan, 2015). The sources, pathways, and accumulation of ML are variable, depending on distance from the coast (Galgani et al., 1996; Mordecai et al., 2011), oceanographic and hydrographic processes (Galgani et al., 2000; Barnes et al., 2009; Lebreton et al., 2017), geomorphologic features and anthropogenic activities (Ramirez-Llodra et al., 2013).

As a result, this contamination by ML has become ubiquitous in aquatic systems, including shallow waters (Chiappone et al., 2002), open oceans (Eriksen et al., 2014), deep-sea (including the Mariana Trench at 10,898 m) (Mordecai et al., 2011; Melli et al., 2017; Chiba et al., 2018), and pristine environments such as remote islands (Lavers and Bond, 2017), and both Arctic and Antarctic polar seas (Barnes et al., 2009; Cózar et al., 2017).

Coral reefs and other reef ecosystems are not an exception (Al-Jufaili et al., 1999; Chiappone et al., 2002, 2005; de Carvalho-Souza and Tinôco, 2011; Lamb et al., 2018). Macro-ML such as derelict fishing gears are known sources of coral damage (Donohue et al., 2001; Chiappone et al., 2002, 2005), and the accumulation of plastic pollution, especially microplastics, has been reported in the Great Barrier Reef World Heritage Area (Reisser et al., 2013; Critchell et al., 2015).

Laboratory studies have documented the ingestion of plastic by scleractinian (reef-building) corals (Hall et al., 2015; Allen et al., 2017); a more recent investigation showed that plastic debris can stress coral by depriving them of light and oxygen and tissue abrasions can facilitate the development of diseases (Lamb et al., 2018).

This study also estimated that 11.1 billion plastic items could be entangling on coral reefs across the Asia-Pacific, with a projected increase of 40% by 2025 (Lamb et al., 2018). Given the important roles played by reefs as highly productive ecosystems and suppliers of environmental services (e.g. food, coastal protection and tourism), such studies are critical to better understand how this anthropogenic stressor can affect the reef ecosystems worldwide.

Our knowledge of the deleterious effects of ML on the various reef taxa are still limited. Nearly 700 marine species are known to interact with marine debris throughout the world (since the last review), and at least 17% of the latter are present in the IUCN Red List (Gall and Thompson, 2015). However, data from many reef species, especially

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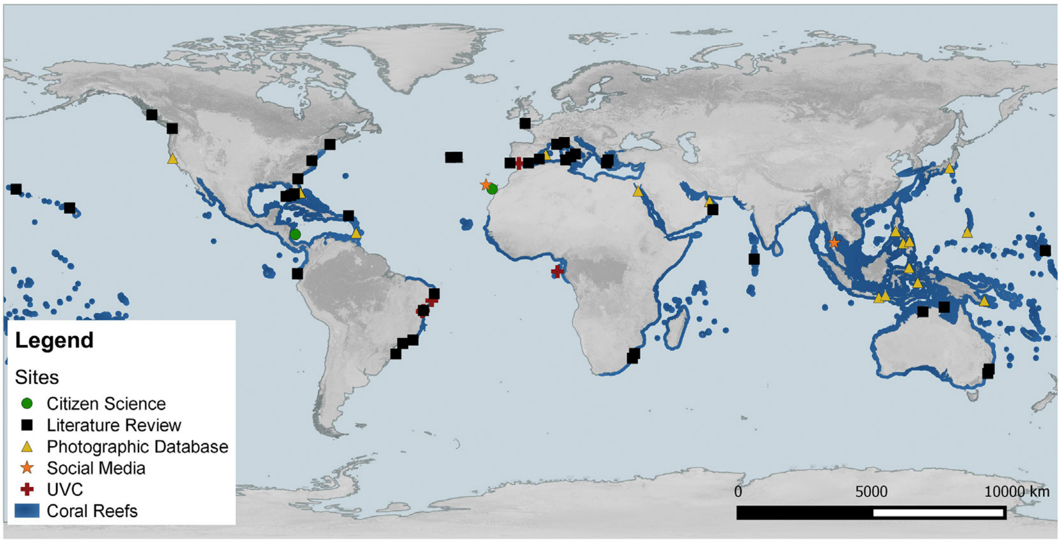

Fig. 1. Distribution of data sampling in reef systems around the world. In blue, the map details represent the global distribution of warm-water coral reefs. Legend: UVC – Underwater visual census. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

reef fishes and invertebrates remain fragmented or underreported.

To address these knowledge gaps, we combine here multiple approaches to marine anthropogenic debris research and highlight and discuss its impacts on reef systems. We employed underwater visual census (UVC), which are routinely use in ecological studies of reef communities (Ferreira et al., 2004; Floeter et al., 2007), to estimate interactions between reef species and ML. Records of these interactions were compiled from different databases and sources of information available in the literature. Based on this spatially extensive dataset covering different reef systems, we were then able to identify potential disruptions of natural processes caused by ML in reef environments.

2. Material and methods

2.1. Study area

Data were gathered from underwater surveys, photographic databases, citizen-scientists, and literature reviews between 2008 and 2018 (Table S1). A total of 70 sites from the Atlantic Ocean, Bali Sea, Caribbean Sea, Indian Ocean, Mediterranean Sea, Pacific Ocean, and Red Sea were assessed (Fig. 1 and Table S1).

2.2. Underwater surveys

The first approach consisted of underwater observations made during daylight hours while snorkeling in shallow waters and using SCUBA equipment in deeper areas. Underwater visual census (UVC) ($n = 200$) were made in 5 areas during approximately 120 h of observation in northeastern Brazil (biogenic and abiogenic reefs), São Tomé Island, São Tomé and Príncipe (biogenic and abiogenic reefs), and southwestern Spain (abiogenic reefs) (Fig. 1). At each site, we counted and identified reef organisms using two sampling methods (semi-quantitative and qualitative, respectively): 1) an adaptation of the Atlantic and Gulf Rapid Reef Assessment – AGRRA protocol (www.agrra.org) using belt transects (120 m^2 each, $n = 30$) at depths between 0.5 and 30 m; 2) an adaptation of the Roving Diver Technique (RDT) (Schmitt and Sullivan, 1996), which consists of intensive random searches recording the maximum possible numbers of ML-associated species (fishes and invertebrates) along a reef during the entire duration of a dive (usually 30–40 min each, $n = 10$).

Data collected during these dives were registered using PVC plates, describing the types of debris found, the associated species, and the types of interactions/behaviors of the biota with the ML; digital photographs were taken where possible. The species were identified to the lowest possible taxonomic level using identification material and the specialized literature (Humann and Deloach, 2002; Humann and Deloach, 2003; Nelson, 2006; Sampaio and Nottingham, 2008; Froese and Pauly, 2016).

2.3. Literature review and compilation of internet-based image databases

The second approach involved the collection of information from the technical literature using the principal scientific databases, search engines (Web of Science, Scopus, Google Scholar, Google), image banks of underwater photography and social media (e.g., Marine Photo Bank, OceanwideImages, Youtube). In addition, information requests were posted to underwater photography forums and citizen-scientist web contacts with submarine photographers were facilitated and compiled for additional records of interactions and disruptions. These sources provided an extensive compilation of associations between marine fauna and ML.

The digital searches used a list of keywords linked with ML and different types of reef environments, such as: marine litter, marine debris, anthropogenic debris, debris, marine pollution, garbage, derelict fishing gear, reefs, coral reefs, biogenic reefs, rocky reefs, rocky shores, rocky substrate, abiogenic reefs, shallow water, hard bottom, lagoons, and bays. The search criteria were based on studies focusing on ML and reef environments/species, without temporal filtering limits.

The information gathered from the publications included: the taxa involved, numbers of events/specimens recorded, site, types of debris, and types of associations and behaviors. When all of this information was not available in a given case, we used the criteria adopted in the review by Baulch and Perry (2014) in relation to historic information, by which, when it was not possible to consult the original article, data available from relevant publications and reviews were incorporated (Laist, 1997; Derraik, 2002; Deudero and Alomar, 2015; Gall and Thompson, 2015; Kühn et al., 2015).

The types of debris were broadly classified (plastic, metal, processed wood, glass, rubber, fishing gear). When detailed information was available it was classified more specifically (e.g., batch of balloons, bottles, ceramic pots, caps, cloth, cups, cutlery, paint buckets, pipes, soda cans, tires).

In terms of the photographic databases and the information and photographs provided by citizen-scientists (Supplemental Information), we likewise adopted as criteria for inclusion the quality of the images (which could allow us to identify the associated organisms), the types of associations, and the debris involved, as well as information about the site and any other additional comments supplied by the photographers.

Although ML ingestion is one of their most well-known impacts (Gall and Thompson, 2015) and has been recorded for a number of species that live in (or use) reef environments at some stage of their life histories (e.g., large fish, turtles, marine mammals), the data related to these occurrences often included records of dead animals without the possibility of determining the exact location of their encounter with the anthropogenic material; as such, these records were not included in the present study.

Additionally, we adapted the analyses used by Deudero and Alomar (2015), consulted the IUCN Red List categories (www.iucnredlist.org), assigned the taxa and revised related information concerning the ecological aspects of the species by consulting the scientific literature (Humann and Deloach, 2002; Humann and Deloach, 2003; Nelson, 2006; Sampaio and Nottingham, 2008) as well as databases such as FishBase (www.fishbase.org; Froese and Pauly, 2016), Worms (www.marinespecies.org), and the Catalogue of Life (www.catalogueoflife.org).

The polar histogram graph was created using code adapted from Ladroue (2012) and R software version 3.5.0 (R Core Team, 2018) and the map was generated using QGIS software version 3.0.2 (QGIS Development Team, 2018). Spatial data of warm reef-building coral species were obtained from the IUCN Red List of Threatened Species website (http://www.iucnredlist.org/technical-documents/spatial-data).

3. Results

A total of 418 reef species belonging to various taxa (Porifera, Cnidaria, Platyhelminthes, Mollusca, Annelida, Arthropoda-Crustacea, Echinodermata, and Chordata) and more than 36,389 individuals were found associated with ML and considered in the present work (Fig. 2; Table S2). The groups with the greatest numbers of species and individuals (respectively) were Chordata (n = 207/5182), Crustacea (n = 62/14065), Cnidaria (n = 59/973), Mollusca (n = 39/13120), and Echinodermata (n = 31/2968).

Among the categories cited in the IUCN Red List, the greatest number of species was classified in the category *not evaluated* (NE) (n = 245), followed by the category *least concern* (LC) (n = 133), and *near threatened* (NT) (n = 15). At least 7% of the ML-associated species were classified in the IUCN Red List as *near threatened* or in more critical categories. This provides preliminary evidence for the potential hazard and exposure level between threatened reef species and ML.

In terms of the types of ML associated with these species, the most common materials were fishing gear (n = 331), followed by plastic (n = 55), metal and glass (n = 20), reflecting the large number of records resulting from studies of derelict fishing gear. Our results indicate that the Pacific and Atlantic oceans contain the vast majority of records (n = 180 and 160, respectively) compared to the Mediterranean Sea (n = 58), and with the Indian Ocean containing 18 records. It should be noted that these records provide an indication of relative sampling effort in different marine regions, rather than providing an accurate view of the number of affected reef species or major exposure to ML.

We identified 5 types of ML associations disturbing or modifying natural marine processes: 1) entanglement and catches in derelict fishing gear (n = 298); 2) as refuge frameworks (n = 86); 3) as a substrate (n = 52); 4) debris covering/smothering the species (n = 37); and, 5) as "mobile homes" (n = 5) (Fig. 3-i). These interactions of ML with reef species were found to be frequent throughout the world, in addition to the more well-publicized impacts of ML on the marine fauna through ingestion and species dispersal (Thiel and Gutow, 2005; Gall and Thompson, 2015).

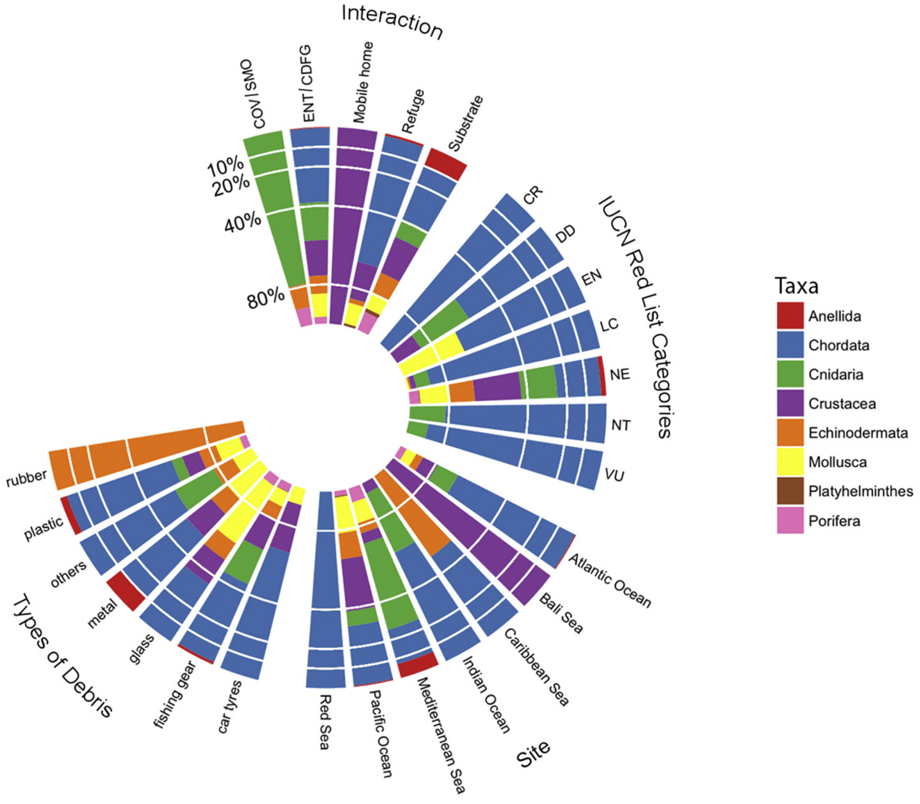

Fig. 2. Comparison of percentage of taxa between interactions, IUCN Categories, location and types of debris. Legend: COV – Covering; SMO – Smothering; ENT – Entanglement; CDFG – Catches in Derelict Fishing Gear; NE – Not Evaluated; DD – Data deficient; LC – Least Concern; NT – Near threatened; VU – Vulnerable; EN – Endangered; CR – Critically endangered.

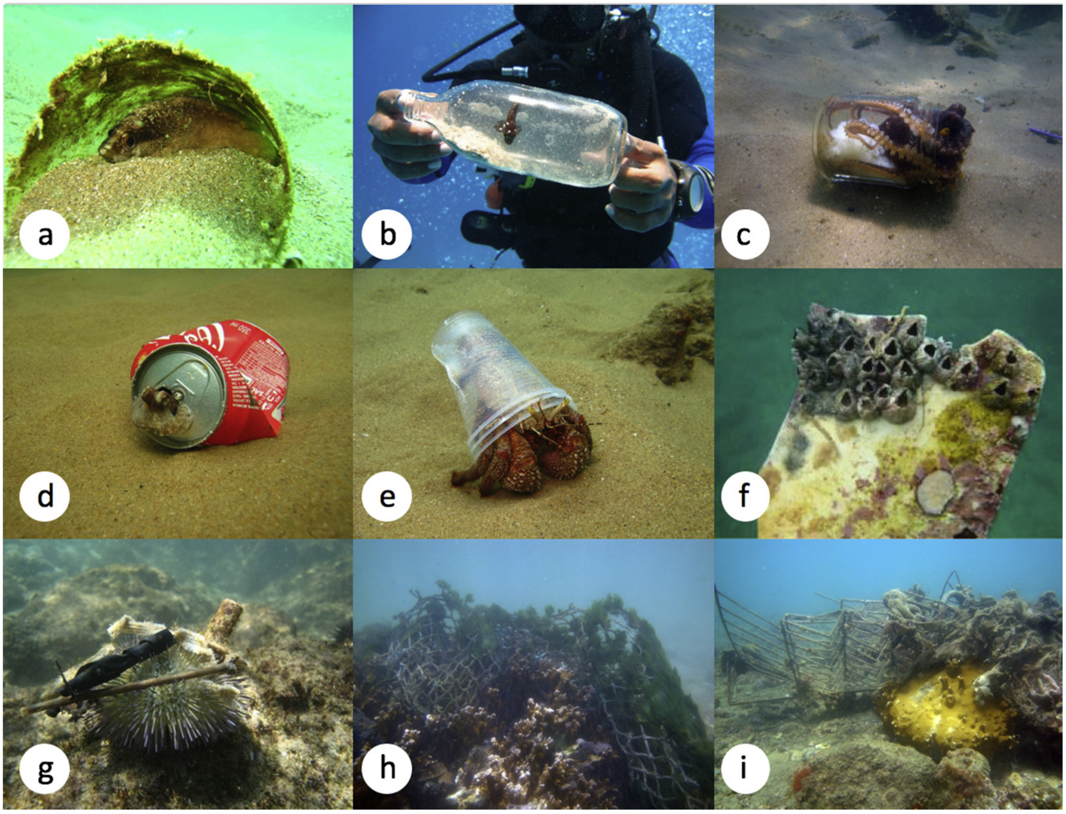

Fig. 3. a–i. Interactions between reef species and ML. a–b: Reef fishes using a plastic and glass bottle as a shelter (refuge), respectively. c–d: *Octopus* spp. were found taking refuge inside a glass jar or soda cans (in photo C, it's possible to see its eggs). e: Hermit crab using plastic cups as their shell ("mobile-home"). f: Barnacles over a partially algal-covered plastic item (substrate). g: Sea urchin covered by plastic items. h: Fishing net entangled on *Millepora alcicornis* colonies. i: Several derelict fishing gear entangling and covering/smothering *Millepora* spp. colonies.

4. Discussion

4.1. Entanglement and catches in derelict fishing gear

Entanglement and/or catches in derelict fishing gear were found to have impacted at least 298 reef species (Table S2; Fig. S2f–i), largely involving entanglement in fishing lines, hooks, or abandoned fishing nets – a situation also known as ghost fishing (Breen, 1990). Derelict fishing gear has a number of detrimental effects, which can be listed as follows: continued catch of target and non-target species, interactions with threatened species, physical impacts on the benthic habitats, and the introduction of synthetic material into the marine food-web (Macfadyen et al., 2009).

There is historical documentation for these types of interactions involving a wide number of animal groups (e.g., invertebrates, fishes, turtles, marine mammals, seabirds) (Laist, 1997; Al-Jufaili et al., 1999; Donohue et al., 2001; Chiappone et al., 2002, 2005; Asoh et al., 2004; Heifetz et al., 2009; Good et al., 2010; Havens et al., 2011; Bilkovic et al., 2014; Gall and Thompson, 2015), including an Atlantic mackerel (*Scomber scombrus* Linnaeus, 1758) wrapped in a section of rubber, and a shortfin mako (*Isurus oxyrinchus* Rafinesque, 1810) with a tire around its neck (Gudger, 1928; Gudger and Hoffmann, 1933).

Among our records there is an Atlantic thread herring, *Opisthonema oglinum* (Lesueur, 1818), with a plastic ring around its body, showing tissue damage and difficulty in swimming. Similar records exist for an axillary seabream, *Pagellus acarne* (Risso, 1827), the silver mojarra *Eucinostomus argenteus* Baird and Girard 1855, tomtate grunt *Haemulon aurolineatum* Cuvier 1830, and gray parrotfish *Sparisoma axillare* (Steindachner, 1878), bearing a plastic collar at the level of its operculum, causing a deep cut in its abdomens (Barreiros and Guerreiro, 2014; Nunes et al., 2018). Sazima et al. (2002) recorded plastic rings around the bodies of juvenile sharpnose sharks, *Rhizoprionodon lalandii* (Müller and Henle, 1839), including one individual with a plastic ring around its mouth and brachial arch reducing its feeding and breathing capabilities.

Crab and echinoderm entanglements in abandoned fishing gear have often been observed, with resulting restrictions in their mobility that could cause their death or make them much more vulnerable to predation. These types of incidents are confounded by predators and scavengers being attracted to the entangled species – resulting in domino effects of damage if those latter organisms also become entangled (Houard et al., 2012; NOAA, 2014).

In terms of benthic organisms, our survey identified various species of sponges and cnidarians such as hard corals, soft corals, and zoanthids impacted by entanglement, especially discarded fishing gear (lines and hooks) (Table S2). In some cases, due to the types and sizes of the abandoned material, both entanglement and smothering occur simultaneously, as was seen, for example, with the coral *Millepora* spp. (Fig. 3h–i) and the Black sea urchin, *Echinometra lucunter* (Linnaeus, 1758) (Fig. S2b).

Abandoned fishing gear can result in damage such as breaking the branches of colonial corals or causing severe lesions on polyps and tissues; encrustation of organisms such as algae are also found on those fishing lines (Table S2). Tissue damage can favor invasion by pathogens or by animals capable of penetrating the coral skeleton and draining colony resources (Bavestrello et al., 1997; Al-Jufaili et al., 1999; NOAA, 2016). Corals and gorgonians are capable of recovering from small lesions, but their healing capacities will depend on the gravity and frequency of their injuries, so that severe damage can lead to colony death (Bavestrello et al., 1997; Asoh et al., 2004; Bo et al., 2013, 2014; Angiolillo et al., 2015; Adelir-Alves et al., 2016; Figueroa-Pico et al., 2016; Cassola et al., 2016). Furthermore, Angiolillo et al. (2015)

showed the positive correlation between the number of dead colonies and the presence of derelict fishing gears in the habitats, indicating the detrimental effects of fisheries.

Hook-and-line fishing gear has been found to cause serious damage to corals, gorgonians, sponges, and colonial zoanthids in reef environments within the Florida Keys National Marine Sanctuary (Chiappone et al., 2002, 2005; NOAA, 2016). Similar impacts were observed on coral reefs in Oman, with serious damage due to fishing gear on the coral *Pocillopora damicornis* (Linnaeus, 1758), varying from 25% to 100% of the total area of the reef (Al-Jufaili et al., 1999).

Other aggravating factors include: (1) the durability of this type of debris in the natural environment (as it is largely composed of synthetic fibers), which, if not removed, can take decades to decay and continue to inflict severe damage (or even death) to the reef fauna (Al-Jufaili et al., 1999); (2) ML can act as vectors for microorganisms and microbial communities that are causal agents for coral diseases, or provide conditions for excessive algal growth (Schleyer and Tomalin, 2000; Wright et al., 2013); (3) impacts on human health and local economies that are dependent on sub-aquatic tourism (through aesthetic damage to submarine landscapes and accidents with swimmers and divers) as well as damage to boats (e.g., entanglement of abandoned fishing gear in boat helices) (Macfadyen et al., 2009; Melli et al., 2017).

4.2. Use as a refuge/shelter

Numerous taxa have been observed using ML as refuges, including reef fish, crustaceans, cephalopods, and other invertebrates (Fig. 3-d; Table S2). The black fin cardinal fish, *Astrapogon puncticulatus* (Poey, 1867), a nocturnal foraging species, was found associated with metal tins, glass jars, and pieces of cloth during our underwater surveys. During a ML collection campaign by local divers on Clean-up Day (2008) in the Todos os Santos Bay, Brazil, *A. puncticulatus*, was also occasionally encountered sheltered in soda cans.

Recreational divers off San Andres Island (Colombian Caribbean) reportedly observed an individual of *A. puncticulatus* using a glass bottle as a shelter (Klava, L. F., *personal communication*) (Fig. 3b). Species of the genus *Astrapogon* normally use empty *Strombus* mollusk shells (Reed, 1992) (including threatened species widely used as food sources and sold as souvenirs). This is due to the overfishing of these gastropod stocks that can force those temporary fish residents to search for alternative shelters – with increasingly abundant ML results in increasing numbers of appropriations as described here.

During a RDT census, two pairs of *Microgobius carri* Fowler, 1945, were observed using plastic cups as shelters in the Todos os Santos Bay (10 m depth). These fish are known to inhabit burrows under stones or shells (Birdsong, 1981; Feitoza et al., 2001). On closer examination, adhered eggs were seen inside one of the cups. The gastropod *Hexaplex trunculus* (Linnaeus, 1758) was likewise observed using ML to attach their large egg masses in the Saronikos Gulf (Aegean Sea), (Katsanevakis et al., 2007). In deep sea coral reefs of the Tyrrhenian Sea, the ML was also used as refuge by numerous crustaceans, sea-urchins, octopuses and fish species (Angiolillo et al., 2015).

At least 8 species of octopuses have been reported using ML as shelter (Fig. S1a–d). In one of these cases, *Octopus insularis* Leite and Haimovici, 2008 was found taking refuge inside a glass jar (and it was possible to see its eggs) (Fig. 3c). Anderson et al. (1999) reported the use of beer bottles for shelter by *Octopus rubescens* Berry, 1953 in sandy or muddy habitats where natural shelters were scarce. In experiments directed towards diversifying soft ocean bottoms along the coast of Greece, *Octopus vulgaris* Cuvier, 1797 was encountered using ML (plastic pots) at a frequency of 38.7%, which increased the cephalopod's local density (Katsanevakis and Verriopoulos, 2004). These authors, however, warned that these octopuses are predators, and unnatural increases in their populations will significantly increase hunting pressure on local benthic communities. More recently, similar observations have been made in *O. vulgaris* in the passage reefs, Azores Archipelago (Rodríguez and Pham, 2017) using a remotely operated vehicle, where it was possible to see that such animals were in direct contact with glass bottles.

There are many implications linked to ML associations, and any apparent “favorable” effect will necessarily exert multiple impacts and knock-on effects that would need to be further studied. As pointed out by Katsanevakis et al. (2007), the view of “positive” effects of ML on marine environments may be extremely naïve in terms of their long-term dangers. Moreover, these interactions contrast with the principle of good environmental status, marine conservation, and sustainability.

The above findings highlight that the decrease of natural shelters vs. increase of ML may be prevailing in reefs systems characterized by intense fishing activities (e.g. anchoring, unfriendly fishing practices, ornamental extractions), poorly controlled recreational activities (e.g. shell collecting, boat traffic) and those close to urban centers (Al-Jufaili et al., 1999; de Carvalho-Souza and Tinôco, 2011; Kowalewski et al., 2014; Cassola et al., 2016).

Marine litter material tends to become degraded or rapidly transported due to physical-chemical and environmental factors (e.g., currents, tides, wave action, and their synergistic effects), exposing the species that use them to predation or egg losses. A recent study of PET bottles on the seafloor of the Saronikos Gulf (Greece) found that they remained intact for approximately 15 years, but then demonstrated significant deterioration (Ioakeimidis et al., 2016).

This degradation will result in the introduction of chemical components into the water column, the formation of plastiglomerates, and interactions of micro-debris with invertebrates and microorganisms (Wright et al., 2013; Corcoran et al., 2014). The availability, and therefore possible ingestion, of micro-debris by the marine biota likewise represents the potential for serious interactions within the trophic chain (see, Gall and Thompson, 2015; Rochman et al., 2015).

4.3. Use as a substrate

A total of 52 records of ML uses as substrates were recorded (Fig. 3f; Table S2). Both mobile and sessile invertebrate species were observed on, or encrusted on, ML (Fig. S1f–i). Experiments using various plastic objects (bottles, jars, and bags) indicated that Poli's stellate barnacle, *Chthamalus stellatus* (Poli, 1791) did not survive for more than five months when encrusted on those objects, with all of the individuals suffering predation by the end of the study (Katsanevakis et al., 2007). These authors also observed a gradual but marked increase in the total number of species and their abundances. The use of ML as a substrate can also provoke substantial alterations in the megafauna community structure and spatial heterogeneity, including new and modified community relationships (Saldanha et al., 2003; Katsanevakis et al., 2007), and occasionally enhancing the settlement of non-indigenous species (Mordecai et al., 2011). Uneputty and Evans (1997) likewise provided evidence for dangers related to the accumulation and use of ML as substrates in Ambon Bay, noting significant differences in the benthic assemblages between regions free of foreign materials or covered by ML. The addition of hard artificial structures, although initially favoring some species, eventually leads to changes in community structures and ecological relationships (Katsanevakis et al., 2007; Airoldi et al., 2009).

Although these ML objects can serve as ocean bottom substrates and can attain substantial masses due to dense encrustations of marine organisms (depending on the locality and depth), these ML objects can also be remobilized or broken through natural physical-chemical and/or anthropogenic actions (e.g., ocean currents, or diving and boating activities). Other factors related to the remobilization of ML within the water column include long-distance dispersal of organisms by rafting and the transportation of invasive species (Thiel and Gutow, 2005; Gregory, 2009).

4.4. Covering and/or smothering

Our survey indicated that covering and/or smothering has impacted at least 37 reef species, principally echinoderms and cnidarians (Fig. S2a–e). Sea urchin species such as *Lytechinus variegatus* (Lamarck, 1816) (Fig. 3g) and *Tripneustes ventricosus* (Lamarck, 1816) (Table S2) have been found covered by ML in the Todos os Santos Bay, Brazil, a known area of high concentration of ML (de Carvalho-Souza and Tinôco, 2011). Sea urchins are known to cover themselves with substrate materials as protection against mechanical injuries associated with abrasion, dislodging, and UV radiation (Dumont et al., 2007). The use of these materials varies according to local availability, although selectivity is described for some species such as *L. variegatus* and *T. ventricosus* (Amato et al., 2008). It is possible that sea urchins use certain ML materials through selectivity, but also because of their high availability, so that these substances are altering relationships in the natural habitats of those animals.

There are numerous reports of ML material (such as cloth and fishing gear) covering *Millepora* corals (Fig. 3h–i), great star corals *Montastrea cavernosa* (Linnaeus, 1766), and starlet corals *Siderastrea* spp., which can lead to physical damage and reduced access to phototrophic and heterotrophic nutrition sources (Richards and Beger, 2011). Suffocation will reduce food acquisition by impeding water circulation for filter feeding (Kühn et al., 2015).

A number of reef sites have demonstrated significant losses of coral cover that appeared to be related to suffocation by macro-debris (Cleary et al., 2006; Richards and Beger, 2011). Cauliflower coral (*Pocillopora meandrina* Dana, 1846) colonies at Oahu, Hawaii, have been found densely covered by fishing gear (65%), with high percentages (80%) of partially or totally dead colonies (Yoshikawa and Asoh, 2004).

It is also known that suffocation impedes gas exchange and severely reduces sediment oxygen levels, with direct consequences for community productivity (Katsanevakis et al., 2007; Gregory, 2009; Mordecai et al., 2011). Aloy et al. (2011) likewise reported alterations in the feeding behavior of the gastropod *Nassarius pullus* (Linnaeus, 1758), with decreasing feeding efficiency with increasing plastic ML covering.

Katsanevakis (2015) recently reported the appearance of new types of ML as a result of illegal immigration in the Mediterranean Sea, including a sunken inflatable raft covered with a layer of marine grass [(*Posidonia oceanica*) (Linnaeus) Delile, 1813]. As such, covering and suffocation by ML in marine environments has resulted in various ecological alterations at both individual and ecosystem levels.

4.5. Use as a “mobile-home”

We found the use of ML as shelter by 5 taxa of hermit crabs (Table S2). Visual census indicated the use of plastic cups by hermit crabs of the family Diogenidae and by *Petrochirus diogenes* (Linnaeus, 1758) and *Clibanarius* sp. along the rocky shores of the Todos os Santos Bay (Fig. 3e). These animals normally appropriate the abandoned shells of large gastropods. A record mentioned by citizen-scientists, dated 1981, refers to the use of a metal milk can by an unknown species of hermit crab in Ribeira, Bahia State, Brazil (Linhares, B., *personal communication*). On the Kuramathi Islands in the Maldives, an unidentified species of hermit crab (Diogenidae) was reported sheltered in a plastic sheet, and those authors noted the negative qualities of that material as being unstable, providing insubstantial protection, and having poor hydrodynamics and the potential for attracting predators due to its bright colors (Barreiros and Luis Jr., 2008).

There are many citations in the literature of unusual shelters used by hermit crabs, including materials such as tusk shells, sponges, dead corals, pieces of rock, and bamboo (Garcia et al., 2003), although ML has only rarely been reported (Barreiros and Luis Jr., 2008). Hermit crabs of the genus *Coenobita* have been reported in the literature and on photography websites as using beach litter as alternative housing materials (Lewis and Rotjan, 2009; Supplemental References); according to those authors, this was due to the limited availability of adequate natural shells for populations of *C. clypeatus* (Fabricius, 1787) and *C. purpureus* Stimpson, 1858.

Two principal hypotheses have arisen to explain why various hermit crab species would be using ML as alternatives for their mobile shelters based on anthropogenic impacts on marine habitats:

(1) Ocean warming and acidification have affected the calcification processes of mollusk shells (Fabry et al., 2008), and.
(2) Shell collecting for ornamental purposes has resulted in their decreased availability in marine habitats (Kowalewski et al., 2014).

Both of these factors apparently collaborate to produce a scarcity of shells with the resultant necessity of encountering alternatives for organisms (such as hermit crabs) that depend on those types of shelters. Alternatives that are fulfilled by the high availability of ML such as cups and similar objects – although the long-term effects and ecological implications of the use of these objects will require greater research attention.

5. Conclusions

Our results illustrate the ways and degree to which ML is impacting ecological processes on the world's reef ecosystems. Entanglement and/or catches by derelict fishing gear stands out as the main type of disruption, especially in hard corals and reef fishes. Use as refuge is also a usual interaction, particularly in the Atlantic Ocean.

The magnitude of the global impact here described could be underestimated given that some studies do not report quantitative data (by specie/interaction). This highlights the need for further research (e.g. quantitative estimates and temporal trends) in order to more fully assess the scale of the problem. We propose integrated studies as the best way to move forward, for example: retrieving information on ML that is recorded in underwater visual surveys (e.g. video transects and photographic techniques) and adding ML as a routine survey variable in long-term reef monitoring programs (e.g. Reef Check, www.reefcheck.org).

Solid-waste management, international agreements and public awareness (e.g. reducing the use of single-use plastic items) are urgent measures if we are to start reducing the impact of ML on these valuable ecosystems.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2018.05.049.

References

Adelir-Alves, J., Rocha, G.R.A., Souza, T.F., Pinheiro, P.C., Freire, K.M.F., 2016. Abandoned, lost or otherwise discarded fishing gears in rocky reefs of southern Brazil. Braz. J. Oceanogr. 64 (4), 427–434. http://dx.doi.org/10.1590/s1679-87592016124806404.

Airoldi, L., Connell, S.D., Beck, M.W., 2009. The loss of natural habitats and the addition of artificial substrata. In: Wahl, M. (Ed.), Marine Hard Bottom Communities. Ecological Studies (Analysis and Synthesis). Vol. 206 Springer, Berlin, Heidelberg.

http://dx.doi.org/10.1007/b76710_19.

Al-Jufaili, S., Al-Jabri, M., Al-Baluchi, A., Baldwin, R.M., Wilson, S.C., West, F., Matthews, A.D., 1999. Human impacts on coral reefs in the Sultanate of Oman. Estuar. Coast. Shelf Sci. 49 (Suppl. 1), 65–74. http://dx.doi.org/10.1016/j.marpolbul.2017.07.030.

Allen, A.S., Seymour, A.C., Rittschof, D., 2017. Chemoreception drives plastic consumption in a hard coral. Mar. Pollut. Bull. 124, 198–205.

Aloy, A.B., Vallejo Jr., B.M., Juinio-Meñez, M.A., 2011. Increased plastic litter cover affects the foraging activity of the sandy intertidal gastropod *Nassarius pullus*. Mar. Pollut. Bull. 62, 1772–1779. http://dx.doi.org/10.1016/j.marpolbul.2011.05.021.

Amato, K.R., Emel, S.L., Lindgren, C.A., Sullan, K.M., Wright, P.R., Gilbert, J., 2008. Covering behaviour of two co-occurring Jamaican sea urchins: differences in the amount of covering and selection of covering material. Bull. Mar. Sci. 82 (2), 255–261.

Anderson, R.C., Hughes, P.D., Mather, J.A., Steele, C.W., 1999. Determination of the diet of *Octopus rubescens* Berry, 1953 (Cephalopoda: Octopodidae), through examination of its beer bottle dens in Puget sound. Malacologia 41, 455–460.

Angiolillo, M., Lorenzo, B.D., Farcomeni, A., Bo, M., Bavestrello, G., Santangelo, G., Cau, A., Mastascusa, V., Cau, A., Sacco, F., Canese, S., 2015. Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy). Mar. Pollut. Bull. 92 (1–2), 149–159. http://dx.doi.org/10.1016/j.marpolbul.2014.12.044.

Asoh, K., Yoshikawa, T., Kosaki, R., Marschall, E.A., 2004. Damage to cauliflower coral by monofilament fishing lines in Hawaii. Conserv. Biol. 18, 1645–1650. http://dx.doi.org/10.1111/j.1523-1739.2004.00122.x.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc., B 364, 1985–1998. http://dx.doi.org/10.1098/rstb.2008.0205.

Barreiros, J.P., Guerreiro, O., 2014. Notes on a plastic debris collar on a juvenile *Pagellus acarne* (Perciformes: Sparidae) from Terceira Island, Azores, NE Atlantic. Bothalia–Pretoria 44, 2–5.

Barreiros, J.P., Luis Jr., O.J., 2008. Use of plastic debris as shelter by an unidentified species of hermit crab from the Maldives. Mar. Biodivers. Rec. 2, 33–34. http://dx.doi.org/10.1017/S1755267208000377.

Baulch, S., Perry, C., 2014. Evaluating the impacts of marine debris on cetaceans. Mar. Pollut. Bull. 80, 210–221. http://dx.doi.org/10.1016/j.marpolbul.2013.12.050.

Bavestrello, G., Cerrano, C., Zanzi, D., Cattaneo-Vietti, R., 1997. Damage by fishing activities to the gorgonian coral *Paramuricea clavata* in the Ligurian Sea. Aquat. Conserv. Mar. Freshwat. Ecosyst. 7, 253–262. http://dx.doi.org/10.1002/(SICI)1099-0755(199709)7:3%3C253::AID-AQC243%3E3.0.CO;2-1.

Bilkovic, D.M., Havens, K., Stanhope, D., Angstadt, K., 2014. Derelict fishing gear in Chesapeake Bay, Virginia: spatial patterns and implications for marine fauna. Mar. Pollut. Bull. 80, 114–123. http://dx.doi.org/10.1016/j.marpolbul.2014.01.034.

Birdsong, R.S., 1981. A review of the gobiid fish genus *Microgobius* Poey. Bull. Mar. Sci. 31 (2), 267–306.

Bo, M., Cerrano, C., Canese, S., Salvati, E., Angiolillo, M., Santangelo, G., Bavestrello, G., 2013. The coral assemblages of an off-shore deep Mediterranean rocky bank (NW Sicily, Italy). Mar. Ecol. 35–3, 332–342. http://dx.doi.org/10.1111/maec.12089.

Bo, M., Bava, S., Canese, S. Angiolillo, Cattaneo-Vietti, M.R., Bavestrello, G., 2014. Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. Biol. Conserv. 171, 167–176. http://dx.doi.org/10.1016/j.biocon.2014.01.011.

Breen, P.A., 1990. A review of ghost fishing by traps and gillnets. In: Shomura, R.S., Godfrey, M.L. (Eds.), Proceedings of the Second International Conference of Marine Debris. U.S. Department of Commerce, NOAA Tech Memo, NMFS, Honolulu, Hawaii, pp. 571–599.

de Carvalho-Souza, G.F., Tinôco, M.S., 2011. Avaliação do Lixo Marinho em Costões Rochosos na Baía de Todos os Santos, Bahia, Brasil. Revista da Gestão Costeira Integrada 11 (1), 135–143. http://dx.doi.org/10.5894/rgci231.

Cassola, G.E., Pacheco, M.S.C., Barbosa, M.C., Hansen, D.M., Ferreira, C.E.L., 2016. Decline in abundance and health state of an Atlantic subtropical gorgonian population. Mar. Pollut. Bull. 104, 329–334. http://dx.doi.org/10.1016/j.marpolbul.2016.01.022.

Chiappone, M., White, A., Swanson, D., Miller, S.L., 2002. Occurrence and biological impacts of fishing gear and other marine debris in the Florida keys. Mar. Pollut. Bull. 44, 597–604. http://dx.doi.org/10.1016/S0025-326X(01)00290-9.

Chiappone, M., Dienes, H., Swanson, D.W., Miller, S.L., 2005. Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida keys National Marine Sanctuary. Biol. Conserv. 121, 221–230. http://dx.doi.org/10.1016/j.biocon.2004.04.023.

Chiba, S., Saito, H., Fletcher, R., Yogi, T., Kayo, M., Miyagi, S., Ogido, M., Fujikura, K., 2018. Human footprint in the abyss: 30 year records of deep-sea plastic debris. Mar. Policy. http://dx.doi.org/10.1016/j.marpol.2018.03.022.

Cleary, D.F.R., Suharsono, Hoeksema, B.W., 2006. Coral diversity across a disturbance gradient in the Pulau Seribu reef complex off Jakarta, Indonesia. Biodivers. Conserv. 15, 3653– – 3674. http://dx.doi.org/10.1007/s10531-004-4692-y.

Corcoran, P.L., Moore, C.J., Jazvac, K., 2014. An anthropogenic marker horizon in the future rock record. GSA Today 24, 4–8. http://dx.doi.org/10.1130/GSAT-G198A.1.

Cózar, A., Martí, E., Duarte, C.M., García-de-Lomas, J., Van Sebille, E., Ballatore, T.J., Eguíluz, V.M., González-Gordillo, J.I., Pedrotti, M.L., Echevarría, F., Romain Troublè, R., Irigoien, X., 2017. The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the thermohaline circulation. Sci. Adv. 3, e1600582. http://dx.doi.org/10.1126/sciadv.1600582.

Critchell, K., Grech, A., Schlaefer, J., Andutta, F.P., Lambrechts, J., Wolanski, E., Hamann, M., 2015. Modelling the fate of marine debris along a complex shoreline: lessons from the Great Barrier Reef. Estuar. Coast. Shelf Sci. 167, 414–426. http://dx.doi.org/10.1016/j.ecss.2015.10.018.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44, 842–852. http://dx.doi.org/10.1016/S0025-326X(02)00220-5.

Deudero, S., Alomar, C., 2015. Mediterranean marine biodiversity under threat: reviewing influence of marine litter on species. Mar. Pollut. Bull. 98, 58–68. http://dx.doi.org/10.1016/j.marpolbul.2015.07.012.

Donohue, M.J., Boland, R., Sramek, C., Antonelis, G., 2001. Derelict fishing gear in the northwestern Hawaiian islands: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. Mar. Pollut. Bull. 42, 1301–1312. http://dx.doi.org/10.1016/S0025-326X(01)00139-4.

Dumont, C.P., Drolet, D., Heschênes, I., Himmelman, J.H., 2007. Multiple factors explain the covering behaviour in the green sea urchin, *Strongylocentrotus droebachiensis*. Anim. Behav. 73, 979–986. http://dx.doi.org/10.1016/j.anbehav.2006.11.008.

Eriksen, M., Lebreton, L.M., Carson, H.S., Thiel, M., Moore, C., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9, e111913. http://dx.doi.org/10.1371/journal.pone.0111913.

Fabry, V.J., Seibel, B.A., Feely, R.A., Orr, J.C., 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. ICES J. Mar. Sci. 65, 414–432. http://dx.doi.org/10.1093/icesjms/fsn048.

Feitoza, B.M., Dias, T.L., Rosa, R.S., 2001. Occurrence of *Microgobius carri* Fowler 1945 (Teleostei: Gobiidae) in the coast of Paraíba, northeastern Brazil, with notes on its ecology. Revista Nordestina de Biologia 15 (1), 107–112.

Ferreira, C.E.L., Floeter, S.R., Gasparini, J.L., Ferreira, B.P., Joyeux, J.C., 2004. Trophic structure patterns of Brazilian reef fishes: a latitudinal comparison. J. Biogeogr. 31, 1093–1106. http://dx.doi.org/10.1111/j.1365-2699.2004.01044.x.

Figueroa-Pico, J., Mero-Del Vale, D., Castillo-Ruperti, R., Macías-Mayorga, D., 2016. Marine debris: implications for conservation of rocky reefs in Manabi, Ecuador (Se Pacific Coast). Mar. Pollut. Bull. 109, 7–13. http://dx.doi.org/10.1016/j.marpolbul.2016.05.070.

Floeter, S.R., Krohling, W., Gasparini, J.L., Ferreira, C.E.L., Zalmon, I.R., 2007. Reef fish community structure on coastal islands of the southeastern Brazil: the influence of exposure and benthic cover. Environ. Biol. Fish 78, 147–160. http://dx.doi.org/10.1007/s10641-006-9084-6.

Froese, R., Pauly, D., 2016. FishBase. World Wide Web Electronic Publication. www.fishbase.org version (01/2016).

Galgani, F., Souplet, A., Cadiou, Y., 1996. Accumulation of debris on the deep sea floor off the French Mediterranean coast. Mar. Ecol. Prog. Ser. 142, 225–234. http://dx.doi.org/10.3354/meps142225.

Galgani, F., Leaute, J.P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y., Mahe, J.C., Poulard, J.C., Nerisson, P., 2000. Litter on the sea floor along European coasts. Mar. Pollut. Bull. 40, 516–527. http://dx.doi.org/10.1016/S0025-326X(99)00234-9.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179. http://dx.doi.org/10.1016/j.marpolbul.2014.12.041.

Garcia, R.B., Meireles, A.L., Mantelatto, F.L., 2003. Unusual shelters occupied by Brazilian hermit crabs (Crustacea: Decapoda: Diogenidae). Braz. J. Biol. 63, 721–722. http://dx.doi.org/10.1590/S1519-69842003000400020.

Good, T.P., June, J.A., Etnier, M.A., Broadhurst, G., 2010. Derelict fishing nets in Puget sound and the northwest straits: patterns and threats to marine fauna. Mar. Pollut. Bull. 60, 39–50. http://dx.doi.org/10.1016/j.marpolbul.2009.09.005.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings -entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc., B 364, 2013–2025. http://dx.doi.org/10.1098/rstb.2008.0265.

Gudger, E.W., 1928. A mackerel (*Scombrus scombrus*) with a rubber band rove through its body. Am. Mus. Novit. 310, 1–6.

Gudger, E.W., Hoffmann, W.H., 1933. A shark encircled with a rubber automobile tire. Sci. Mon. 33, 275–277.

Hall, N.M., Berry, K.L.E., Rintoul, L., Hoogenboom, M.O., 2015. Microplastic ingestion by scleractinian corals. Mar. Biol. 162, 725–732. http://dx.doi.org/10.1007/s00227-015-2619-7.

Havens, K., Bilkovic, D.M., Stanhope, D., Angstadt, K., 2011. Fishery failure, unemployed commercial fishers, and lost blue crab pots: an unexpected success story. Environ. Sci. Pol. 14, 445–450. http://dx.doi.org/10.1016/j.envsci.2011.01.002.

Heifetz, J., Stone, R.P., Shotwell, S.K., 2009. Damage and disturbance to coral and sponge habitat of the Aleutian archipelago. Mar. Ecol. Prog. Ser. 397, 295–303. http://dx.doi.org/10.3354/meps08304.

Houard, T., Boudouresque, C.F., Barcelo, A., Cottalorda, J.-M., Formentin, J.Y., Jullian, E., Kerlidou, B., Pironneau, E., 2012. Occurrence of a lost fishing net within the marine area of the Port-Cross national park (Provence, northwestern Mediterranean Sea). Scientific Report Port-Cros National Park 25, 109–118.

Humann, P., Deloach, N., 2002. Reef Fish identification: Florida, Caribbean, Bahamas. New World Publications, Jacksonville.

Humann, P., Deloach, N., 2003. Reef Creatures Identification: Florida, Caribbean, Bahamas. New World Publications, Jacksonville.

Ioakeimidis, C., Fotopoulou, K.N., Karapanagioti, H.K., Geraga, M., Zeri, C., Papathanassiou, E., Galgani, F., Papatheodorou, G., 2016. The degradation potential of PET bottles in the marine environment: an ATR-FTIR based approach. Sci. Rep. 6 (23501). http://dx.doi.org/10.1038/srep23501.

Katsanevakis, S., 2015. Illegal immigration in the eastern Aegean Sea: a new source of marine litter. Mediterr. Mar. Sci. 16 (3), 605–608. http://dx.doi.org/10.12681/mms.1463.

Katsanevakis, S., Verriopoulos, G., 2004. Den ecology of *Octopus vulgaris*, Cuvier 1797, on soft sediment: availability and types of shelter. Sci. Mar. 68, 147–157. http://dx.doi.org/10.3989/scimar.2004.68n1147.

Katsanevakis, S., Verriopoulos, G., Nicolaidou, A., Thessalou-Legaki, M., 2007. Effect of marine litter on the benthic megafauna of coastal soft bottoms: a manipulative field experiment. Mar. Pollut. Bull. 54, 771–778. http://dx.doi.org/10.1016/j.marpolbul.

2006.12.016.

Kowalewski, M., Domènech, R., Martinell, J., 2014. Vanishing clams on an Iberian Beach: local consequences and global implications of accelerating loss of shells to tourism. PLoS One 9 (1), e83615. http://dx.doi.org/10.1371/journal.pone.0083615.

Kühn, S., Bravo Rebolledo, E.L., Van Franeker, J.A., 2015. Deleterious effects of litter on marine life. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer, Berlin, pp. 75–116. http://dx.doi.org/10.1007/978-3-319-16510-3_4.

Ladroue, C., 2012. Polar Histogram Pretty and Useful_Christophe Ladroue. chrisladroue.com/wp-content/uploads/2012/02/polarHistogram.R.zip.

Laist, D.W., 1997. Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records. Springer Series on Environmental Management Springer, New York. http://dx.doi.org/10.1007/978-1-4613-8486-1_10.

Lamb, J.B., Willis, B.L., Fiorenza, E.A., Couch, C.S., Howard, R., Rader, D.N., True, J.D., Kelly, L.A., Ahmad, A., Jompa, J., Harvell, C.D., 2018. Plastic waste associated with disease on coral reefs. Science 359 (6374), 460–462. http://dx.doi.org/10.1126/science.aar3320.

Lavers, J.L., Bond, A.L., 2017. Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. Proc. Natl. Acad. Sci. U. S. A. 114, 6052–6055. http://dx.doi.org/10.1073/pnas.1619818114.

Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., Reisser, J., 2017. River plastic emissions to the world's oceans. Nat. Commun. 8. http://dx.doi.org/10.1038/ncomms15611.

Lewis, S.M., Rotjan, R.D., 2009. Vacancy chains provide aggregate benefits to *Coenobita clypeatus* hermit crabs. Ethology 115, 356–365. http://dx.doi.org/10.1111/j.1439-0310.2009.01626.x.

Macfadyen, G., Huntington, T., Cappell, R., 2009. Abandoned, lost or otherwise discarded fishing gear. In: UNEP Regional Seas Reports and Studies, No. 185; FAO Fisheries and Aquaculture Technical Paper, No. 523. Vol. 2009 UNEP/FAO, Rome (115 p).

Melli, V., Angiolillo, M., Ronchi, F., Canese, S., Giovanardi, O., Querin, S., Fortibuoni, T., 2017. The first assessment of marine debris in a site of community importance in the north-western Adriatic Sea (Mediterranean Sea). Mar. Pollut. Bull. 114, 821–830. http://dx.doi.org/10.1016/j.marpolbul.2016.11.012.

Mordecai, G., Tyler, P.A., Masson, D.G., Huvenne, V.A.I., 2011. Litter in submarine canyons off the west coast of Portugal. Deep Sea Res., Part II 58, 2489–2496. http://dx.doi.org/10.1016/j.dsr2.2011.08.009.

Nelson, J.S., 2006. Fishes of the World, 4th ed. John Wiley & Sons, Hoboken (New Jersey, USA) (601 p).

NOAA. Marine Debris Program, 2014. Report on the Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States. Silver Spring, MD. Vol. 28.

NOAA. Marine Debris Program, 2016. Report on Marine Debris Impacts on Coastal and Benthic Habitats. National Oceanic and Atmospheric Administration Marine Debris Program, Silver Spring, MD, pp. 31.

Nunes, J.A.C.C., Sampaio, C.L.S., Barros, F., Leduc, A.O.H.C., 2018. Plastic debris collars: an underreported stressor in tropical reef fishes. Mar. Pollut. Bull. 129, 802–805. http://dx.doi.org/10.1016/j.marpolbul.2017.10.076.

QGIS Development Team, 2018. QGIS Geographic Information System. Software Version 3.0.2. Open Source Geospatial Foundation Project. http://www.qgis.org/.

R Core Team, 2018. R: A Language and Environment for Statistical Computing. Software version 3.5.0. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org.

Ramirez-Llodra, E., De Mol, B., Company, J.B., Coll, M., Sardà, F., 2013. Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea. Prog. Oceanogr. 118, 273–287. http://dx.doi.org/10.1016/j.pocean.2013.07.027.

Reed, S.E., 1992. *Astrapogon alutus* (Perciformes: Apogonidae) found in the mantle cavity of *Strombus pugilis* (Mesogastropoda: Strombidae). Bull. Mar. Sci. 50 (1), 227.

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B.D., Proietti, M., Thums, M., Pattiaratchi, C., 2013. Marine plastic pollution in waters around Australia: characteristics, concentrations, and pathways. PLoS One 8 (11), e80466. http://dx.doi.org/10.1371/journal.pone.0080466.

Richards, Z.T., Beger, M., 2011. A quantification of the standing stock of macro-debris in Majuro lagoon and its effect on hard coral communities. Mar. Pollut. Bull. 62, 1693–1701. http://dx.doi.org/10.1016/j.marpolbul.2011.06.003.

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F.C., Werorilangi, S., Teh, S.J., 2015. Anthropogenic debris in seafood: plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Sci. Rep. 5 (14340). http://dx.doi.org/10.1038/srep14340.

Rodríguez, Y., Pham, C.K., 2017. Marine litter on the seafloor of the Faial-Pico passage, Azores archipelago. Mar. Pollut. Bull. 116 (1–2), 448–453. http://dx.doi.org/10.1016/j.marpolbul.2017.01.018.

Ryan, P.G., 2015. A brief history of marine litter research. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer International, New York. http://dx.doi.org/10.1016/j.marpolbul.2017.01.018.

Saldanha, H.J., Sancho, G., Santos, M.N., Puente, E., Gaspar, M.B., Bilbao, A., Monteiro, C.C., Gomez, E., Arregi, L., 2003. The use of biofouling for ageing lost nets: a case study. Fish. Res. 64, 141–150. http://dx.doi.org/10.1016/S0165-7836(03)00213-3.

Sampaio, C.L.S., Nottingham, M.C., 2008. Guia para Identificação de Peixes Ornamentais Brasileiros, 1 edition. Ibama, Brasília.

Sazima, I., Gadig, O.B.F., Namora, R.C., Motta, F.S., 2002. Plastic debris collars on juvenile carcharhinid sharks (*Rhizoprionodon lalandii*) in Southwest Atlantic. Mar. Pollut. Bull. 44, 1147–1149. http://dx.doi.org/10.1016/S0025-326X(02)00141-8.

Schleyer, M.H., Tomalin, B.J., 2000. Damage on South African coral reefs and an assessment of their sustainable diving capacity using a fisheries approach. Bull. Mar. Sci. 67, 1025–1042.

Schmitt, E.F., Sullivan, K.M., 1996. Analysis of a volunteer method for collecting fish presence and abundance data in the Florida Keys. Bull. Mar. Sci. 59 (2), 404–416.

Thiel, M., Gutow, L., 2005. The ecology of rafting in the marine environment. II. The rafting organisms and community. Oceanogr. Mar. Biol. 43, 279–418.

Uneputty, P., Evans, S.M., 1997. The impact of plastic debris on the biota of tidal flats in Ambon Bay (Eastern Indonesia). Mar. Environ. Res. 44, 233–242. http://dx.doi.org/10.1016/S0141-1136(97)00002-0.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut. 178, 483–492. http://dx.doi.org/10.1016/j.envpol.2013.02.031.

Yoshikawa, T., Asoh, K., 2004. Entanglement of monofilament fishing lines and coral death. Biol. Conserv. 117, 557–560. http://dx.doi.org/10.1016/j.biocon.2003.09.025.