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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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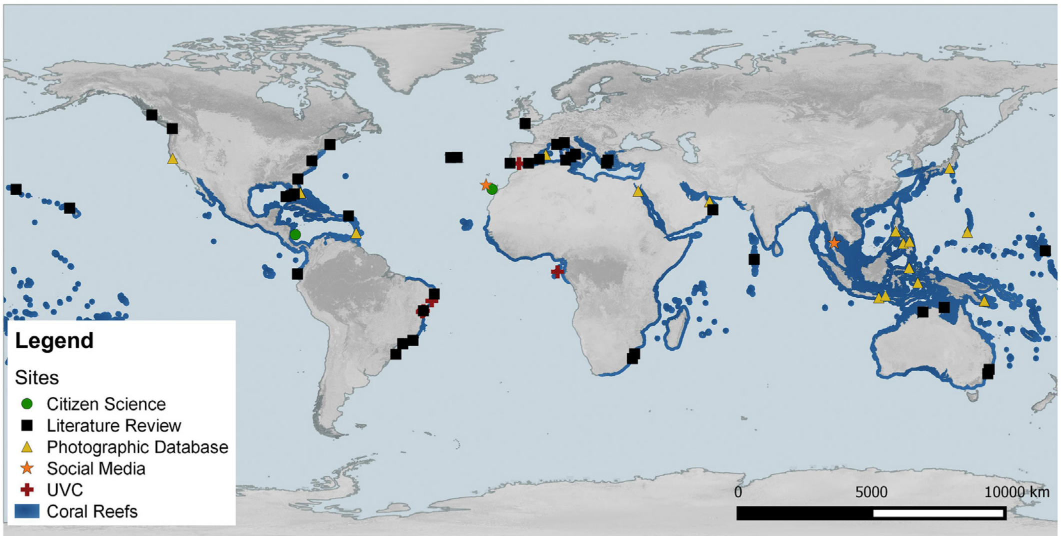

Fig. 1. Distribution of data sampling in reef systems around the world. In blue, the map details represent the global distribution of warm-water coral reefs. Legend: UVC – Underwater visual census. (For interpretation of the references to colour in this figure legend, the reader is referred to the web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