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Abundance of litter on Condor seamount (Azores, Portugal, Northeast Atlantic)

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ABSTRACT

Marine litter is an emerging problem for the world's ocean health but little is known on its distribution and abundance on seamounts and how it affects deep-sea ecosystems. The scientific underwater laboratory set up on Condor seamount offered an ideal case study for the first documentation of litter distribution on a shallow seamount with historical fishing. A total of 48 video transects deployed on the summit ($n=45$) and the northern flank ($n=3$) covered an area of 0.031 and 0.025 km^2, respectively, revealing 55 litter items. Litter density on the summit was 1439 litter items km^{-2}, whilst on the deeper northern flank, estimates indicate densities of 397 litter items km^{-2}. Lost fishing line was the dominant litter item encountered on both areas (73% of total litter on the summit and 50% on northern flank), all being entirely or partly entangled in the locally abundant gorgonians *Dentomuricea* cf. *meteor* and *Viminella flagellum*. Other items included lost weights, anchors and glass bottles. The predominance of lost fishing gear identifies the source of litter on Condor seamount as exclusively ocean-based and related to fishing activities. Abundance of litter on the Condor seamount was much lower than that reported from other locations closer to populated areas.

1. Introduction

The deep-sea realm is generally perceived as a vast underwater area isolated from anthropogenic influences. However, there is an increasing amount of data suggesting the deep sea is not protected from human activities (Ramirez-Llodra et al., 2011; Thiel, 2003). In addition to the most well known anthropogenic practices such as fishing or oil and gas exploitation (Santos et al., 2012), recent studies suggest marine litter to be abundant in the deep sea with unknown consequences to its inhabitants (Keller et al., 2010; Miyake et al., 2011; Mordecai et al., 2011; Ramirez-Llodra et al., accepted; Wei et al., 2012).

Marine litter, defined as "any persistent manufactured or processed solid material discarded, disposed of or abandoned in the marine environment" (UNEP, 2009), comes from a wide variety of sources. The discharging can be either from ocean or land-based sources, including shipping (merchant, public, leisure), oil platforms installation and operation, fishing, open ocean dumping, waste from dump sites on the coastline or on river banks and littering of beaches (UNEP, 2009). Litter supply and deposition on the ocean floor is guided by a complex set of interactions between human activities, hydrography and geomorphology (Galgani et al., 2000). For example, canyons have been suggested to act as pathways for litter transfer from coastal regions to the deep-sea floor (Galgani et al., 1996; Mordecai et al., 2011; Ramirez-Llodra et al., accepted). Litter accumulation in the Arctic could be a result of large scale currents, such as the North-Atlantic drift and the West Spitsbergen current, transporting litter from the north-east Atlantic, down to the seafloor by strong winds (Bergmann and Klages, 2012; Kukulka et al., 2012).

Seamounts are "undersea mountains" that are typically located far from coastal urban areas. They are areas with enhanced productivity considered as hotspots for biodiversity (Morato et al., 2010a; Pitcher et al., 2007). Some seamounts are fragile ecosystems threatened by intense fishing pressure, resulting in overexploitation of fish stocks but also in the destruction of habitat-building organisms by fishing gear (Pitcher et al., 2010). No studies have looked at the occurrence and distribution of marine litter on seamounts. Thus, the objective of the study was to investigate the distribution and abundance of litter on Condor seamount, a traditional fishing ground recently closed to fishing for research purposes (Morato et al., 2010b).

2. Materials and methods

2.1. Study site

Condor seamount is located 17 km southwest of Faial Island, Azores Archipelago (Portugal). The area has been used by local fisherman for decades, using handlines and bottom longline

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mostly down to 600 m (Menezes et al., this issue), and was recently closed to fishing for research purposes (year 2010; Morato et al., 2010b). It is a linear underwater volcano with a length of 35 km and 2–6 km wide, with a total surface area of 447 km^2 (Fig. 1). It is a shallow seamount with a moderately flat summit, reaching 184 m at the most western side, and with sloping flanks extending down to 1000–1700 m (Tempera et al., 2012a). The summit (defined as the top area with a depth <300 m and slope generally $<5^\circ$) has a total area of 6.85 km^2 (Fernando Tempera, unpublished data). The seamount is a rich area hosting dense coral gardens, sponge aggregations as well as many fish species of commercial interest.

2.2. Sampling

Between 2010 and 2011, 48 dives were conducted on Condor seamount using two different platforms: the exploratory Remote Operated Vehicle (ROV) *SP* (IMAR-DOP/UAç, rated 300 m) and the working class ROV *Luso* (EMEPC, rated 6000 m). ROV *SP* is equipped with two cameras; one color camera (570 line/02 Lux super HAD color) and one black and white camera (430 LINE/ 0.03 Lux). The camera on ROV *Luso* is a high definition camera (Optical 10 ×, f=5.1–51 mm).

The objectives of the dives were to survey benthic habitats and collect coral samples. The duration of each dive was limited by weather conditions and bottom current and varied from 7 min to 60 min for ROV *SP* and between 150 and 540 min for ROV *Luso*. 45 dives were performed on the summit at depths ranging from 185 to 265 m whilst three dives were conducted on the northern flank, between 297 and 1092 m (Table 1).

The geographic position of ROV *SP* and ROV *Luso* was recorded by USBL systems (Ultra Short Baseline). The navigational data were filtered for outliers and smoothed with a moving average to remove false loops. Overall, the distance covered ranged between 102 and 3583 m per dive (average 420 m) and included only the portion of the video when the ROV was near the bottom (off-bottom sequences were excluded from the analysis).

The surveyed area was estimated using the average width of view of each platform. The width of view was calculated for 449 frames (randomly selected), from 15 different dives for ROV *SP* and 141 frames from two dives for ROV *Luso* using the scaling lasers projected on the seafloor.

2.3. Video analysis

Video transects were annotated systematically for the presence of marine litter. Video annotation was conducted with the Customizable Observation Video Image Recorder – COVER (v0.7.2, Ifremer; Carré, 2010), allowing data geo-location and description of items to be recorded simultaneously. Litter items were attributed to one of the following categories; "monofilament longline", "multifilament longline", "glass", "plastic" and "other items"

3. Results and discussion

A total of 55 litter items were encountered within a total area of 56,430 m^2 (or 0.056 km^2) (Table 1). Total litter density on the seamount summit was 1439 items km^{-2} whilst total litter density on the northern flank was 397 items km^{-2} (Table 1). Lost fishing lines were the primary litter item present on the summit and flank, representing 73% and 50% of total litter items, respectively (Fig. 2), with monofilament lines being the dominant type. The remaining litter items consisted of glass bottles (10% on flank and 11% on summit) and other fishing-related objects (40% on flank and 16% on summit) such as weights, a hammer and an anchor (Fig. 3). No plastic items were found.

Litter abundance in the deep sea has been investigated in other regions using trawl, ROV's, manned submersibles and side can sonar (Bergmann and Klages, 2012; Galgani et al. 1995, 1996, 2000; Keller et al., 2010; Mordecai et al., 2011; Ramirez-Llodra et al., accepted; Stevens et al., 2000; Watters et al., 2010; Wei et al., 2012), with the deepest litter item found at 7212 m (Miyake et al., 2011). Although comparisons between areas can reflect differences in sampling methodologies, the densities reported

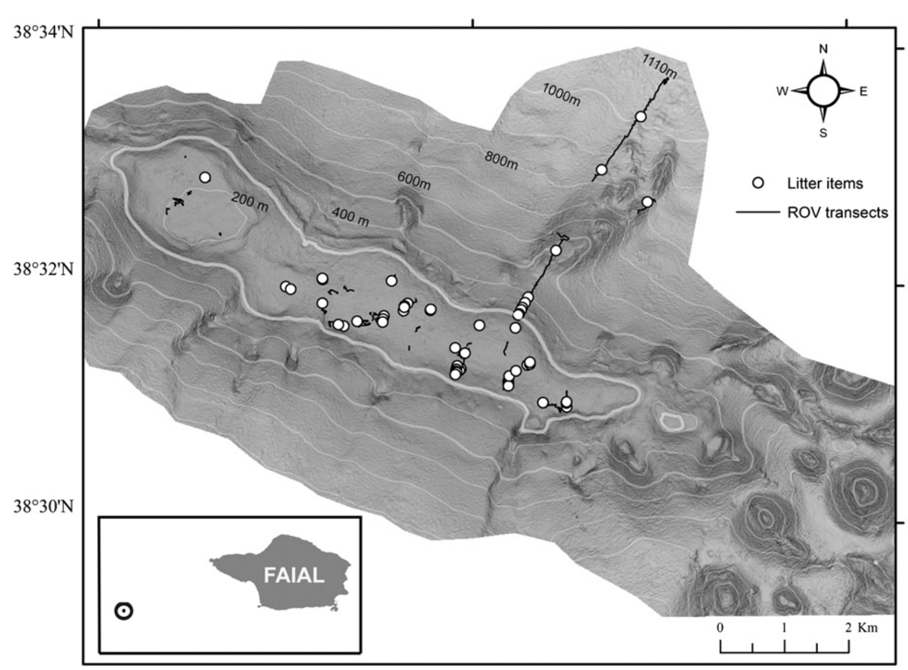

Fig. 1. ROV transects conducted on Condor seamount and position of litter items. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

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Table 1
Description of the remote operated vehicles dive transects and litter abundance on the summit and northern flank of Condor seamount. Abundance is presented as items of litter per 100 m of ROV track, converted to area by assuming a width of view of 3.7 m (average $\pm$SD 0.8 m) for transects made with ROV *Luso* and 2.3 m (average $\pm$SD 1.1 m) for ROV *SP*.

Location	No. of transects	Depth range (m)	Total distance (km)	Total area covered (km^2)	Number of litter items	Litter items 100 m^{-1}	Litter items km^{-2}
Summit	45	185–265	13.3	0.03 ± 0.01	45	0.3	1439
Northern flank	3	297–1092	6.8	0.03 ± 0.01	10	0.1	397
Total	48	185–1092	20.1	0.06 ± 0.02	55	0.3	975

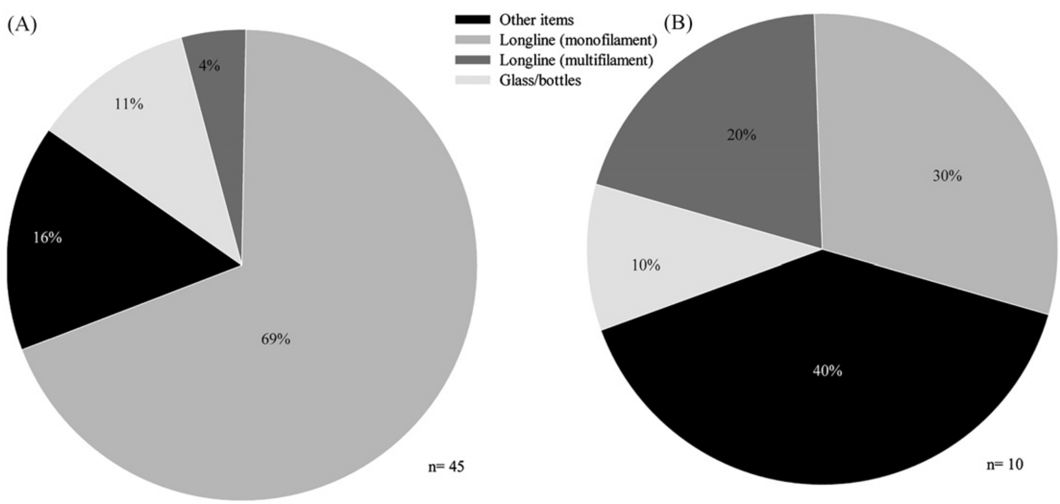

Fig. 2. Proportion of litter items found on the (A) summit and (B) northern flank of Condor seamount (n refers to the total number of litter items).

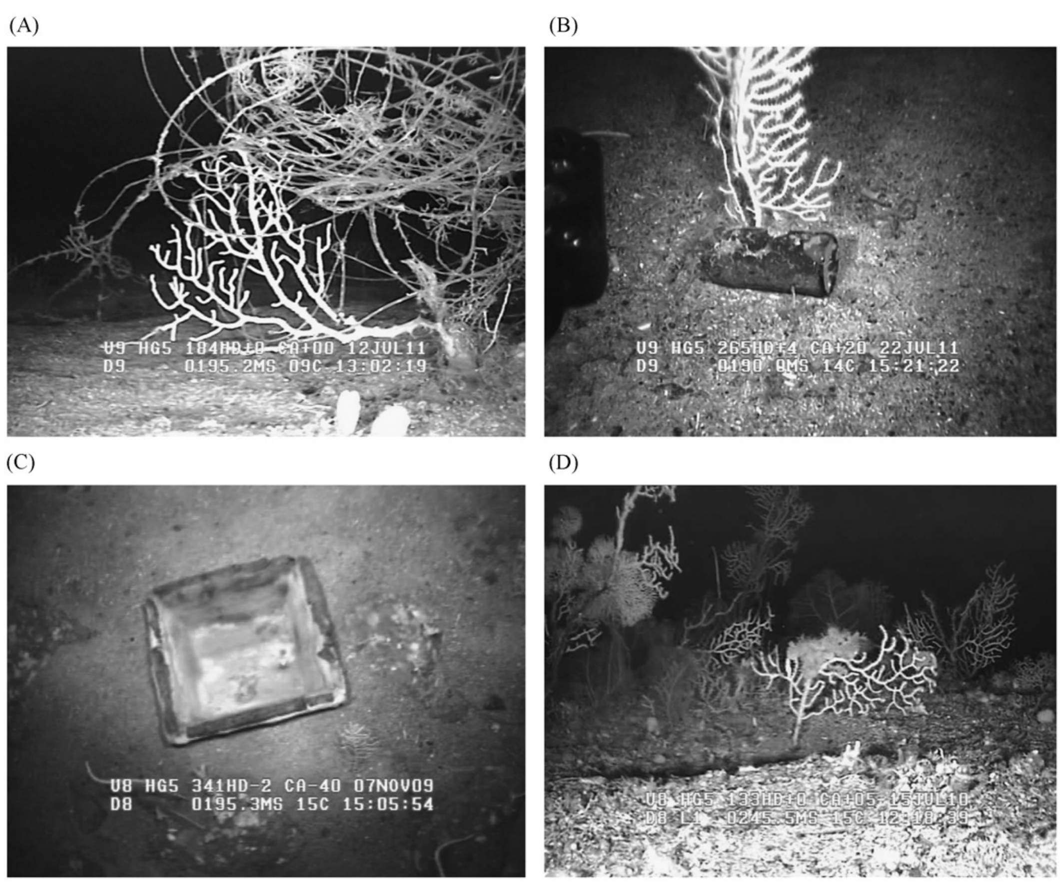

Fig. 3. Litter items on Condor seamount and interactions with local fauna. (A) close up of a *Dentomuricea* cf. *meteor* entangled within a longline; (B) glass bottle next to *Dentomuricea* cf. *meteor*; (C) lost wooden box used by fisherman to hook their longlines; and (D) several *Dentomuricea* cf. *meteor* partially damaged.

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here were below the ones reported for deep-water areas adjacent to populated areas, such as the Lisbon canyon (Mordecai et al., 2011), with densities of 6600 litter items km^{-2}. In contrast to the dominance of fishing gear on Condor seamount, litter items in Lisbon canyons were almost exclusively of terrestrial origin with plastic being the dominant litter type. Surveys conducted with the manned submersible *Cyana* in the north Mediterranean Sea (Galgani et al., 1996), reported densities of up to 11.2 items 100 m^{-1} of transect, which are also much higher than our estimates (0.3 items 100 m^{-1}). Litter densities on Condor seamount, a commercial fishing ground, were also much lower than surveys in areas where recreational fishing activities are intense, as off California (Watters et al., 2010). In these areas, litter densities reached up to 38 items 100 m^{-1}, whereas on Condor seamount, maximum litter densities on one transect was two items 100 m^{-1}.

Litter composition identifies commercial bottom fishing as the principal activity occurring on Condor seamount. Tourism activities such as game fishing and shark diving are increasing and also present potential sources of marine litter (Ressurreição and Giacomello, this issue). Other studies have found marine debris originating from ocean-based activities (fishing, ships, etc.) to be the most important source in locations far from population centers (Katsanevakis and Katsarou, 2004; Lee et al., 2006; Watters et al., 2010). Even though Condor seamount is located just 17 km from the coast, the deep-waters separating the seamount from coastal areas probably acting as a barrier, prevent the deposition of land-based litter on the seamount.

Almost no information exists on the impact of litter on deep-sea ecosystems. Similar to other studies which report organisms entangled within litter items (June, 1990; Mordecai et al., 2011) our images showed fishing lines partly entangled within gorgonians *Dentomuricea* cf. *meteor* (Fig. 3a) and *Viminella flagellum*. These are the dominant sessile organisms found on the seamount down to circa 500 m (Tempera et al., 2012a), the most exploited depths by past operating fisheries (Menezes et al., this issue). Nevertheless, all corals observed where considered alive from their standing position and coloration but had some occasional broken parts. Damaged colonies may be more vulnerable to parasitism by other corals like zoanthids (Carreiro-Silva et al., 2011) and eventually die, as demonstrated for shallow-water Anthozoans (Asoh et al., 2004; Bavestrello et al., 1997; Yoshikawa and Asoh, 2004). Another impact of lost fishing gear is through ghost fishing. However, unlike lost fishing nets (Brown and Macfadyen, 2007) our observations did not suggest that lost fishing lines continued to fish after being lost.

The dominant type of litter items in the world's ocean is plastic (Derraik, 2002). Plastic accumulates in the marine environment at an alarming rate with the situation in the deep sea being more critical since its degradation rate is much lower than in surface waters (Gregory and Andrady, 2003). Unlike other deep sea sites, where plastic bags and bottles are the most common plastic items (Galgani et al., 1995, 2000; June, 1990), these were not observed on Condor seamount. Monofilament fishing line was the only type of plastic observed. Although it remains to be determined if the gorgonians on Condor seamount might survive entanglement, research efforts in the Azores are concentrating on identifying the localization of vulnerable marine ecosystems (VMEs) (e.g. Morato et al., 2008; Santos et al., 1995; Tempera et al., 2012b) to better manage the distribution of fishing effort on such areas.

The glass component of the litter identified on Condor seamount, is mostly from beer bottles. We estimated an average 160 bottles km^{-2} on the seamount summit, a component of the marine debris that could be minimized by developing public awareness and educational efforts. In the Azores, such work is currently underway since several years namely through an EU-Life Project (see www.horta.uac.pt/projectos/macmar/life/sens.html) and three InterReg MAC (see www.macmar.info).

Quantifying litter solely from ROV images may underestimate their densities as buried and small litter items are not accounted (Spengler and Costa, 2008). However, the use of trawls on complex rocky habitats or in areas with large densities of habitat buildng invertebrates is not appropriate and the increasing amount of ROV footage collected for other purposes offers an excellent opportunity to investigate the abundance of litter items in the deep sea.

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