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Distribution and composition of floating macro litter off the Azores archipelago and Madeira (NE Atlantic) using opportunistic surveys

Philippine Chambault[a,b,*], Frederic Vandeperre[a,b,c], Miguel Machete[a,b], João Carvalho Lagoa[a,b], Christopher Kim Pham[a,b,c]

[a] IMAR, Instituto do Mar, Departamento de Oceanografia e Pescas, Universidade dos Açores, 9901-862, Horta, Portugal
[b] OKEANOS, Universidade dos Açores, Departamento de Oceanografia e Pescas, 9901-862, Horta, Portugal
[c] MARE, Marine and Environmental Sciences Centre, Universidade dos Açores, 9901-862, Horta, Portugal

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ABSTRACT

The distribution and composition of macro litter floating around oceanic islands is poorly known, especially in the North Atlantic. Due to its isolated location at the fringe of the North Atlantic subtropical gyre, the Azores archipelago has recently been proposed as a potential retention zone for floating litter. To further investigate this assumption, opportunistic surveys from pole-and-line tuna fishing boats were performed from 2015 to 2017 to document (1) the distribution and (2) the composition of the floating macro litter present off the Azores and Madeira islands. Among the 2406 visual transects, 482 floating debris were recorded and were mainly composed of general plastic user items (48%), plastic packaging (21%) and derelict fishing gears (18%). Average number of debris per transect was 0.19 ± 0.5, with a total number ranging between 0 and 5 items per transect. For the majority of transects (84%), no debris was observed, 13% of the transects contained a single item, and only 3% contained more than one item. Although debris between 2.5 and 5 cm were recorded, 93% of the debris were larger than 5 cm. The GLMs showed strong effect of the observer ($p < 0.001$) and the standardized densities accounting for the observer bias were higher (1.39 ± 0.14 items.km^{-2}) than the observed densities (0.78 ± 0.07 items.km^{-2}). Debris densities were however relatively low and tended to aggregate around the Central group of the Azores (standardized mean: 0.90 ± 0.20 items.km^{-2}). Our findings therefore suggest that most of the debris might originate from far away land-based sources and from fishing activities. This study highlights the potential of fisheries observer programs to obtain cost-effective information on floating macro debris that are essential to support the implementation of the European Marine Strategy Framework Directive.

1. Introduction

In response to the increasing number of anthropogenic stressors that jeopardize ocean resources and health, the European Union adopted in 2008 the European Marine Strategy Framework Directive (MSFD, 2008/56/EC). This directive aims to achieve a Good Environmental Status (GES) of the EU's marine waters by 2020. Among the 11 descriptors listed in the Annex I of the MSFD for determining the GES, descriptor 10 refers to “Marine litter”. Marine litter is defined by the United Nations Environment Program (UNEP) as “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment” (UNEP, 2009). Plastic accounts for the majority of the debris found in the oceans (Derraik, 2002). It is estimated that between 4.8 and 12.7 million metric tons of plastic waste entered the ocean in 2010 (Jambeck et al., 2015). Although the majority of marine debris eventually sink to the seafloor or are washed up on the coastal zone, most debris will first float at the sea surface, being transported over long distances by winds and ocean currents (Galgani et al., 2015).

Over the past 10 years, a large number of studies have investigated the distribution and abundance of floating macro litter in the Mediterranean Sea (Aliani et al., 2003; Arcangeli et al., 2018; Darmon et al., 2017; Deudero and Alomar, 2015; Di-Méglio and Campana, 2017; Suaria and Aliani, 2014), the Pacific Ocean (Hinojosa and Thiel, 2009; Pichel et al., 2012, 2007; Titmus and David Hyrenbach, 2011), and in the Atlantic Ocean (Barnes and Milner, 2005; Ryan, 2014; Sá et al., 2016). Despite the few studies conducted in the different oceanic basins, the distribution and composition of macro litter remains poorly described in remote areas such as oceanic islands.

The advances in numerical modeling enabled to counterbalance this

* Corresponding author. IMAR, Instituto do Mar, Departamento de Oceanografia e Pescas, Universidade dos Açores, 9901-862, Horta, Portugal.
E-mail address: philippine.chambault@gmail.com (P. Chambault).

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lack of *in situ* observations in some locations by simulating the dispersal of particles (i.e. floating micro and macro debris) in the ocean using oceanic circulation models. Such studies have provided useful information on the transport, accumulation zones and potential origins of debris at different scales (Hardesty et al., 2017; Lebreton et al., 2018, 2012; Mansui et al., 2015; Martinez et al., 2009; Maximenko et al., 2012; van Sebille et al., 2015, 2012), confirming therefore the high proportion of debris, particularly microplastics, that accumulate in subtropical gyres.

Due to its isolated location at the fringe of the North Atlantic subtropical gyre (1400 km west of Europe and 2000 km east of North America) and its complex oceanographic structures (Gould, 1985; Kase, 1996; Kielmann and Käse, 1987; Klein and Siedler, 1989; Sy, 1988), the Azores archipelago has recently been proposed as a potential retention zone for floating particles (Sala et al., 2016). The Azores are also known to be a biodiversity hotspot (Santos et al., 1996), hosting a large number of marine megafauna species such as cetaceans (e.g. Clua and Grosvalet, 2001; Hartman et al., 2008; Magalhães et al., 2002; Silva, 2007; Silva et al., 2014; Steiner et al., 2008), seabirds (e.g. Monteiro et al., 1999, 1996), fishes (e.g. Thorrold et al., 2014; Vandeperre et al., 2014a, 2014b) and sea turtles (Bolten et al., 1998; Santos et al., 2008). Such mobile species may be injured by marine debris, either via entanglement or via direct ingestion, and a few studies conducted in the Azores along with anecdotal information have already documented such interactions (Barreiros and Raykov, 2014; Frick et al., 2009; Pham et al., 2017). In order to adequately assess the risk for Azorean biodiversity, information on the spatio-temporal distribution of floating debris around the Azores is necessary.

The present study aims therefore to investigate (1) the distribution and (2) the composition of the floating macro litter (> 2.5 cm, MSFD Technical Subgroup on Marine Litter, 2013) presents around the Azores and Madeira. During three years (2015–2017), opportunistic surveys from pole-and-line tuna fishing boats were performed in the Azores archipelago and off Madeira. Based on Sala et al. (2016), the study region was divided into five groups (Western, Central, Eastern, Madeira and offshore) in order to compare the debris densities between the islands that should be associated with different retention times.

2. Materials and methods

2.1. Data collection

Under the Azorean Fisheries Observer Program (POPA; www.popaobserver.org), standardized opportunistic surveys from pole-and-line tuna fishing boats were performed between 2015 and 2017 in the Azores archipelago and off Madeira (Fig. 1). The fishing activity occurs mostly between May and November, limiting our observations mostly during spring and summer. The data consist of 10 min visual transects which were performed up to 6 times a day (every 2 h, i.e. 09:30; 11:30; 13:30; 15:30; 17:30; 19:30), at a speed between 8 and 10 knots. Transects have no predetermined track and are only performed when the vessels are travelling or searching for tuna, and when weather conditions are favorable (i.e. Beaufort Sea state < 6). The start and end positions of each transect were also recorded, along with the visibility (bad, medium, good and very good), the glare, the Beaufort Sea state, the observer (n = 27) and the boat (n = 18).

The floating macro debris > 2.5 cm (MSFD Technical Subgroup on Marine Litter, 2013) were recorded from the flying bridge by one observer looking at each side of the vessel, approximately 8 m above sea level, within a 50 m observation strip on each side (i.e. a fixed-width strip transect of 100 m). Each sighting was differentiated between a single item or a patch of aggregated items (when impossible to be discriminated for obtaining individual counts). The identification and categorization of items was adapted from the MSFD master list (Directive, 2013). Plastic items were divided into packaging (bottles and containers, lids and lid-rings, bags and food wrapping, etc.), fishery-related plastic (ropes and nets, floats, and other fishing gear), general plastic user items (designed for repeated use, including fragments, rubber, unlike packaging). Non-plastic items were divided by type of material (metal, glass and paper). Two additional categories were created for clothing and unknown items. Size classes for each sighting was also recorded as follows: 2.5–5 cm, 5–15 cm, 15–30 cm, 30–60 cm and > 60 cm.

2.2. Statistical analysis

All statistical analyses were performed using R software version 3.5.0 (R Core Team, 2018). To assess the effect of temporal, spatial, operational and sea state variables on debris density, a series of Generalized Linear Models (GLMs) was performed using the *MASS* package on R. The response variable was the number of debris counts sighted per transect. We employed a Negative Binomial error distribution, as such distribution can provide good fits when dealing with over-dispersed count data (Lindén and Mäntyniemi, 2011). Three potential predictors related to the sea state were used: glare, visibility and beaufort. Temporal and spatial variables such as year, month and group, as well as the operational variable “observer” were also added to the model. The sampling effort expressed in km was included as an *offset*. The models with all possible combinations were compared using the Akaike Information Criterion (AIC) and the model associated with the lowest AIC was retained. Finally, observed densities were corrected for the observer effect using the estimates derived from the selected model to obtain a standardized density estimate.

2.3. Spatial analysis

The debris density was first calculated for each transect: $D = \frac{N}{w * L}$, where N is the total number of marine debris counts recorded in each transect, w the strip width (100 m) and L the survey effort (in km). Based on the geographical extent of the study region (from 30 to 41 °N and from 33° to 15°W), we then defined a grid of 0.1 × 0.1 decimal degree (~10 km^2) from which the debris densities were aggregated (the survey effort and the number of items) for the three years together. Finally, density maps were calculated based on the average densities of each transect per 0.1° grid cell.

Following Sala et al.'s (2016) stratification, the study area was then divided into five groups: the Western group (composed of Flores and Corvo Islands), the Central group (Faial, Pico, São Jorge, Graciosa and Terceira Islands), the Eastern group (São Miguel and Santa Maria Islands), Madeira and Offshore (Fig. 1). The average densities of the macro debris were finally calculated for each of the five groups over the three years together.

The observed debris positions were used to estimate the kernel density of marine litter off the Azores and Madeira. A kernel density analysis was performed by combining the three years of sampling using the *kernelUD* function from *adehabitatHR* package on R (Calenge, 2006) and the least square cross-validation method (Seaman and Powell, 1998) to find the optimal smoothing parameter. The corresponding area expressed in km^2 was then calculated within each kernel contour.

3. Results

3.1. Survey effort and number of debris per transect

Over the entire sampling period (from 2015 to 2017), a total of 2406 transects were performed. The annual number of transects recorded varied from 92 in 2016 to 1530 in 2017. The total survey time was 401 h for a survey area of 651 km^2 (Table 1). The sampling effort was heterogeneous among years, with a higher effort performed in 2017 (4013.9 km and 255 h), and a minimum effort in 2016 (377.1 km and 15.3 h). Between 2015 and 2017, a total of 482 floating debris were recorded, with a minimum of 115 in 2016 and a maximum of 227 in

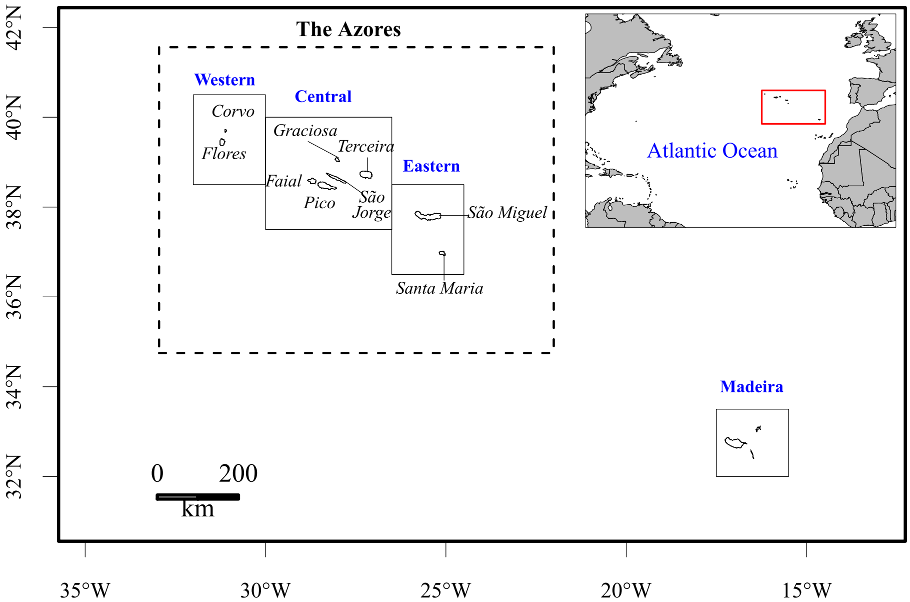

Fig. 1. Study area of the Azores and Madeira located in the North-East Atlantic Ocean (red box). The boxes refer to the four groups identified: Western, Central, Eastern and Madeira, and the names of the islands are indicated in italic. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2017. The number of debris per transect varied between 0 and 5 items, reaching on average 0.19 ± 0.5 items per transect. For the majority of transects (84%), no debris was observed. Thirteen percent of the transects contained one item, and only 3% contained more than one item. Throughout the sightings, 90% (n = 433) were classified as single items whilst only 10% (n=48) were observed as aggregates, and therefore, impossible to enumerate.

3.2. Composition and size

In terms of debris composition, three categories dominated and accounted for 87% of the sightings: general plastic, plastic packaging and fishing gear (Fig. 2a). General plastic accounted for 48% of the macro debris sighted, plastic packaging represented 21% and fishing gear 18% of the debris recorded. Although debris 2.5–5 cm were recorded, 93% of the debris were larger than 5 cm (Fig. 2b).

3.3. Debris' density

The observed debris density per transect ranged between 0.16 and 123.4 items.km^{-2} and was on average (mean ± SE) 0.78 ± 0.07 items.km^{-2} (Table 1). Glare, visibility and group were not selected in the best model but rather observer, Beaufort, month and year which had a significant effect on debris' density (Table 3). The most significant variables were the Beaufort state ($p < 0.001$) and the observer ($p < 0.001$). The standardized density when taking into account the observer bias was globally higher than the observed density (1.39 ± 0.14 items.km^{-2}) (See Table 1).

3.4. Temporal variability

Both observed and standardized densities were higher in 2016 (5.03 ± 0.81 and 17.91 ± 2.99 items.km^{-2}) compared to 2015 (0.59 ± 0.05 and 1.39 ± 0.14 items.km^{-2}), and it differed significantly among years (GLM: $p < 0.05$, Table 2). With the exception of October and November, the proportion of debris types was similar between the different months, typically dominated by general plastic, followed by plastic packaging and then by fishing gear (Fig. 3a). During autumn (October and November), only debris larger than 15 cm were sighted (Fig. 3b). Debris smaller than 5 cm were recorded only in spring and summer (April to August), and in larger proportion in April, representing 50% of the observations. Debris density also differed significantly according to months (GLM: $p < 0.005$, Table 2), being maximum from April to July and minimum from August to October (Fig. 4a).

3.5. Spatial variability

The sampling was performed in function of the fishing activity and was therefore patchily distributed over the study region, being concentrated in the Central group (mostly around Faial and east of Pico) and covering 3002.1 km (Table 3, Figs. 4b and 5a). The total area sampled was lower in the Western group (16.3 km^2) and maximum in the Central group (300.2 km^2). The total number of marine debris sighted ranged from 6 in the Western group to 262 items in the Central group (Table 3 and Fig. 5b).

From 2015 to 2017, the distribution of the standardized density was heterogeneous over the study area (Fig. 5c). The observed density per transect was relatively low for all groups, ranging from (mean ± SE) 0.49 ± 0.12 items.km^{-2} in Madeira group to (mean ± SE)

Table 1
Summary of the survey effort (number of transects, time, distance and area), number of marine debris sighted and average density for each year. Values of the debris densities are means ± SE.

Year	Effort (N transects)	Effort time (hours)	Effort in distance (km)	Effort area (km^2)	N debris (N items)	Observed density (N items.km^{-2})	Standardized density (N items.km^{-2})
2015	784	130.6	2119.4	211.9	140	0.59 ± 0.05	1.39 ± 0.14
2016	92	15.3	377.1	37.7	115	5.03 ± 0.81	17.91 ± 2.99
2017	1530	255	4013.9	401.4	227	0.62 ± 0.09	0.40 ± 0.05
	2406	*401*	*6510*	*651*	*482*	*0.78 ± 0.07*	*1.39 ± 0.14*

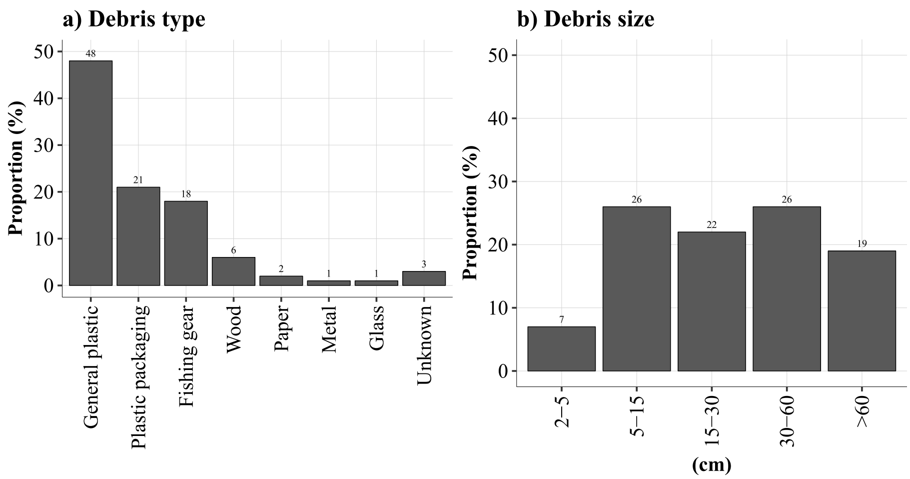

Fig. 2. Histograms of the (a) type and (b) size of the macro marine debris sighted during the three years of sampling.

Table 2
Summary of the GLM relating the debris' density to potential drivers, i.e. environmental conditions, seasonality and observer.

Variable	df	Deviance	Residual deviance	p value
Observer	26	337.61	1305.9	< 0.001
Beaufort	5	22.34	1283.6	< 0.001
Month	7	19.87	1263.7	< 0.005
Year	1	5.33	1258.4	< 0.05

Table 3
Summary of the survey effort (in km), the area covered, the total number of debris sighted and the average debris density (N items.km^{-2}) for each group. Values of the debris densities are means ± SE.

Group	Effort (km)	Area covered (km^2)	N debris	Observed density (N items.km^{-2})	Standardized density (N items.km^{-2})
Western	162.8	16.3	6	0.49 ± 0.24	1.21 ± 0.63
Central	3002.1	300.2	262	0.95 ± 0.13	1.90 ± 0.20
Eastern	1312.7	131.3	72	0.65 ± 0.14	1.39 ± 0.48
Madeira	363.7	36.3	20	0.49 ± 0.12	0.27 ± 0.08
Offshore	1669.1	166.9	122	0.66 ± 0.09	0.79 ± 0.11

0.95 ± 0.13 items.km^{-2} in the Central group (Table 3 Fig. 4b and Fig. 5c). However, the group had no significant effect on the debris density as this variable was not retained in the best model. The standardized densities were higher than the observed densities for all groups but similar trends among groups were observed (Fig. 4b and Table 3).

The kernel density contours are presented in Fig. 6 and indicate a higher number of floating debris in the Central and Eastern groups. The area of debris aggregation as indicated by the 10% kernel contours covers an area of 2357 km^2 and was concentrated in the Central group, west of Pico Island.

4. Discussion

This is the first study investigating the distribution and composition of floating macro debris off the Azores and Madeira islands. Due to the location of the Azores at the fringe of the North Atlantic subtropical gyre, which is known to be an accumulation zone for floating debris (Cózar et al., 2014), our study confirms the presence of macro debris in this area, mostly composed of plastics.

Among the 2406 visual surveys that were conducted, 482 floating debris were recorded, of which 69% were plastics. The dominance of plastic items (69%) is in accordance with many studies investigating the abundance and composition of floating litter worldwide (Barnes and Milner, 2005; Bergmann et al., 2016; Ryan, 2014, 2013; Ryan et al., 2014; Sá et al., 2016; Suaria and Aliani, 2014). Beach sampling conducted locally in Faial Island in the Azores also confirmed the dominance of plastic debris (2–30 cm) in this area (Pieper et al., 2015; Ríos et al., 2018). It is well established that the presence of such plastics in the marine environment pose a significant threat to marine megafauna via entanglement (Laist, 1997) or direct ingestion (Robards et al., 1997; Ryan, 2015). Some studies conducted in the Azores have already provided evidence of negative interaction between plastic debris and loggerhead turtles (Barreiros and Raykov, 2014; Frick et al., 2009; Pham et al., 2017), and it is likely that other marine animals are being affected by these floating debris. Our study and monitoring program

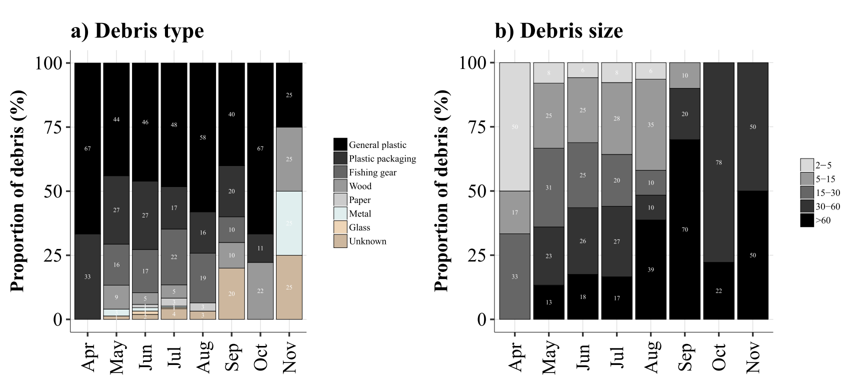

Fig. 3. Histograms of the proportion of marine debris recorded monthly according to (a) the type and (b) the size of the debris (in cm) during the three years of sampling.

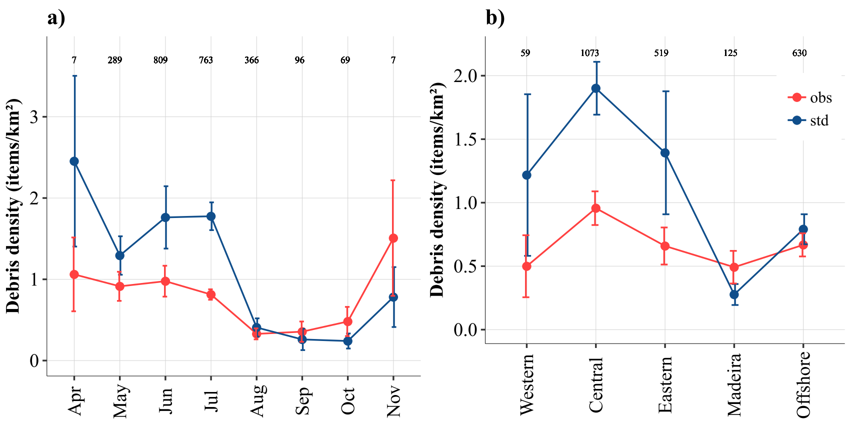

Fig. 4. Debris density (mean ± SE) calculated for each (a) month and for each (b) group between 2015 and 2017 for the observed (red) and standardized values (blue). The numbers at the top refer to the sample size, i.e. the number of transects performed per group and per month. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

could therefore be beneficial in the future to identify the critical areas of interactions between floating debris and marine megafauna species. On the basis of previous studies conducted on sea turtles (Darmon et al., 2017; Mrosovsky et al., 2009; Schuyler et al., 2015), cetaceans (Di-Méglio and Campana, 2017) or seabirds (Wilcox et al., 2015), it would be relevant to combine our results with information on the spatial distribution of marine megafauna in the Azores in order to highlight the areas of high exposure to plastics. Our results show higher number of debris and higher densities close to the shore, particularly in the Central group around Faial and Pico Islands. The Azores are recognized as a key habitat for many species of cetacean, and particularly in the Central group (Clua and Grosvalet, 2001; Silva et al., 2014). Given the high density of plastic debris in this area, such species might therefore be injured by the plastic floating on the sea surface, and in fact, every year, entanglements are being reported by local whale watching operators (e.g. TALASSA et al., 2010). Our findings reinforce therefore the need for implementation of a monitoring program on the interactions between marine megafauna and plastic debris off the Azores and Madeira.

The average debris density was relatively low (mean ± SE: 0.78 ± 0.07 items.km^{-2}, range: 0.16–123.4 items.km^{-2}) compared to densities estimated in offshore waters of mainland Portugal by Sá et al., 2016 (mean: 2.98 items.km^{-2}, range: 1.2–11.5 items.km^{-2}) and by Barnes and Milner (2005, range: 3–9 items.km^{-2}). Although care should be taken when comparing studies due to inherent differences in methodology (e.g. distance samplings vs. strip transects; differences in survey design, lower size detection limits, etc.), the densities found around the Azores and Madeira were comparable to some studies done in other oceanic locations. For example, in the North Pacific west off Japan, Shiomoto and Kameda (2005) reported debris densities ranging between 0.1 and 0.8 items.km^{-2} while maximum debris densities documented West of Hawaii were 0.5 item. km^{-2} (Matsumura and Nasu, 1997). In the Southern Ocean, Ryan et al. (2014) found similar levels of floating debris (0.58 items. km^{-2}). However, Ryan (2014)

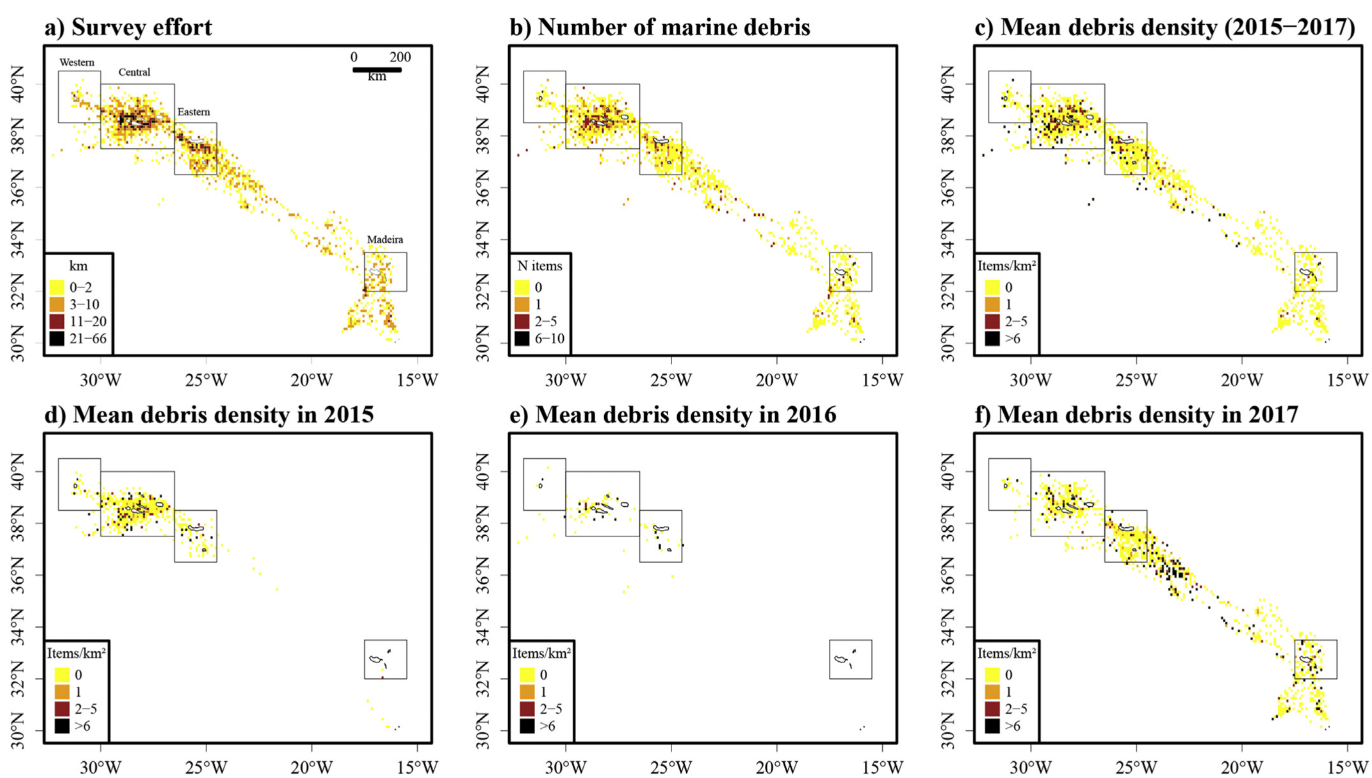

Fig. 5. Maps of the (a) survey effort (in km), (b) the total number of macro debris recorded (N items), (c) the mean standardized densities recorded during the three years (N items.km^{-2}), (d) in 2015 (N items.km^{-2}), (e) in 2016 (N items.km^{-2}) and (f) in 2017 (N items.km^{-2}).The squares in each panel refer to the four groups. The resolution of the six grids is 0.1 × 0.1 decimal degree (~10 km^2).

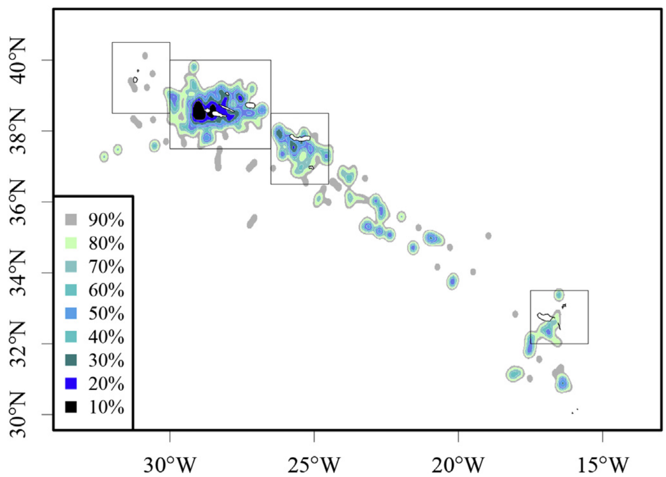

Fig. 6. Kernel density contours of the floating debris over the three years of sampling.

found higher densities in the southeast Atlantic Ocean, both within the South-Atlantic gyre (6.2 ± 1.3 items km^{-2}) and adjacent oceanic waters (2.7 ± 0.3 items km^{-2}) but also around the Tristan da Cunha island (1.0 ± 0.4 items km^{-2}).

The Azores and Madeira are located far from the large population centers where most land-based debris originate. Lebreton et al. (2012) highlighted that the main debris sources of the North Atlantic are the Central and North American coasts (accounting for 64–66%), which are located 2000 km west of the Azores. Given the long distance between the Azores and the Central and North American coasts, the low debris densities found in our study could be partly due to partial sinking to the seafloor before reaching the region and/or their degradation into microplastics (that cannot be detected using our sampling technique) or to accumulation elsewhere outside our study area, such as inside the gyre. Similarly, in the South Atlantic Ocean, Ryan (2014) observed a decrease in macro debris density from coastal waters to oceanic waters. Using beach surveys, Ríos et al. (2018) also confirmed the predominance of small plastic fragments on the coastline of the Azores as opposed to large macro-debris, a finding that was in line with another study showing a high abundance of microplastics around the archipelago (Enders et al., 2015).

Unlike our findings, studies conducted on the seafloor revealed that macro debris in the Azores archipelago are dominated by derelict fishing gears, mainly longlines (Pham et al., 2014, 2013; Rodríguez and Pham, 2017). The low contribution of fishing gears (18%) found floating at the surface compared to plastic packaging and other general plastic items (69%) may be partly due to the limited number of nets used around the Azores. Indeed, another study conducted in the Great Pacific Garbage Patch (in the North Pacific gyre), estimated that 86% of the macro debris contribution was made up of fishing nets (Lebreton et al., 2018). Similarly in the South Atlantic, Ryan (2014) estimated that fishing items accounted for 44% of the debris in oceanic waters which reinforces the low contribution of fishing gears around the Azores and Madeira.

Lower densities were estimated in summer (standardized mean ± SE: 1.2 ± 0.1 $items.km^{-2}$) compared to spring (standardized mean ± SE: 1.6 ± 0.2 $items.km^{-2}$). Such variation may be related to the seasonality of the Azores Current that narrows in summer and moves farther south during this period (Klein and Siedler, 1989), probably advecting debris outside the study region. Nevertheless, verifying the seasonality of marine debris in this region and investigating how it is influenced by oceanographic processes will require longer time series and conceivably an adapted monitoring design. Such variability could also be partly explained by the observer bias (skills, training, motivation, fatigue, etc.).

Besides this temporal variability, our findings also demonstrated some spatial variability of debris density along the study area. Debris densities were slightly higher (but not significantly) in the Central group compared to the other areas, which is in accordance with a previous study based on numerical simulations that highlighted an accumulation of particles in the Central group (Sala et al., 2016). The authors evidenced that the capture capacity of the islands and the retention time was related to the size of the islands, explaining why this area retained more particles and therefore more macro debris. As it had been confirmed by our kernel analysis, further monitoring efforts could therefore focus on the Central group, particularly west of Pico and Faial Islands where most of the debris tend to accumulate. Located close to shore, this area could serve as a good case-study area for long-term monitoring of floating debris in the region.

Despite the lack of a standardized design, this study demonstrates the utility of using fishing boats as a platform for monitoring floating debris in response to the implementation of the MSFD. Although not designed as a marine litter monitoring program, the "POPA" fisheries observer program is a promising tool for obtaining long-term data on the distribution, quantities and typology of floating marine debris presents in the Azores archipelago and off Madeira. The three-year of sampling covered a total area of 651 km^2 of sea surface. Despite the important sampling effort performed given the extended size of the study region (1575 km W-E and over 1110 km N-S), sampling was mostly concentrated close to the shores of the islands as a consequence of the fishing activity of the pole-and-line boats with no predetermined track.

To get information on the debris distribution more offshore, it would be necessary to cover the entire Exclusive Economic Zones of the Azores and Madeira, either by extending the observer program to other fishing fleets or by implementing a new methodology based on dedicated ship-based or aerial surveys using planes or unmanned aerial vehicles (UAVs). Plane surveys enable to cover larger areas and are less prone to changes in litter detectability (Lecke-Mitchell and Mullin, 1992; Pichel et al., 2007), but such technique prevents from detecting small items and are far more costly than ship-based surveys. On the other hand, UAVs provide a more cost-effective alternative for surveying large areas close to the ground/sea surface (Koh and Wich, 2012), generating high resolution imagery allowing the detection of small items by reducing errors in aerial estimation of wildlife populations (Hodgson et al., 2016; Rodríguez et al., 2012; Smith et al., 2016). With the methodology employed in the present study (visual observations from fishing boats), macro debris of 5 cm could be sighted but the majority (93%) were > 5 cm, suggesting a lower detectability for smaller items. We therefore recommend performing simultaneously a UAV survey together with the methodology used in this study to compare both approaches and assess the detectability of small items from a UAV. According to the results, if UAV is reliable, it could be used in the near future to sample offshore areas and cover the entire EEZs of the Azores and Madeira at reasonable costs.

Overall, the results of this study suggest that although located off the North Atlantic Subtropical Gyre, the amount of floating macro-debris around the Azores is lower compared to areas found closer to continental shelves. Our results point out that most of the debris likely originate from far away land-based sources and from fishing activities. This study highlights the utility of fisheries observer programs to obtain cost-effective information on macro debris floating around the Azores and Madeira that are essential to support the implementation of the MSFD.

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References

Aliani, S., Griffa, A., Molcard, A., 2003. Floating debris in the ligurian sea, north-western mediterranean. Mar. Pollut. Bull. 46, 1142–1149. https://doi.org/10.1016/S0025-326X(03)00192-9.

Arcangeli, A., Campana, I., Angeletti, D., Atzori, F., Azzolin, M., Carosso, L., Di Miccoli, V., Giacoletti, A., Gregorietti, M., Luperini, C., Paraboschi, M., Pellegrino, G., Ramazio, M., Sarà, G., Crosti, R., 2018. Amount, composition, and spatial distribution of floating macro litter along fixed trans-border transects in the Mediterranean basin. Mar. Pollut. Bull. 129, 545–554. https://doi.org/10.1016/j.marpolbul.2017.10.028.

Barnes, D.K.A., Milner, P., 2005. Drifting plastic and its consequences for sessile organism dispersal in the Atlantic Ocean. Mar. Biol. 146, 815–825. https://doi.org/10.1007/s00227-004-1474-8.

Barreiros, J.P., Raykov, V.S., 2014. Lethal lesions and amputation caused by plastic debris and fishing gear on the loggerhead turtle *Caretta caretta* (Linnaeus, 1758). Three case reports from Terceira Island, Azores (NE Atlantic). Mar. Pollut. Bull. 86, 518–522. https://doi.org/10.1016/j.marpolbul.2014.07.020.

Bergmann, M., Sandhop, N., Schewe, I., D'Hert, D., 2016. Observations of floating anthropogenic litter in the barents sea and fram strait, Arctic. Polar Biol. 39, 553–560. https://doi.org/10.1007/s00300-015-1795-8.

Bolten, A.B., Bjorndal, K.A., Martins, H.R., Dellinger, T., Biscoito, M.J., Encalada, S.E., Bowen, B.W., 1998. Atlantic developmental migrations of loggerhead turtles demonstrated by mtDNA sequence analysis. Ecol. Appl. 8, 1–7. https://doi.org/10.1890/1051-0761(1998)008[0001:TDMOLS]2.0.CO;2.

Calenge, C., 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecol. Model. 197, 516–519.

Clua, É., Grosvalet, F., 2001. Mixed-species feeding aggregation of dolphins, large tunas and seabirds in the Azores. Aquat. Living Resour. 14, 11–18. https://doi.org/10.1016/S0990-7440(00)01097-4.

R Core Team, 2018. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M.L., Duarte, C.M., 2014. Plastic debris in the open ocean. Proc. Natl. Acad. Sci. Unit. States Am. 111, 10239–10244. https://doi.org/10.1073/pnas.1314705111.

Darmon, G., Miaud, C., Claro, F., Doremus, G., Galgani, F., 2017. Risk assessment reveals high exposure of sea turtles to marine debris in French Mediterranean and metropolitan Atlantic waters. In: Deep Sea Research Part II: Topical Studies in Oceanography, Abundance, Distribution and Habitats of Atlantic and Mediterranean Marine Megafauna, vol. 141. pp. 319–328. https://doi.org/10.1016/j.dsr2.2016.07.005.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44, 842–852. https://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. https://doi.org/10.1016/j.marpolbul.2015.07.012.

Di-Méglio, N., Campana, I., 2017. Floating macro-litter along the Mediterranean French coast: composition, density, distribution and overlap with cetacean range. Mar. Pollut. Bull. 118, 155–166. https://doi.org/10.1016/j.marpolbul.2017.02.026.

Directive, S.F., 2013. Guidance on Monitoring of Marine Litter in European Seas.

Enders, K., Lenz, R., Stedmon, C.A., Nielsen, T.G., 2015. Abundance, size and polymer composition of marine microplastics ≥10μm in the Atlantic Ocean and their modelled vertical distribution. Mar. Pollut. Bull. 100, 70–81. https://doi.org/10.1016/j.marpolbul.2015.09.027.

Frick, M.G., Williams, K.L., Bolten, A.B., Bjorndal, K.A., Martins, H.R., 2009. Foraging ecology of oceanic-stage loggerhead turtles *Caretta caretta*. Endangered Species Research 9, 91–97. https://doi.org/10.3354/esr00227.

Galgani, F., Hanke, G., Maes, T., 2015. Global distribution, composition and abundance of marine litter. In: Marine Anthropogenic Litter. Springer, Cham, pp. 29–56. https://doi.org/10.1007/978-3-319-16510-3_2.

Gould, W.J., 1985. Physical oceanography of the Azores front. Prog. Oceanogr. 14, 167–190. https://doi.org/10.1016/0079-6611(85)90010-2.

Hardesty, B.D., Harari, J., Isobe, A., Lebreton, L., Maximenko, N., Potemra, J., van Sebille, E., Vethaak, A.D., Wilcox, C., 2017. Using numerical model simulations to improve the understanding of micro-plastic distribution and pathways in the marine environment. Front. Mar. Sci. 4. https://doi.org/10.3389/fmars.2017.00030.

Hartman, K.L., Visser, F., Hendriks, A.J.E., 2008. Social structure of Risso's dolphins (*Grampus griseus*) at the Azores: a stratified community based on highly associated social units. Can. J. Zool. 86, 294–306. https://doi.org/10.1139/Z07-138.

Hinojosa, I.A., Thiel, M., 2009. Floating marine debris in fjords, gulfs and channels of Southern Chile. Mar. Pollut. Bull. 58, 341–350. https://doi.org/10.1016/j.marpolbul.2008.10.020.

Hodgson, J.C., Baylis, S.M., Mott, R., Herrod, A., Clarke, R.H., 2016. Precision wildlife monitoring using unmanned aerial vehicles. Sci. Rep. 6, 22574. https://doi.org/10.1038/srep22574.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347, 768–771. https://doi.org/10.1126/science.1260352.

Kase, R.H., 1996. The gulf stream, the North atlantic current, and the origin of the Azores current. In: The Warm Water Sphere of the North Atlantic Ocean 291–337.

Kielmann, J., Käse, R.H., 1987. Numerical modeling of meander and eddy formation in the Azores current frontal zone. J. Phys. Oceanogr. 17, 529–541 https://doi.org/10.1175/1520-0485(1987)017 < 0529:NMOMAE > 2.0.CO;2.

Klein, B., Siedler, G., 1989. On the origin of the Azores current. J. Geophys. Res.: Oceans 94, 6159–6168. https://doi.org/10.1029/JC094iC05p06159.

Koh, L.P., Wich, S.A., 2012. Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. In: Tropical Conservation Science 5. pp. 121–132. https://doi.org/10.1177/194008291200500202.

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. In: Marine Debris, Springer Series on Environmental Management. Springer, New York, NY, pp. 99–139. https://doi.org/10.1007/978-1-4613-8486-1_10.

Lebreton, L.C.-M., Greer, S.D., Borrero, J.C., 2012. Numerical modelling of floating debris in the world's oceans. Mar. Pollut. Bull. 64, 653–661. https://doi.org/10.1016/j.marpolbul.2011.10.027.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., Reisser, J., 2018. Evidence that the Great pacific garbage patch is rapidly accumulating plastic. Sci. Rep. 8, 4666. https://doi.org/10.1038/s41598-018-22939-w.

Lecke-Mitchell, K.M., Mullin, K., 1992. Distribution and abundance of large floating plastic in the north-central Gulf of Mexico. Mar. Pollut. Bull. 24, 598–601. https://doi.org/10.1016/0025-326X(92)90279-F.

Lindén, A., Mäntyniemi, S., 2011. Using the negative binomial distribution to model overdispersion in ecological count data. Ecology 92, 1414–1421. https://doi.org/10.1890/10-1831.1.

Magalhães, S., Prieto, R., Silva, A., Gonçalves, J., Afonso-Dias, M., Santos, R., 2002. Short-term reactions of sperm whales (*Physeter macrocephalus*) to whale-watching vessels in the Azores. Aquat. Mamm. 28, 267–274.

Mansui, J., Molcard, A., Ourmières, Y., 2015. Modelling the transport and accumulation of floating marine debris in the Mediterranean basin. Mar. Pollut. Bull. 91, 249–257. https://doi.org/10.1016/j.marpolbul.2014.11.037.

Martinez, E., Maamaatuaiahutapu, K., Taillandier, V., 2009. Floating marine debris surface drift: convergence and accumulation toward the South Pacific subtropical gyre. Mar. Pollut. Bull. 58, 1347–1355. https://doi.org/10.1016/j.marpolbul.2009.04.022.

Matsumura, S., Nasu, K., 1997. Distribution of floating debris in the North Pacific Ocean: sighting surveys 1986–1991. In: Marine Debris, Springer Series on Environmental Management. Springer, New York, NY, pp. 15–24. https://doi.org/10.1007/978-1-4613-8486-1_3.

Maximenko, N., Hafner, J., Niiler, P., 2012. Pathways of marine debris derived from trajectories of Lagrangian drifters. In: Marine Pollution Bulletin, At-sea Detection of Derelict Fishing Gear 65. pp. 51–62. https://doi.org/10.1016/j.marpolbul.2011.04.016.

Monteiro, L.R., Ramos, J.A., Furness, R.W., 1996. Past and present status and conservation of the seabirds breeding in the Azores Archipelago. Biol. Conserv. 78, 319–328. https://doi.org/10.1016/S0006-3207(96)00037-7.

Monteiro, L.R., Ramos, J.A., Pereira, J.C., Monteiro, P.R., Feio, R.S., Thompson, D.R., Bearhop, S., Furness, R.W., Laranjo, M., Hilton, G., Neves, V.C., Groz, M.P., Thompson, K.R., 1999. Status and distribution of fea's petrel, bulwer's petrel, Manx shearwater, little shearwater and band-rumped storm-petrel in the Azores archipelago. In: Waterbirds: The International Journal of Waterbird Biology 22. pp. 358–366. https://doi.org/10.2307/1522111.

Mrosovsky, N., Ryan, G.D., James, M.C., 2009. Leatherback turtles: the menace of plastic. Mar. Pollut. Bull. 58, 287–289. https://doi.org/10.1016/j.marpolbul.2008.10.018.

MSFD Technical Subgroup on Marine Litter, 2013. Guidance on Monitoring of Marine Litter in European Seas. Joint Research Centre Scientific and Policy Reports. European Commission 128 p.

Pham, C.K., Gomes-Pereira, J.N., Isidro, E.J., Santos, R.S., Morato, T., 2013. Abundance of litter on condor seamount (Azores, Portugal, Northeast Atlantic). Deep sea research Part II: topical studies in oceanography. In: An Integrated Approach for Studying Seamounts: CONDOR Observatory 98. pp. 204–208. https://doi.org/10.1016/j.dsr2.2013.01.011.

Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., Canals, M., Company, J.B., Davies, J., Duineveld, G., Galgani, F., Howell, K.L., Huvenne, V.A.I., Isidro, E., Jones, D.O.B., Lastras, G., Morato, T., Gomes-Pereira, J.N., Purser, A., Stewart, H., Tojeira, I., Tubau, X., Rooij, D.V., Tyler, P.A., 2014. Marine litter distribution and density in european seas, from the shelves to deep basins. PLoS One 9, e95839. https://doi.org/10.1371/journal.pone.0095839.

Pham, C.K., Rodríguez, Y., Dauphin, A., Carriço, R., Frias, J.P.G.L., Vandeperre, F., Otero, V., Santos, M.R., Martins, H.R., Bolten, A.B., Bjorndal, K.A., 2017. Plastic ingestion in oceanic-stage loggerhead sea turtles (*Caretta caretta*) off the North Atlantic subtropical gyre. Mar. Pollut. Bull. 121, 222–229. https://doi.org/10.1016/j.marpolbul.2017.06.008.

Pichel, W.G., Churnside, J.H., Veenstra, T.S., Foley, D.G., Friedman, K.S., Brainard, R.E., Nicoll, J.B., Zheng, Q., Clemente-Colón, P., 2007. Marine debris collects within the North pacific subtropical convergence zone. Mar. Pollut. Bull. 54, 1207–1211. https://doi.org/10.1016/j.marpolbul.2007.04.010.

Pichel, W.G., Veenstra, T.S., Churnside, J.H., Arabini, E., Friedman, K.S., Foley, D.G.,

Brainard, R.E., Kiefer, D., Ogle, S., Clemente-Colón, P., Li, X., 2012. GhostNet marine debris survey in the Gulf of Alaska – satellite guidance and aircraft observations. In: Marine Pollution Bulletin, At-sea Detection of Derelict Fishing Gear 65. pp. 28–41. https://doi.org/10.1016/j.marpolbul.2011.10.009.

Pieper, C., Ventura, M.A., Martins, A., Cunha, R.T., 2015. Beach debris in the Azores (NE atlantic): faial island as a first case study. Mar. Pollut. Bull. 101, 575–582. https://doi.org/10.1016/j.marpolbul.2015.10.056.

Ríos, N., Frias, J.P.G.L., Rodríguez, Y., Carriço, R., Garcia, S.M., Juliano, M., Pham, C.K., 2018. Spatio-temporal variability of beached macro-litter on remote islands of the North Atlantic. Mar. Pollut. Bull. 133, 304–311. https://doi.org/10.1016/j.marpolbul.2018.05.038.

Robards, M.D., Gould, P.J., Piatt, J.F., 1997. The highest global concentrations and increased abundance of oceanic plastic debris in the North pacific: evidence from seabirds. In: Marine Debris, Springer Series on Environmental Management. Springer, New York, NY, pp. 71–80. https://doi.org/10.1007/978-1-4613-8486-1_8.

Rodríguez, Y., Pham, C.K., 2017. Marine litter on the seafloor of the faial-pico passage, Azores archipelago. Mar. Pollut. Bull. 116, 448–453. https://doi.org/10.1016/j.marpolbul.2017.01.018.

Rodríguez, A., Negro, J.J., Mulero, M., Rodríguez, C., Hernández-Pliego, J., Bustamante, J., 2012. The eye in the sky: combined use of unmanned aerial systems and GPS data loggers for ecological research and conservation of small birds. PLoS One 7, e50336. https://doi.org/10.1371/journal.pone.0050336.

Ryan, P.G., 2013. A simple technique for counting marine debris at sea reveals steep litter gradients between the Straits of Malacca and the Bay of Bengal. Mar. Pollut. Bull. 69, 128–136. https://doi.org/10.1016/j.marpolbul.2013.01.016.

Ryan, P.G., 2014. Litter survey detects the South Atlantic 'garbage patch. Mar. Pollut. Bull. 79, 220–224. https://doi.org/10.1016/j.marpolbul.2013.12.010.

Ryan, P.G., 2015. How quickly do albatrosses and petrels digest plastic particles? Environ. Pollut. 207, 438–440. https://doi.org/10.1016/j.envpol.2015.08.005.

Ryan, P.G., Musker, S., Rink, A., 2014. Low densities of drifting litter in the African sector of the Southern Ocean. Mar. Pollut. Bull. 89, 16–19. https://doi.org/10.1016/j.marpolbul.2014.10.043.

Sá, S., Bastos-Santos, J., Araújo, H., Ferreira, M., Duro, V., Alves, F., Panta-Ferreira, B., Nicolau, L., Eira, C., Vingada, J., 2016. Spatial distribution of floating marine debris in offshore continental Portuguese waters. Mar. Pollut. Bull. 104, 269–278. https://doi.org/10.1016/j.marpolbul.2016.01.011.

Sala, I., Harrison, C.S., Caldeira, R.M.A., 2016. The role of the Azores Archipelago in capturing and retaining incoming particles. J. Mar. Syst. 154, 146–156. https://doi.org/10.1016/j.jmarsys.2015.10.001.

Santos, S.S., Hawkins, S., Monteiro, L.R., Alves, M., Isidro, E.J., 1996. Marine research, resources and conservation in the Azores. Oceanogr. Lit. Rev. 9, 901.

Santos, M.A., Bolten, A.B., Martins, H.R., Riewald, B., Bjorndal, K.A., 2008. Air-breathing visitors to seamounts: sea Turtles. In: Seamounts: Ecology, Fisheries & Conservation. Wiley-Blackwell, pp. 239–244. https://doi.org/10.1002/9780470691953.ch12b.

Schuyler, Q.A., Chris, Wilcox, Townsend Kathy, A., Wedemeyer-Strombel Kathryn, R., George, Balazs, Erik, Sebille, Britta Denise, Hardesty, 2015. Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. Global Change Biol. 22, 567–576. https://doi.org/10.1111/gcb.13078.

Seaman, D.E., Powell, R.A., 1998. Kernel Home Range Estimation Program (Kernelhr). Documentation of the Program.

Shiomoto, A., Kameda, T., 2005. Distribution of manufactured floating marine debris in near-shore areas around Japan. Mar. Pollut. Bull. 11, 1430–1432. https://doi.org/10.1016/j.marpolbul.2005.08.020.

Silva, M.A., 2007. Population Biology of Bottlenose Dolphins in the Azores Archipelago. Thesis. University of St Andrews.

Silva, M.A., Prieto, R., Cascão, I., Seabra, M.I., Machete, M., Baumgartner, M.F., Santos, R.S., 2014. Spatial and temporal distribution of cetaceans in the mid-Atlantic waters around the Azores. Mar. Biol. Res. 10, 123–137. https://doi.org/10.1080/17451000.2013.793814.

Smith, C.E., Sykora-Bodie, S.T., Bloodworth, B., Pack, S.M., Spradlin, T.R., LeBoeuf, N.R., 2016. Assessment of known impacts of unmanned aerial systems (UAS) on marine mammals: data gaps and recommendations for researchers in the United States. J. Unmanned Veh. Syst. 4, 31–44. https://doi.org/10.1139/juvs-2015-0017.

Steiner, L., Silva, M.A., Zereba, J., Leal, M.J., 2008. Bryde's whales, *Balaenoptera edeni*, observed in the Azores: a new species record for the region. In: Marine Biodiversity Records 1. https://doi.org/10.1017/S1755267207007282.

Suaria, G., Aliani, S., 2014. Floating debris in the Mediterranean Sea. Mar. Pollut. Bull. 86, 494–504. https://doi.org/10.1016/j.marpolbul.2014.06.025.

Sy, A., 1988. Investigation of large-scale circulation patterns in the central North Atlantic: the North atlantic current, the Azores current, and the mediterranean water plume in the area of the mid-atlantic ridge. In: Deep Sea Research Part A. Oceanographic Research Papers 35. pp. 383–413. https://doi.org/10.1016/0198-0149(88)90017-9.

Talassa, a., Azores, w., Azores, m., 2010. Portugal. Progress Report on Cetacean Research, January 2003 to December 2006, with Statistical Data for the Calendar Year 2003, 2004, 2005 and 2006. (no. 4). Atlantic.

Thorrold, S.R., Afonso, P., Fontes, J., Braun, C.D., Santos, R.S., Skomal, G.B., Berumen, M.L., 2014. Extreme diving behaviour in devil rays links surface waters and the deep ocean. Nat. Commun. 5, 4274. https://doi.org/10.1038/ncomms5274.

Titmus, A.J., David Hyrenbach, K., 2011. Habitat associations of floating debris and marine birds in the North East Pacific Ocean at coarse and meso spatial scales. Mar. Pollut. Bull. 62, 2496–2506. https://doi.org/10.1016/j.marpolbul.2011.08.007.

UNEP, 2009. Marine Litter: a Global Challenge. Nairobi.

van Sebille, E., England, M.H., Froyland, G., 2012. Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environ. Res. Lett. 7, 044040. https://doi.org/10.1088/1748-9326/7/4/044040.

van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Franeker, J.A. van, Eriksen, M., Siegel, D., Galgani, F., Law, K.L., 2015. A global inventory of small floating plastic debris. Environ. Res. Lett. 10, 124006. https://doi.org/10.1088/1748-9326/10/12/124006.

Vandeperre, F., Aires-da-Silva, A., Fontes, J., Santos, M., Santos, R.S., Afonso, P., 2014a. Movements of blue sharks (*Prionace glauca*) across their life history. PLoS One 9, e103538. https://doi.org/10.1371/journal.pone.0103538.

Vandeperre, F., Aires-da-Silva, A., Santos, M., Ferreira, R., Bolten, A.B., Serrao Santos, R., Afonso, P., 2014b. Demography and ecology of blue shark (*Prionace glauca*) in the central North Atlantic. Fish. Res. 153, 89–102. https://doi.org/10.1016/j.fishres.2014.01.006.

Wilcox, C., Sebille, E.V., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proc. Natl. Acad. Sci. Unit. States Am. 112, 11899–11904. https://doi.org/10.1073/pnas.1502108112.