Spatial distribution of floating marine debris in offshore continental Portuguese waters

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Abstract

This study presents data on abundance and density of macro-floating marine debris (FMD), including their composition, spatial distribution and potential sources off continental Portugal. FMD were assessed by shipboard visual surveys covering ±252,833 km² until the 220 nm limit. The FMD average density was 2.98 items/km² and abundance amounted to 752,740 items. Unidentified plastics constitute the major bulk of FMD (density = 0.46 items/km²; abundance = 117,390 items), followed by styrofoam, derelict or lost materials from fisheries, paper/cardboard and wood material. The North sector of the area presents higher FMD diversity and abundances, probably as a result of the high number of navigation corridors and fisheries operating in that sector. Most FMD originate from local sources, namely discharges from vessels and derelict material from fisheries. Considering the identifiable items, cables and fishing lines were the only fishing related items among the top ten FMD items in Portuguese offshore waters.

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1. Introduction

Pollution by marine litter is presently recognized as a worldwide problem and a major threat to marine ecosystems (Galgani et al., 2010; Cole et al., 2011; Hammer et al., 2012; Depledge et al., 2013; Pham et al., 2014). Some of the major impacts of marine debris on marine fauna are related to entanglement and ingestion, mostly due to several types of plastics (e.g. synthetic fiber ropes, plastic sheets and strapping tape) or discarded fishing gear (e.g. rope, nets, lines and trawls) particularly affecting seabirds (Votier et al., 2011), sea turtles (Casale et al., 2010; Vélez-Rubio et al., 2013) and marine mammals (Boren et al., 2006).

Entanglement consequences to marine animals range from restriction of movements to amputation and death (Marine Mammal Commission, 2001; Derraik, 2002; National Research Council, 2009). Ingestion of marine debris by marine animals (Ryan, 2008; Bond et al., 2013; Campani et al., 2013; Codina-García et al., 2013; Schuyler et al., 2014) can cause physical blockage in the digestive system and reduced absorption of nutrients (National Research Council, 2009), leading to starvation or digestive injuries and death (Derraik, 2002).

Plastics are predominant among marine litter worldwide (Derraik, 2002; UNEP, 2009; Depledge et al., 2013) being presently considered a serious hazard to the environment (GESAMP, 2010; Hammer et al., 2012). Most plastics degrade slowly into different sized objects ultimately becoming microplastics measuring <5 mm in diameter (Arthur et al., 2009), which represent a long-term threat to entire marine food webs (Andrady, 2011; Cole et al., 2011; Martins and Sobral, 2011; Fossi et al., 2012).

Marine debris can be found floating at the sea surface, in the water column, stranded on coastlines, and/or deposited on the seafloor (Barnes et al., 2009; Ryan et al., 2009; Goldstein et al., 2013; Galgani et al., 2015) including the Arctic (Bergmann and Klages, 2012; Bergmann et al., 2015) and surveying the different marine compartments requires different methodologies (Ryan et al., 2009; Galgani et al., 2013, 2015). Larger debris on beaches are surveyed by item counts along transects, floating debris are surveyed by ship-based observations of the sea surface, and sink/deposited debris on the seafloor are surveyed by bottom-trawls, ROV’s and divers. Microplastic surveys require sampling the top of the intertidal and subtidal sediment using appropriate collection instruments, neutron net tows for the sea surface, and zooplankton net tows for sampling the water column (Galgani et al., 2013). Several techniques have been used to assess microplastics in sediments (see Van Cauwenberge et al., 2015 for a review).

With respect to larger floating marine debris (FMD), representing a wide range of marine litter items floating on the oceans’ surface, they
are present in all oceans and higher abundances are frequently found in the principal shipping routes and coastal waters adjacent to major urban regions (Thiel et al., 2003; Hinojosa and Thiel, 2009) and/or along the principal ocean current systems (Kubota, 1994; Shiomoto and Kameda, 2005).

The Portuguese continental waters comprise major shipping corridors connecting the Mediterranean, Northern Europe and the Western Atlantic. Also, fisheries represent a very significant part of the country’s economy, with a fishing fleet with over 4800 vessels and more than 20,000 fishing licenses issued annually (INE, 2012). Therefore, ships potentially represent an important source of marine debris. However, no data on FMD abundance was ever recorded in order to evaluate the potential threats to the Portuguese continental marine ecosystems and their species. In fact, the only existing studies referring to marine litter in this region refer to benthic marine debris on the western Iberian continental margin (Mordecai et al., 2011; Neves, 2013), macrodebris and microplastics accumulated on beaches (Martins and Sobral, 2011; OSPAR, 2007; Frias et al., 2010; Antunes et al., 2013), and microplastics in the water column near the coastline (Frias et al., 2014).

According to the Marine Strategy Framework Directive (2008/56/EC), on the determination of Good Environmental Status, marine litter should not cause harm to the coastal and marine environment, and trends in the amount of litter in the water column (including floating at the surface) should be characterized (2010/477/EU). Therefore, the present study provides estimates of abundance and density of floating marine debris, as well as their spatial distribution along the Portuguese Continental offshore waters.

2. Methods

2.1. Study area

The Portuguese continental waters are confined between the 36.5°N and the 41.5°N. The country's EEZ comprises 327,667 km². The continental shelf (23,728 km²) has a narrow profile apart from a region between the river Minho and the Nazaré Canyon. The offshore area is used by fisheries (mainly bottom or pelagic trawlers and long-liners) and hosts several well-defined navigation corridors connecting Europe, Africa and the American Continent.

The surveyed area is influenced by two major current systems: the Canary (CC) and Portugal (PoC) Currents that form the eastern limb of the North Atlantic Subtropical Gyre. Considering the circulation features described in the literature and those recurrently registered in hydrology observations and satellite data (see Mason et al., 2005; Peliz et al., 2005), the Iberian Basin is separated into two distinct areas. A northern area, where the large-scale current flow is predominantly southward due to the Portugal Current (PoC 1) (Fig. 1) and the poleward flow is confined to the vicinity of the slope. To the west, between the Galicia Bank and the coast, southward cold intrusions are recurrently observed (eastern branch of the Portugal Current, PoC 2). In this region there is a recurrent frontal system at about 39–40°N, designated as Western Iberia Winter Fronts (WIWiFs). They represent the transition to the southern area of the Iberian Atlantic Basin. In the southern area, the PoC is less influential and an eastward advection of relatively warm and salty waters becomes important as the main generating mechanism of the poleward flow. In the vicinity of the coast, this front is deflected northward

Fig. 1. Schemes of seasonal upper ocean circulation regimes in western Iberia and Gulf of Cadiz. PoC (1), Portugal Current; PoC (2), Portugal Current Eastern Branch; WIWiFs, Western Iberia Winter Fronts; IPC, Iberian Poleward Current; AC, Azores Current; GCNR, Gulf of Cadiz northern recirculation; ACEB, Azores Current Eastern Branch; RAE, Recurrent anticyclonic eddy; S, Swiddies; MCC, Meddies and companion cyclone; E, Eddy activity; CC, Canary current.

Adapted from Peliz et al. (2005) and Mason et al. (2005).

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generating the Iberian Poleward Current (IPC). A second frontal system to the south of 36°N represents the eastern end of the Azores Current (AC).

2.2. Survey methodology

Floating marine debris were assessed along predefined linear transects (T1–T14, see Fig. 2 and Table 1) by shipboard visual surveys performed during the summer of 2011 (22 July–4 August, 8–11 August and 7–15 September) aboard the Santa Maria Manuela, a 68.64 m sailing vessel (overall length), 11 fore-and-aft sails and a total area of 1130 m². The survey occurred between the 50 nm limits and the 220 nm limits off continental Portugal, covering an area of about 252,833 km². This campaign was integrated in the first offshore survey of the position at 1-min intervals.

In order to save searching time, sighting data were collected on passing mode. Items sighted off effort were disregarded. Locations were registered with a Global Positioning System (GPS) connected to the computer, and on synchronized handheld GPS devices set to register the position at 1-min intervals.

2.3. Abundance and density estimates in the surveyed area

Conventional distance sampling (Buckland et al., 2001) is an established suitable methodology to estimate density and abundance of biological or physical populations including floating debris (see Lecke-Mitchell and Mullin, 1997; Titmus and Hyrenbach, 2011; Fewster et al., 2009; Williams et al., 2011; Goldstein et al., 2013; Suaria and Alami, 2014).

In the present study, a total of 14 samplers (T1–T14, linear transects), with equal angle at a random starting point, were obtained in Distance ver. 6.1 Beta 1 (Thomas et al., 2010) to allow for a homogeneous coverage probability of the study area, thus guaranteeing a representative coverage of the study area. Linear transects and search efforts are shown in Fig. 2 and the characteristics of each transect are given in Table 1.

Data analyses were also performed in Distance 6.1 Beta 1 (Thomas et al., 2010). Initially, a global detection function was derived by pooling the data from all types of debris, followed by post-stratification to estimate densities/abundances for each debris size class. Additionally, estimates were derived using independent detection functions calculated for each item size. All estimates were submitted to a non-parametric bootstrap procedure (1000 replicates). The adjustment combinations for the tested models were: uniform key with cosine adjustments; half-normal key with cosine adjustments; half-normal key with Hermite polynomial adjustments; hazard-rate key with simple polynomial adjustments (Thomas et al., 2010). Model selection was guided by the Akaike’s Information Criterion (AIC), considering that lower AICs indicate detection functions with the best fit. The detection functions used for total FMD and for each FMD size class are presented in Fig. 3. To better fit the detection functions, 5% of the longest perpendicular distances were discarded (Buckland et al., 2001; Thomas et al., 2010).

To obtain detection functions and estimates of abundance and density of the different FMD size classes, an analysis was performed for each size class. In these analyses the model used was hazard-rate key with simple polynomial adjustments and 5% of the longest perpendicular distances were also discarded. Data were also submitted to a non-parametric bootstrap procedure (1000 replicates), performed on samples within strata.

The software Arc Map 10.0 was used to visualize the survey transects and the effort made, and to produce Kernel density maps showing spatial clustering of floating debris sightings (the geographic areas presenting a higher probability of FMD occurrence). The Kernel density estimate is a widely used approach to quantify spatial abundance because it represents a true probability density function to be used in
statistical analyses (Tetley et al., 2012). Also, it is considered a useful tool to provide a general view of the spatial distribution of several types of events (Fortin et al., 2005; Fieberg, 2007; Santos et al., 2012).

This analysis was performed using ArcGIS 10 using the Spatial Analyst Tools, the selected cell size was 0.01 (~1 km²) and the search radius was kept at 1 (~100 km) due to the dispersion of the data in a vast area. The probability contours (desired percentage of total probability within the smallest area) were obtained by dividing the volume contours in 10% intervals. Therefore, the 10% probability contour contains 10% of presence probability within the smallest area on the surface of the kernel density map (Quakenbush et al., 2010). The probability of occurrence of debris should be read as inversely proportional to the value of the contour. In the present study, the 10% density isopleth was selected to define the core areas that surround the highest concentration areas. The area between the coastline and the 50 nm limit was not considered in the kernel analysis, because no effort was performed in that area.

Table 2

<table>
<thead>
<tr>
<th>Transect</th>
<th>Date</th>
<th>Start Time (h)</th>
<th>Stop Time (h)</th>
<th>Last depth</th>
<th>n_sight</th>
<th>r_sight</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>July 24</td>
<td>10:11:04-18:14:00</td>
<td></td>
<td></td>
<td>73.96</td>
<td>9</td>
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<tr>
<td>T2</td>
<td>July 24</td>
<td>18:54:00-21:00:00</td>
<td></td>
<td></td>
<td>149.57</td>
<td>13</td>
</tr>
<tr>
<td>T3</td>
<td>July 25</td>
<td>08:12:36-19:56:07</td>
<td></td>
<td></td>
<td>3.58</td>
<td>1</td>
</tr>
<tr>
<td>T4</td>
<td>September 7</td>
<td>07:33:00-20:16:04</td>
<td></td>
<td></td>
<td>90.59</td>
<td>40.89</td>
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<tr>
<td>T5</td>
<td>September 8</td>
<td>07:35:00-20:10:12</td>
<td></td>
<td></td>
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<td>13.51</td>
</tr>
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<td>T6</td>
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<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T7</td>
<td>September 10</td>
<td>12:38:11-20:20:30</td>
<td></td>
<td></td>
<td>149.57</td>
<td>13</td>
</tr>
<tr>
<td>T8</td>
<td>September 11</td>
<td>07:32:30-17:48:24</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T9</td>
<td>September 12</td>
<td>18:21:35-20:20:00</td>
<td></td>
<td></td>
<td>149.57</td>
<td>13</td>
</tr>
<tr>
<td>T10</td>
<td>September 13</td>
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<td>13.51</td>
</tr>
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<td>September 14</td>
<td>07:30:46-20:12:27</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>South sector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T12</td>
<td>August 3</td>
<td>07:31:00-18:32:12</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T13</td>
<td>August 2</td>
<td>10:10:03-20:10:03</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T14</td>
<td>July 31</td>
<td>08:30:12-19:30:15</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T15</td>
<td>July 28</td>
<td>09:00:42-21:00:00</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T16</td>
<td>July 29</td>
<td>07:40:08-18:23:00</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
<tr>
<td>T17</td>
<td>July 29</td>
<td>19:54:10-20:53:34</td>
<td></td>
<td></td>
<td>73.96</td>
<td>13.51</td>
</tr>
</tbody>
</table>

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2.4. Estimate of FMD relative densities per transect

Following the approach made by Thiel et al. (2003), FMD relative densities ($D = \text{items/km}^2$) were calculated for each transect using the following equation:

$$D = \frac{n}{2(w/1000)L}$$

where $n$ is the number of observed FMD items, $w$ is the maximum distance perpendicular to the transect and $L$ is the total length of the transect (in km). In this case, $w$ corresponds to 300 m according to the truncation measure assumed in the previous analysis using Distance Sampling.

Based on oceanographic and topographic differences of the survey area, we aggregated transects in two regional sectors (Fig. 2): the north sector that encompasses transects 1 to 7 (from the border with Galician waters until the northern border of the Tagus Abyssal plain) and the south sector that includes transects 8 to 14 (from the northern border of the Tagus Abyssal plain until the Ampère seamount). However, only 13 samplers were surveyed (some were only partially surveyed, see Fig. 2) because of bad weather conditions. For each regional sector ($T_1$–$T_7$, north and $T_8$–$T_{13}$, south Portuguese offshore areas) and for each transect we determined the relative density of all items, the mean number of different types of floating debris (richness), and the mean dominance (Simpson’s $k$).

The statistical analysis follows the approach used by Thiel et al. (2013). Differences in regional FMD composition were visualized through a 2D non-metric multidimensional scaling. The relative contribution of each particular FMD category to differences in composition was evaluated using a similarity percentage analysis (SIMPER). The cut-off for typifying and distinguishing was set at 0.01 (i.e. FMD types that were responsible for typifying or distinguishing ≥1% of the variation within a regional sector). Differences in the composition of FMD categories, between regional sectors and surveyed transects were evaluated using a permutational analysis of variance (PERMANOVA, 9999 runs) and a post-hoc test, based on the Bray–Curtis index of similarity. FMD relative densities were transformed using log $(x + 1)$ in order to meet the assumption of homoscedastic variances. Analyses were carried out using the free software PAST v. 2.12 (Hammer et al., 2001).

3. Results

3.1. Composition and FMD abundance and density

FMD were found in all surveyed transects. The number of sightings per transect are presented in Table 1. The number of debris items per transect ($r_t$) ranges between 1.22 and 11.51 debris sightings/km, indicating a high variability in sightings distribution.

All recorded sightings ($n = 608$) were entered to Distance 6.1 Beta 1. After the right-truncation at a strip width of 300 m, the number of sightings decreased to 586. According to the detection function that best described the data, we selected the model hazard-rate with simple polynomial adjustments. Mean density of debris (items per km$^2$) in the study area was 2.98 (95% CI: 1.98–4.48; CV = 20.31%) and marine debris total abundance was 752,740 (95% CI: 500,100–1.133,000; CV = 20.31%) pieces.

The most common debris category was unidentified plastics with a density of 0.46 items per km$^2$, and a total abundance for the entire surveyed area of 117,390 pieces (Table 2). The next most important FMD items were Styrofoam popcorn, Plastic bag and Other plastic items, ranging from 0.26 to 0.36 items per km$^2$ (with a total abundance...
Density (items per km²), abundance (number of items) and respective coefficients of variation (%CV) and 95% Confidence Intervals (95% CI) of each size class (S, M, L, XL). Class S refers to the largest materials allowed for release from ships (MARPOL Annex V regulations).

Class sizes adapted from Ribic et al. (1992) and Galgani et al. (2013).

<table>
<thead>
<tr>
<th>Class</th>
<th>Size (cm)</th>
<th>Density</th>
<th>95% CI</th>
<th>Abundance</th>
<th>95% CI</th>
<th>%CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>&lt;2.5</td>
<td>0.4536</td>
<td>0.17948 - 1.1462</td>
<td>114,700</td>
<td>45,386 - 289,850</td>
<td>45.73</td>
</tr>
<tr>
<td>M</td>
<td>≤10</td>
<td>1.0104</td>
<td>0.49315 - 2.0703</td>
<td>255,520</td>
<td>124,710 - 523,550</td>
<td>34.92</td>
</tr>
<tr>
<td>L</td>
<td>≤100</td>
<td>1.3707</td>
<td>0.75233 - 2.4973</td>
<td>346,630</td>
<td>190,250 - 631,540</td>
<td>29.16</td>
</tr>
<tr>
<td>XL</td>
<td>&gt;100</td>
<td>0.1529</td>
<td>0.06043 - 0.3871</td>
<td>38,676</td>
<td>15,281 - 97,889</td>
<td>47.53</td>
</tr>
</tbody>
</table>

Fig. 4. Floating marine debris kernel density map. Kernel density estimates are presented in equal intervals of 10% increments, with warmer tones representing the higher concentration areas (10%). North sector and South sector indicate regions surveyed by T₁ to T₇ and T₈ to T₁₃, respectively.

3.2. Geographical distribution of FMD in Portuguese offshore waters

The kernel density percent volume contours indicate that FMD in the survey area are not evenly distributed. In the FMD kernel density map (Fig. 4) it is possible to see that the highest number of FMD items was found in the north sector of the study area, especially in the areas corresponding to transects 4 to 7.

The 10% kernel volume contour for FMD in the north sector covers an area of 2522 km² (only 1% of the study area) and no high concentration areas were reported for the south sector. However, the 50% kernel volume contour for FMD (defined in this study as core areas of FMD occurrence) cover 21,610 km² representing 8.5% of the whole study area. These core areas occur only in the north sector (Fig. 4).

As for the mean relative densities of floating debris, results are in accordance with the Kernel spatial analysis. During the offshore survey, the FMD mean relative densities were higher in the north sector when comparing with the south sector (Fig. 5a), as confirmed by the two-way PERMANOVA (PseudoF₁,₅ = 0.2125, P = 0.014, see full details in Table 4). Transects 1 and 2 present relative density values similar to Transects 8 to 13, even though the first two transects occur in the north sector, while the other 6 occur in the south sector (Fig. 5a). The average number of floating debris categories (FMD type richness) found in the north sector was 14.85 and only 11.67 in the south sector (Fig. 5b). However, despite the richness variation, the average dominance of floating debris was very similar in both sectors (Fig. 5c), which indicates that in areas of low floating litter richness, floating litter relative density is also low, while for the transects with higher richness, relative densities reported were also higher.

Differences between the FMD composition in the north and south sectors are confirmed by non-metric multidimensional scaling (nMDS) (Fig. 6a), even though transects 1 and 2 (north sector) are more similar to transects in the south sector due to their low FMD relative density. The differences in composition between the north and south sectors were mostly driven by Unidentified plastics and Styrofoam popcorn (SIMPER >10%, Fig. 6b), followed by Paper sheet, Plastic bottle, Lost fishing floats, Plastic bag and Other debris (SIMPER > 5%, Fig. 6b). The remaining categories in Fig. 6b contribute to differences with values between only 1 and 5%. Besides presenting a lower abundance of floating debris, the south sector also presents a smaller number of categories that contribute to its differentiation from the north sector. The most differentiating categories in the south sector identified by Simper analysis were wood pallet or crate, wood lumber or board, and wood lumber or board, and other styrofoam item. The categories with highest contributions to the differentiation in the north sector were plastic bottle, Plastic bag, lost fishing floats, styrofoam popcorn, unidentified plastics, paper sheet, plastic strap, metal can, styrofoam food or beverage containers, wood.
log or branch, other metal, cables and fishing lines (CALI) and Other plastic items (PLOT).

4. Discussion

4.1. Composition and abundance of FMD

Plastics are the most predominant floating debris type in Portuguese offshore waters, alike other regions in the world (Dixon and Dixon, 1983; Vauk and Schrey, 1987; Thiel and Gutow, 2005; Barnes et al., 2009; Thiel et al., 2011, 2013). In Portugal, plastic items had already been described as the dominant marine debris type covering the sea bottom and submarine canyons, and deposited on beaches (OSPAR, 2007; Mordecai et al., 2011; Neves, 2013). In the present study, FMD density estimates (average of 2.98 items/km²) are similar to those reported for the North Sea (Dixon and Dixon, 1983), in near-shore areas around Japan (Shiomoto and Kameda, 2005) and for the Antarctic Peninsula, Drake’s Passage, South Georgia, Falklands, Aberdeen-Shetlands and West Spitsbergen (Barnes et al., 2009), where densities of marine debris varied up to 5 items/km². However, higher FMD density values were already reported in the western North Atlantic (DuFaut and Whitehead, 1994), in coastal waters of Indonesia (Willoughby et al., 1997), in the Mediterranean Sea (Aliani et al., 2003; Suaria and Aliani, 2014), in the English Channel, Atlantic Ocean 20–50°N, and Atlantic Ocean 20–10°S (Barnes et al., 2009), in the eastern North Pacific (Titmus and Hyrenbach, 2011), the North Sea (Thiel et al., 2011), the East China Sea (Kim, 2011), and in Chile (Thiel et al., 2013) where density estimates reached over 70 items/km².

With respect to FMD size classes, the XL size class was the least abundant. Very large size marine debris materials can have a mixed origin. They may be more common after winter storms and catastrophic events (such as floods, tsunamis, earthquakes, etc.) when large pieces of wood, metals and plastics can be transported by rivers’ run-off. Also, very large pieces of debris could be associated with maritime accidents or cargo losses during storms. The low number of very large items may be related with the survey being performed during summer when storms are less frequent with lower risks of maritime accidents or cargo losses. L and M marine debris, mainly consisting of several plastic categories and cables and fishing lines, are highly resistant, being more durable and allowing them to float for longer periods (Ryan et al., 2009) while other materials such as wood, cloth and rags are more easily degraded.
4.2. Potential sources and distribution of FMD

Possible FMD sources in offshore waters are extremely difficult to identify since FMD may remain afloat for extended periods (Sheavly and Register, 2007; Hinojosa and Thiel, 2009). In Continental Portugal, land sources include river discharges and coastal urban centers. Marine sources include fisheries and recreational maritime activities (Neves, 2013), commercial vessels and cruise ships (Martins and Sobral, 2011). The highest FMD densities co-occur with major navigation corridors (from North America and Northern Europe to Portugal, the Mediterranean and Northern Africa) (see Fig. 7). Therefore, ships using the different navigation corridors in the area may represent a major source of FMD in these deeper offshore waters.

Cables or fishing lines detected as plastic derelict materials from fisheries, were the only fishing related items that appeared among the top ten FMD items in Portuguese offshore waters, evidencing the local source of the majority of the FMD detected. In fact, long-lines and pelagic trawls are the more commonly used fishing gears in these waters, while bottom set nets are almost completely absent (Gordon et al., 2003). The fishing industry is clearly one of the responsible sources, considering the significant density and abundance of cables and fishing lines.

In the present survey, only two out of the 608 detected items presented epibiont colonization (a fishing buoy and a bottle). Since epibiont-loaded FMD suggest a floating longevity of several months (Thiel and Gutow, 2004), most of the observed FMD had been relatively recently discharged in the marine environment. Also, since the surveyed area is far off the coast, local marine sources (mainly discharges from vessels, derelict material from fishing activities and cargo losses) should be responsible for most of the detected FMD.

The study area's upper ocean circulation regimes may play an important role in FMD density distribution. The high-density FMD areas (10% of Kernel) and even the FMD core areas (50% of Kernel) (Fig. 4) are located in regions where several oceanographically dynamic features interact (Fig. 1). With respect to the northern core area, the Portugal Current with a southward direction, and also the Western Iberian current, may influence the accumulation of FMD. In this region, it is also possible to find several recurrent eddies, the largest one being clearly associated with the highest concentration of FMD in this sector (Figs. 1 and 4). There were no FMD core areas in the southern region, although some FMD concentration (60% Kernel) was detected between the Ampere seamount and the end of the S. Vicente canyon probably resulting from the transport of FMD along the Eastern Branch of the Azores current together with the northern recirculation at the Gulf of Cadiz. During calm weather, when relatively stable fronts are frequent, floating items accumulate near these frontal zones and temporary small gyres or eddies possibly act as retention zones for floating items (Ryan, 1988; Dippner, 1993; Skov and Prins, 2001; Pichel et al., 2007; Thiel et al., 2013). FMD with higher floatability found in the Portuguese offshore waters will probably be transported farther until the North Atlantic garbage patch (Sheavly and Register, 2007; Law et al., 2010; Thiel et al., 2011; Maximenko et al., 2012).

4.3. Conclusions and future work

Plastic items are the major component of floating marine debris (FMD) in Portuguese offshore waters. The higher diversity and abundance of FMD in the North sector of the study area appears to be associated with the high number of navigation corridors, and most of the FMD...
may originate from local marine sources [recently released fishing items]. Future studies concerning Portuguese waters should focus on the implementation of routine surveys to estimate steady state at sea and to monitor the distribution of FMD both in offshore and near shore waters, in order to model the dynamics of FMD (source, sink areas and long drifting movements) and to evaluate FMD persistence at the sea surface. By incorporating data on cetacean, seabird and sea turtle occurrence it will be possible to assess injury and mortality risks to protected species in one of the most important migration pathways between the North Sea, Western African waters and the Mediterranean Sea.

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