Marine traffic and potential impacts towards cetaceans within the Madeira EEZ

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ABSTRACT

Human population growth has resulted in an increase of marine traffic. This has been associated with wildlife disturbance and the effects are expected to increase with continued traffic expansion. A particularly impacted group is cetaceans, known to play an important role in the sustainability and regulation of marine ecosystems. An assessment of marine traffic can therefore contribute towards wildlife conservation measures, especially when evaluated in the context of important areas for cetaceans. The present study took place in Madeira's Exclusive Economic Zone (EEZ), an area hosting a high diversity of cetacean species as well as island-associated groups. Automatic Identification System (AIS) data were collected from a land station between 2008 and 2011 and marine traffic and cetacean visual data collected during shipboard surveys between 2001 and 2011. Results show that Madeira's offshore traffic (up to 12 n.miles from the shore) corresponds to approximately 12% and 22% of the traffic observed in the Baltic and North Sea, respectively. It is mostly composed of cargo ships navigating over fixed routes and using the area as a passage towards different destinations. Cruise ships intersect the area mainly to reach Funchal's port. The number of recreational boats in the area was found to be underestimated since many of them are not equipped with AIS devices. The level of Madeira inshore traffic is harder to evaluate since it is a small area encompassing a shipping route, yet it may represent 0.8% of the traffic recorded in the Strait of Gibraltar. According to the inshore shipboard survey data, coastal marine traffic is mainly composed of fishing boats (47%), recreational boats (24%), ships (17%), whalewatching boats (10%) and big game fishing boats (2%). Most inshore and offshore vessels were found to be navigating at over 10 knots. An inshore 'higher use corridor' common to both vessels and cetaceans was identified as a potential danger zone.

KEYWORDS: ATLANTIC OCEAN; SUSTAINABILITY; SURVEY – VESSEL; DISTRIBUTION; NORTHERN HEMISPHERE; FIN WHALE; SHORT-FINNED PILOT WHALE; BEAKED WHALES; SPERM WHALE; BOTTLENOSE DOLPHIN; ATLANTIC SPOTTED DOLPHIN; COMMON DOLPHIN

INTRODUCTION

Marine traffic has been associated with a high potential of disturbance towards marine species, such as whales and dolphins, and this negative effect is expected to continue increasing as a consequence of continued traffic expansion (Nowacek *et al.*, 2001).

Cetaceans manifest behavioural changes (Piwetz *et al.,* 2012) that could trigger shifts in habitat use, temporary displacement and an increase in energy consumption. When continuously exposing the animals to these pressures long term consequences, such as changes in survival rates or population size, might follow (Bejder *et al*., 2006; Constantine *et al*., 2004; Nowacek *et al.,* 2001).

Over recent decades, due to the vast expansion of marine traffic, cetaceans have also been victims of increased ship strikes all around the world (Carrillo and Ritter, 2008; Laist *et al.,* 2001; Silber *et al.,* 2012; Waerebeek *et al*., 2007). Marine traffic is acknowledged as a worldwide threat towards whale and dolphin populations and is being addressed by various mitigation strategies, some supported by the International Maritime Organization (IMO), especially in regions where there are overlapping areas of busy marine traffic and high cetacean density (IWC, 2011; Panigada *et al*., 2006; Ritter, 2007; Silber *et al*., 2012). The International Whaling Commission (IWC) is playing a lead role by proposing mitigation measures and legislation on ship strikes, creating a ship strikes database, working with other bodies both intergovernmental and non-governmental and supporting specialist workshops (IWC, 2016).

Moreover, cetaceans attract a significant interest from the general public, resulting in significant growth of the whalewatching industry (Jelinski *et al*., 2002; Orams, 2000). This in turn raises the need to monitor the industry and adopt codes of conduct and regulations in order to minimise its impact on cetaceans and ensure its sustainability (Ritter, 2003).

Shipping traffic appears to be a significant fraction of the anthropogenic sound input into the marine environment (Southall, 2005; Weilgart, 2007) and the potential impact of this on cetaceans has been considered an important issue (Southall, 2005). Marine mammals rely on hearing as their main sense. Thus, they are vulnerable to ocean noise pollution that might be the cause of some strandings and mortality incidents, among other disturbances, or chronic effects such as 'masking', altered vocal behaviour, hearing damage, increase in stress levels, habitat displacement and alterations in migration routes (Weilgart, 2007).

Coastal cetaceans are even more exposed to anthropogenic disturbances, especially in highly populated areas, where the effects can be cumulative (Piwetz *et al.,* 2012).

The present study took place in Madeira's Exclusive Economic Zone (EEZ) and provides, for the first time, information regarding traffic distribution patterns within the study area. The geographical position of Madeira's

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archipelago near the shipping corridors connecting Europe to South America and Africa. Madeira is itself the destination of many cruise ships, cargo ships and leisure crafts. It is constantly surrounded and sought out by marine traffic. These islands, as other islands in the Atlantic, are feeding, reproductive and breeding grounds for several whale and dolphin species (Alves *et al.,* 2013; Dinis, 2014; Freitas *et al.*, 2004b).

In January 2005, the use of Automatic Identification System (AIS) devices became mandatory for ships with gross tonnage (GT) equal or superior to 300 and all passenger ships of every size, following the ruling of IMO's International Convention for the Safety Of Life At Sea (SOLAS). AIS is a ship-to-ship and ship-to-shore message system based on VHF signals, which provides static and dynamic data related with each vessel trip (Silber *et al*., 2012). Later the European Union, through the Directive 2009/17/EC, established the mandatory use of AIS devices in fishing vessels and other vessels over 15m (IWC, 2011), where the Madeira Autonomous Region is included (Ministério da Agricultura do Mar do Ambiente e do Ordenamento do Território, 2012). The previously mentioned ruling promoted the wide use of AIS that in turn became an important source of data on marine traffic worldwide.

The main goals of the present study are to: (1) assess the spatial and temporal distributions of the inshore and offshore marine traffic of the Madeira archipelago; (2) identify zones of higher and lower marine traffic within the study area according to the type of vessel; and (3) identify zones of overlap between higher marine traffic areas and higher occurrence of cetaceans.

METHODOLOGY

Study area

The research focused on the Madeira EEZ (Fig. 1), including the inshore waters around Madeira, Desertas and Porto Santo Islands. These volcanic islands are located in the Atlantic Ocean at an average latitude and longitude of 32° 46'N and 16° 46'W and 635km from Africa's West coast. Madeira stands isolated from the closest mainland and nearby archipelagos by depths greater than 4,000m. The archipelago main islands are surrounded by several steep submarine canyons, with a small continental shelf, and often influenced by the Gulf Stream current, thus presenting favourable conditions to hold a substantial level of marine biodiversity (Aguin-Pombo and Carvalho, 2009).

The offshore study area comprises the entire Madeira EEZ, an area of approximately 454,479km^2 (VLIZ, 2014). The inshore study area is about 4,500km^2, which includes the coastal waters from shore up to 12 n.miles, divided into eight survey sectors, covering depths from 0 to –2,000m (Fig. 1).

Data sources

In order to characterise the vessels' temporal and spatial distribution in the offshore and inshore waters of the Madeira Archipelago, two different types of data were used: (1) records collected during shipboard surveys carried out by the Madeira Whale Museum (MWM) research team from 2001–12, in the context of different projects (2001–02 – Project Cetáceos Madeira; 2007–08 – Project Emacetus; 2010–12 – Project Cetáceos Madeira II); (2) AIS data supplied by Administração dos Portos da Região Autónoma da Madeira (APRAM) recorded between 2008 and 2011.

The first type of data was used to build inshore 'traffic sighting rates distribution maps' to compare with 'cetacean sighting rate distribution maps' obtained from data gathered by the same platforms and within the same time period. This gives an overview of the regional marine traffic patterns, allowing identification of higher and lower inshore vessel traffic zones and the detection of possible areas of potential conflict between cetaceans and vessels.

The second type of data was used for: (1) preliminary characterisation of the Madeira offshore traffic; and (2) corroboration of the inshore traffic sighting rates distribution maps (previously described).

Both spatial and temporal analyses were run, pooling the data by boat type and season. The summer and winter

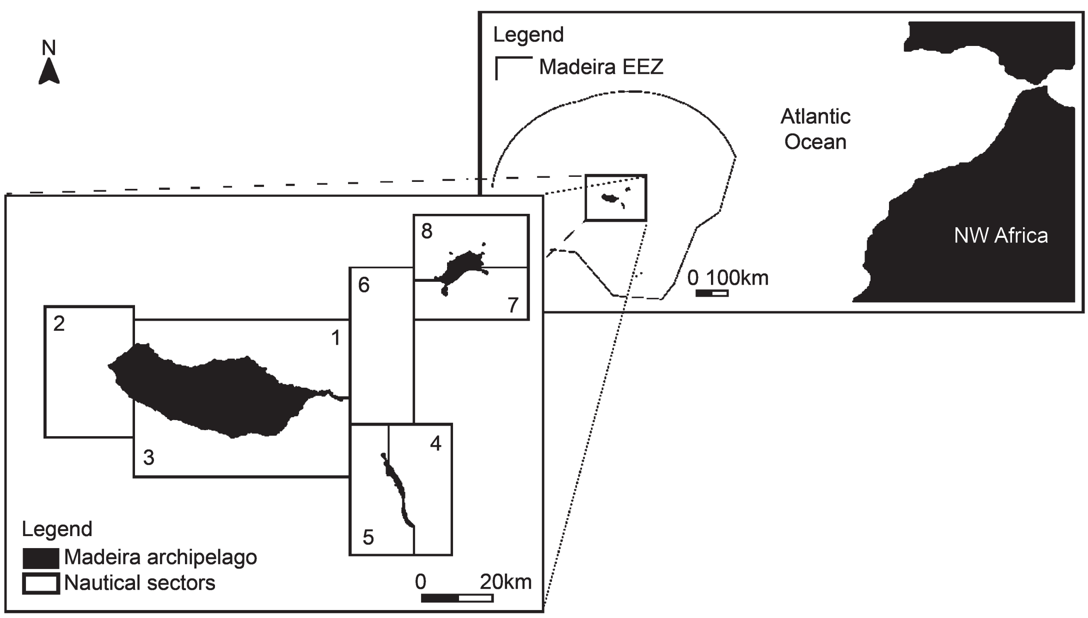

Fig. 1. Study area.

seasons were defined as the periods between June–October and November–May, respectively.

AIS data

Database management

Among the several AIS ship report parameters, only the equipment ID, position, date, Speed Over Ground (SOG) and type of boat attributes were used in this paper.

The data gathered were displayed and validated using ArcGIS 10.1 (ESRI, Redlands, CA, USA). The number of the vessels' position tracks was reduced to one point of coordinates (and related parameters) for each thousand degree cell within the polygon that limits Madeira EEZ, thus reducing the number of coordinates to be handled. This procedure enabled reconstruction of routes, although possibly with some sample bias in areas of heavy route crossing.

Mapping vessels positions tracks

In order to keep the maps presenting the vessels tracks perceptible, a seven day period of vessels' tracks was considered enough to illustrate the traffic scenario (Eiden and Martinsen, 2010). The first week from each month was chosen, except for March from which the last week was used (the only available data).

Vessel types from the AIS data files were organised into four categories: cargo ships (cargo vessels or cisterns); cruise ships (passenger ships); recreational boats (wing-in-ground-effect craft, high speed craft or practical dinghy); and other type of vessels (tugboat, vessel or no classification). When counting the number of vessels per week, each vessel was considered only once.

Speed grid maps

Vessel speed is one of the important factors which might determine the severity of a ship collision with a whale.

A raster file (in ASCII format) was generated, where the vessels medium SOG value was associated to each pixel, creating speed grid maps. The speed grid maps for the offshore traffic area are represented in a grid of 10 × 10 n.miles (18.52 ×18.52km), while the speed grid maps for the inshore traffic area are represented in a grid of 2 × 2 n.miles (3.704 × 3.704km). All vessel types were considered in the same text file.

The probability of a whale being lethally injured by a ship strike is > 50% if the vessel is navigating at speeds over 10 knots, but if the incident occurs while the ship is moving > 15 knots, the chances of a lethal injury increases from 80% to 100% (Vanderlaan and Taggart, 2007). For this study, vessels travelling at ≤ 10 knots were considered as 'low' speed while vessels > 10 knots were considered as 'high' speed.

Shipboard survey collected data

Field work methods

The sampling methods and protocol for cetacean sightings and traffic data collection remained unchanged in its critical aspects over the years.

The shipboard surveys were carried out in Beaufort Sea state ≤ 3. Two research vessels were used during the study period, R/V *Calcamar* for the 2001–02 surveys and the R/V *Ziphius* from 2004 onwards. The first vessel is a 12m open deck wooden fishing boat with an average surveying speed of 5.5 knots and with the observing points at an average height of 3m. The second vessel is a steel motor sail boat with an average survey speed of 6.5 knots and two dedicated observation platforms, one placed ahead midship (one observer) and the other astern (two observers), both at an average height of 4.5m. The field work aimed primarily at surveying cetaceans and was done according to distance sampling methodology (single platform). Each sector of the study area was sampled on average twice every three months, with randomly placed zig-zag transects.

A minimum of three observers scanned the sea continuously looking for animals and every hour all the marine traffic observed up to the horizon, 360° around the vessel, was recorded in a computer using Logger 2000 software, along with the observation effort.

Traffic data recorded

The traffic data recorded included: sighting time; observed vessel(s) type(s) (recreational boat – private vessel with less than 24m in length; fishing boat – commercial fishing boat of any size; big game fishing boat; ships – private or commercial vessel with more than 24m in length; whalewatching boats – vessels with less than 24m in length); number of boats of each type; estimated visibility recorded in classes (visibility ≤ 1 n.miles; 1 < visibility ≤ 3 n.miles; 3 < visibility ≤ 5 n.miles; visibility > 5 n.miles); and the identification of the data recorder.

Every observation was tagged with the research vessel's GPS position at the moment of the sighting, i.e. the longitude and latitude recorded do not correspond to the precise position of the observed vessels. Consequently the records of the vessel sightings have an associated position with an error up to 15 n.miles (≈ 22km) (roughly the maximum distance at which a vessel would be identified taking into account the observation platform height) and vary also according to the observed vessel's type/height (smaller boats are detected at much closer ranges and with a smaller associated position error in relation to the research vessel GPS position). One pair of coordinates might correspond to more than one vessel, according to the number of boats spotted at a particular time. The vessel estimated distance and direction was not taken into account. Furthermore (considering that the traffic data was collected every hour) it is possible that a few vessels might have been registered more than once, depending on their trajectory, change in trajectory and speed in relation to the research vessel and observation conditions.

The data collected were separated into two periods according to the vessels' classification: (1) 2001–09: vessels were classified only as ships, recreational boats or fishing boats; (2) 2010–12: whalewatching and big game fishing were added to the vessel classification list.

Cetacean information records

Data on cetacean sightings included: the date and initial time of the sighting; vessels position at the initial time of the sighting; estimated radial distance and angle to the bow at the initial sighting time; species; minimum, average and maximum group size; and the number of calves.

Mapping vessels estimated locations

The vessels' locations were plotted in a vector environment over a grid with resolution of 2 × 2 n.miles (3.704 × 3.704km), covering the inshore study area. The Madeira Archipelago coastlines and pre-defined inshore survey sectors were also overlaid within the same range.

The observation effort value of each grid cell was represented through a colour gradient in order to show the areas that were more intensely surveyed. The effort was measured as the sum of kilometres of the research vessel's trackline in each cell.

Subsequently, the results were represented on three types of maps: (1) types of vessels distribution maps – pie chart maps, where the proportion of every type of boat was represented per cell; (2) plot of research vessel's locations projected over the effort grid where the sightings points were represented with variable diameters according to the number of boat detections associated with each pair of coordinates; and (3) traffic sighting rates distribution maps – each grid cell's vessel sighting rate, calculated by dividing the number of boats sighted in each cell by the respective survey effort and represented through a colour gradient over the grid.

To avoid misleadingly high sighting rate values in surveyed cells with very low effort, any grid cell with survey effort less than 5km (grid cell diagonal length) (Fortuna, 2006) was filtered out and not quantified in either of the resulting GIS maps. This procedure was systematically applied to all the maps, according to vessel type and seasonality. A seasonal analysis was only possible for traffic sighting rate distributions for vessel types recorded during the whole sampling period (2001–12), i.e. ships, recreational boats and fishing boats.

Mapping cetacean estimated locations

Cetacean sightings data were displayed in the same vector environment as the traffic data.

Following the same procedure, two types of maps were created: (1) cetacean species' distribution maps: pie chart maps, where the proportion of the more relevant species of cetaceans was represented per cell, i.e. by dividing the estimated number of sighted animals of a certain species in an encounter by the total number of animals of all species sighted in the same cell; and (2) cetaceans' sighting rate distribution maps: each grid cell corresponds to the cetacean sighting rate, calculated by dividing the number of cetacean sightings for each cell by the respective survey effort, and represented through a colour gradient over the grid. An additional map was made showing the sighting rates of cetacean groups with calves, i.e. the number of cetacean groups sighted with calves in each cell (disregarding the number of calves) divided by the corresponding survey effort and represented through a colour gradient over the grid.

Likewise, for the marine traffic maps, only cells with a minimum value of 5km of survey effort were displayed.

Data analysis

The normality of the AIS traffic data, as well as the shipboard surveys traffic and cetaceans' data were tested using Shapiro-Wilk and Kolmogorov-Smirnov tests. A *t*-test was applied to the AIS data to check for the existence of a significant difference between winter and summer season distributions.

A Kruskal-Wallis test was run with both general and seasonal traffic sighting rates distributions from the shipboard surveys to check for the existence of significant differences between the sectors. If one distribution was found to be heterogeneously distributed across the area ($p < 0.05$), a Mann-Whitney test was applied to find out which sectors were statistically different from each other and to detect significant seasonal variations in the same sector. The same procedure was applied to the cetacean distributions.

The statistical tests were run in IBM SPSS Statistics 19 software.

RESULTS

AIS data

Offshore traffic distribution

The number of vessels crossing the Madeira EEZ varied between 100 and 300 vessels per week (Fig. 2a). The highest traffic peaks are in the summer months (August 2008 and September 2009) and the lowest in the winter season (February 2009 and May 2011). Nevertheless, no significant differences were found (t-test results $p > 0.05$) between seasons.

The Madeira EEZ was found to be intersected by an average of 188 vessels per week, i.e. 0.0004 vessels per km^2.

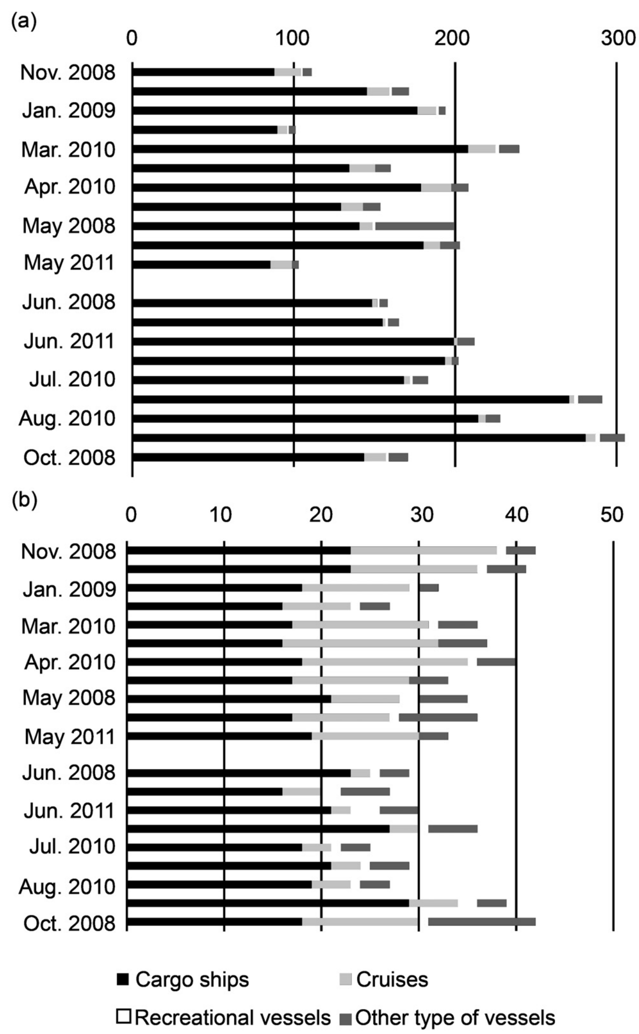

Fig. 2. Number of vessels per week and the percentage of vessel type incidence per each representative month during the Winter (November–May) and Summer (June–October), between 2008 and 2011: (a) offshore traffic; (b) inshore traffic.

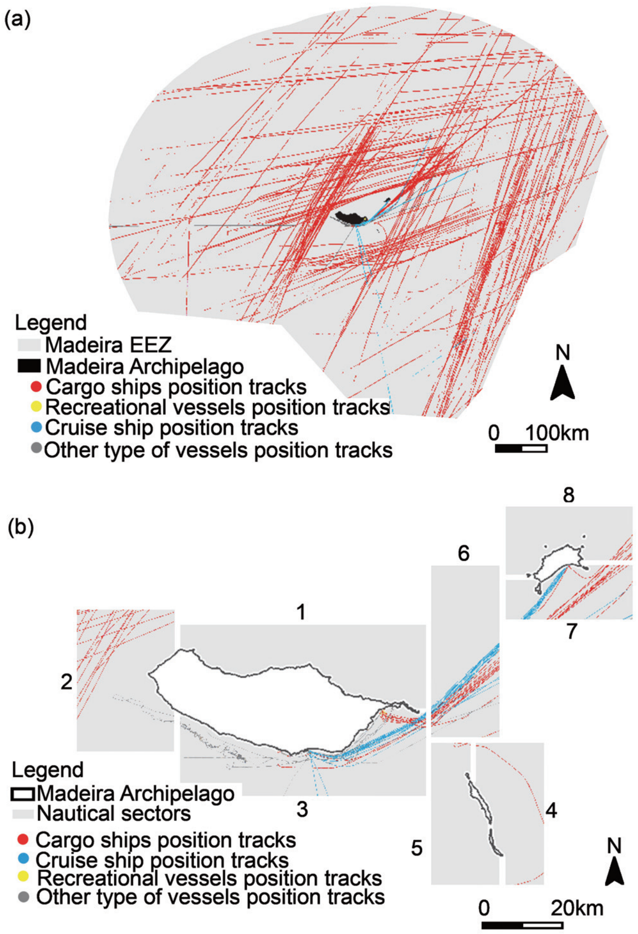

Fig. 3. Vessel position tracks projected over the Madeira EEZ area. Some areas show higher track density shipping lanes. Only one representative map (July 2008) is displayed among the 20 representative months used in the present study: (a) offshore traffic; (b) inshore traffic.

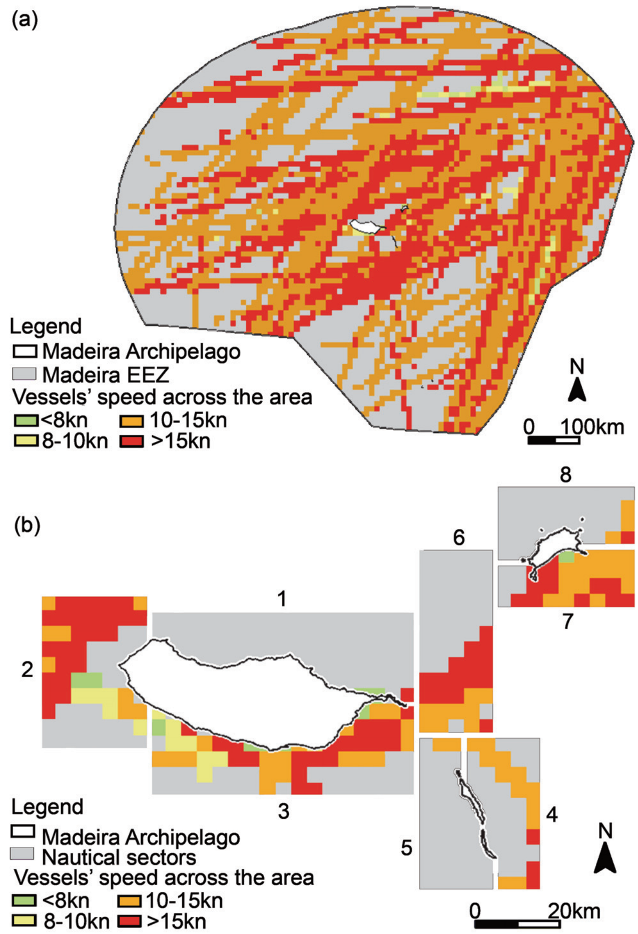

Fig. 4. Speed grid cell maps displayed within the Madeira ZEE area. Each pixel represents the vessels Speed Over Ground (SOG) average value. Only one representative map (July 2008) is displayed among the 20 representative months used in the present study. The 'low' speed cells are coloured in green and yellow and the 'high' speed cells are coloured in orange and red: (a) offshore traffic; (b) inshore traffic.

Traffic composition does not vary considerably, with cargo ships representing at least 70% of all traffic, followed by either unclassified vessels or cruises/ferries, in variable proportions (Fig. 2a). May 2008 stands out as an outlier from the remaining sampled months, with the 'other type of vessels' category representing a greater proportion of the traffic composition.

It was possible to identify five recurrent shipping lanes (see Fig. 3), common to all 20 AIS traffic monthly maps (only July is presented for 2008): three lanes presenting a NE–SW orientation, one at the West side and the other two at the East side of the islands; two orientated on an E–W axe: one to the South and the other to the North of the islands. The NE–SW orientated shipping lane, located further East from the Madeira Island seems to be more intensively used. All these shipping lanes are mostly used by cargo ships.

Inshore traffic distribution

The number of vessels registered by the AIS system varied between 27 and 42 boats per week, year round. This inshore area was also mainly intersected by cargo ships (Fig. 2b and Fig. 3b), many of them navigating closer to Madeira.

The inshore traffic area was intersected by an average of 34 vessels per week, i.e. 0.008 vessels per km^2.

Vessel speeds

Though all vessel types were considered, the speed values are mostly from ships (including cargos and cruises), accounting for at least 70% in both offshore and inshore traffic composition of one week of each sampled month (Fig. 4).

In general, both inshore and offshore cells present on average 'high' speed traffic.

Traffic data collected in inshore shipboard surveys

A total of 830 vessels were sighted, 401 between 2001 and 2009 (54% fishing boats, 27% recreational boats and 15% ships) and 429 between 2010 and 2012 (47% fishing boats, 24% recreational boats, 17% ships, 10% whalewatching boats and 2% big game fishing boats).

All types of vessels' sighting rates revealed a non-normal distribution ($p < 0.05$).

The descriptive statistics data (mean and standard deviation) for the general and seasonal vessels' sighting rate distribution, for each type of vessel and for all sectors, are presented in Table 1.

The Mann-Whitney test results are presented in Fig. 5, according to the type and season of vessels' sighting rate distributions.

All vessels

According to Fig. 5 and Figs 6a and 6b, Sector 3 is significantly different (Mann-Whitney test significant results for $p < 0.05$) from all the remaining sectors and holds the highest average

Table 1

Mean and standard deviation (SD) of the traffic sighting rates (number of vessels per 10km) distribution maps according to boat per vessel type and seasonality.

Vessel type	Season	Total area		Sector 1		Sector 2		Sector 3		Sector 4		Sector 5		Sector 6		Sector 7		Sector 8	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AV	S0	0.66	1.22	0.42	0.69	0.41	0.86	1.59	2.16	0.30	0.57	0.41	0.57	0.56	0.72	0.31	0.34	0.66	0.95
	S1	0.69	1.53	0.53	1.36	0.62	1.29	1.46	2.59	0.49	1.23	0.48	0.88	0.50	0.76	0.32	0.49	0.55	0.90
	S2	0.58	1.42	0.34	0.76	0.32	1.01	1.35	2.43	0.26	1.01	0.39	0.60	0.67	1.23	0.27	0.45	0.53	1.40
S	S0	0.14	0.42	0.03	0.11	0.14	0.59	0.37	0.68	0.06	0.16	0.08	0.20	0.15	0.31	0.07	0.13	0.06	0.19
	S1	0.14	0.41	0.05	0.16	0.19	0.69	0.32	0.59	0.12	0.32	0.06	0.24	0.13	0.28	0.08	0.20	0.04	0.23
	S2	0.13	0.47	0.02	0.09	0.12	0.69	0.34	0.74	0.05	0.19	0.11	0.29	0.17	0.42	0.05	0.13	0.05	0.20
RB	S0	0.18	0.46	0.09	0.34	0.02	0.10	0.46	0.78	0.11	0.31	0.12	0.33	0.20	0.44	0.13	0.20	0.12	0.30
	S1	0.17	0.57	0.18	0.77	0.06	0.19	0.38	0.89	0.11	0.44	0.10	0.33	0.14	0.32	0.13	0.28	0.08	0.25
	S2	0.19	0.69	0.03	0.17	0.00	0.00	0.55	1.23	0.05	0.16	0.07	0.17	0.34	0.93	0.12	0.29	0.13	0.53
FB	S0	0.29	0.54	0.29	0.46	0.23	0.59	0.52	0.77	0.10	0.21	0.22	0.27	0.21	0.35	0.11	0.18	0.48	0.75
	S1	0.33	0.81	0.31	0.70	0.36	1.01	0.49	1.21	0.26	0.65	0.32	0.50	0.23	0.43	0.11	0.24	0.43	0.86
	S2	0.24	0.63	0.29	0.73	0.22	0.72	0.44	0.78	0.04	0.17	0.21	0.37	0.16	0.54	0.10	0.23	0.32	0.87
WWB	S0	0.04	0.30	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
BGF	S0	0.007	0.70	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Key: Vessel type: AV = all vessels; S = ships; RB = recreational boats; FB = fishing boats; WWB = whalewatching boats; BGF = big game fishing boats. Season: S0 = general distribution; S1 = winter distribution; S2 = summer distribution.

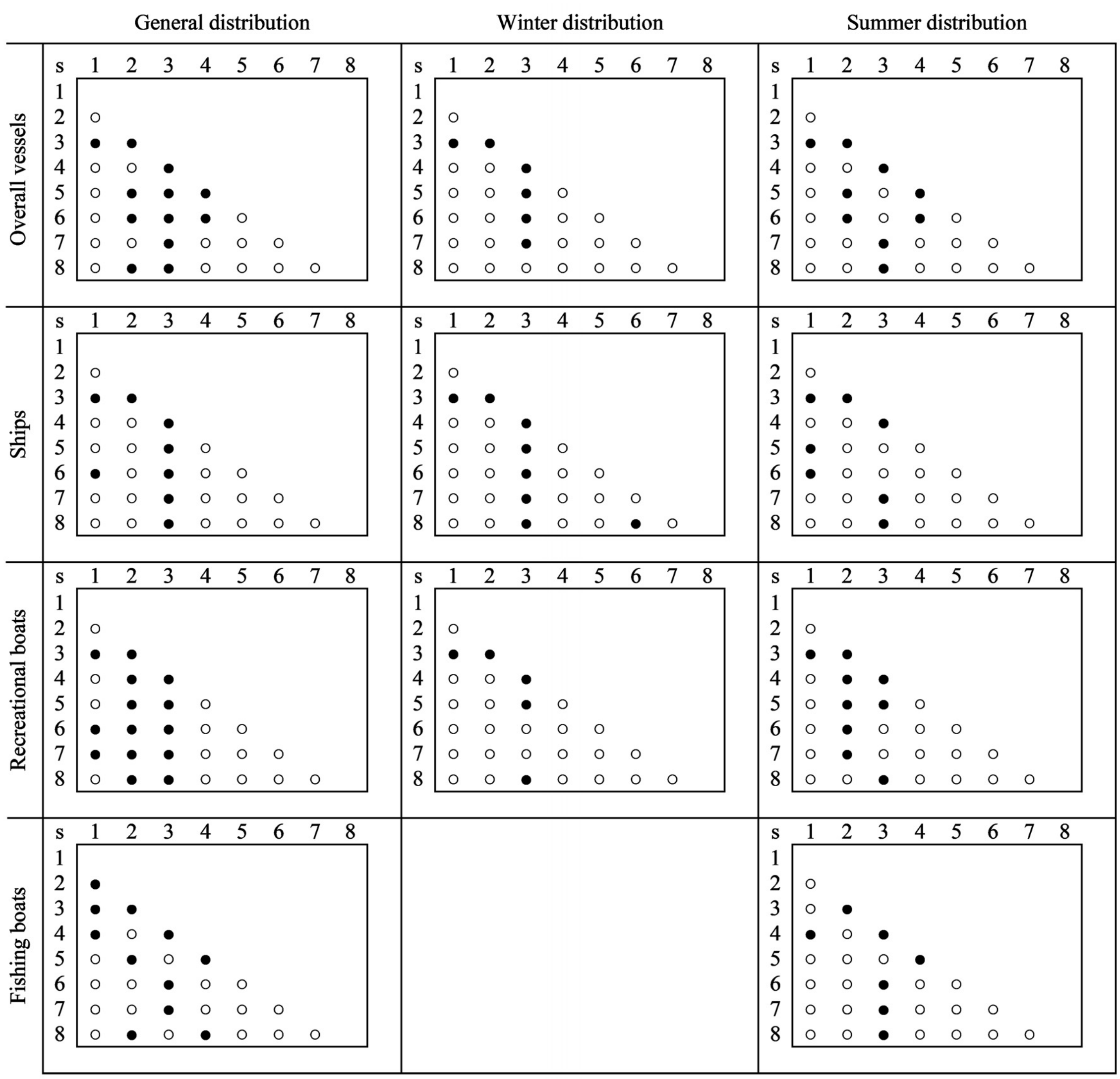

Fig. 5. Results of the Mann-Whitney tests for the different types of vessels and seasonality (winter and summer). Matrix comparing vessel sighting rates distribution across the sectors of the study area. Key: Black circles P ≤ 0.05; White circles P > 0.05.

vessels' sighting rates, standing out as the inshore traffic 'busy zone'. Sectors 2 and 4 are the less intensive traffic areas. Sector 2 is significantly different from every other sector except 4 and 7. However, apart from Sector 3, only Sectors 5 and 6 are also significantly different from Sector 4. Thus, Sectors 3, 5 and 6 present higher traffic activity. During the winter, Sector 3 is the more intensively used sector, significantly different from all the remaining sectors, except Sector 8. During the summer season, Sector 3 is significantly different from all sectors except 5 and 6, indicating a higher traffic activity in those areas. However, no significant seasonal variations were found in any of the sectors.

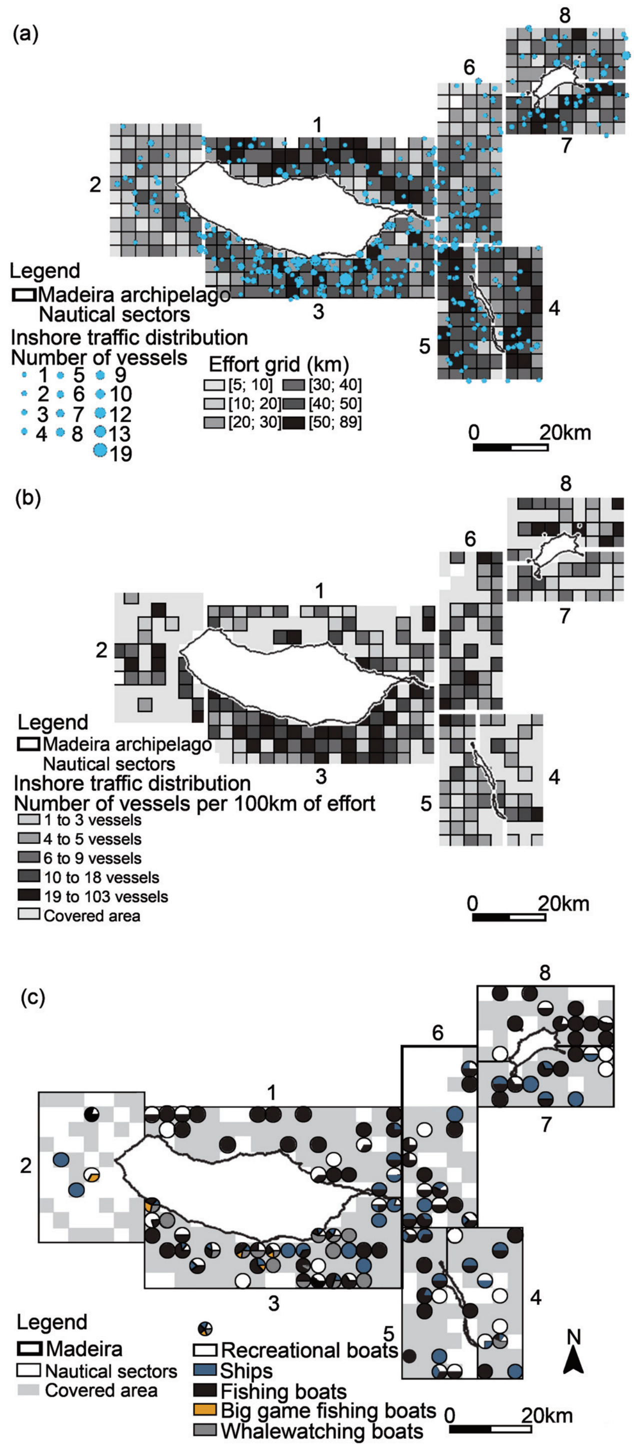

Fig. 6. Inshore traffic distribution maps: (a) plot of all vessel locations over the effort grid. Each coordinate point may correspond to more than one vessel sighting, represented through a variable circle diameter. Each effort grid cell presents a different gradient depending how much it was surveyed; (b) general traffic sightings rates distribution map (each cell value corresponds to the number of vessels per 100km of effort); (c) inshore vessel type distribution represented through a pie chart per grid cell representing the proportion of each type of vessel sighted in that location for the period 2010–12.

Ships

In both general and winter ship traffic distributions, Sector 3 had the higher activity and is significantly different from the remaining sectors. Sector 6 has a higher level of ship traffic, being also significantly different from the Sectors 1 and 8, with the lowest general and winter ship traffic distributions, respectively. During the summer season, Sector 3 is no longer significantly different from Sectors 5 and 6, indicating an increase in ship traffic in those areas. However, no significant seasonal variations were found in any of the sectors.

Recreational boats, whalewatching boats and big game fishing boats

Though recreational boats are spread throughout all sectors, Sectors 3, 6 and 7 present a higher activity (Table 1 and Fig. 5), particularly in Sector 3 that is significantly different from all sectors, except 6 and 7, for both winter and summer seasons. Sector 2 is more active during the winter (Mann-Whitney test significant results for $p < 0.05$).

All the whalewatching boats' sightings positions are located in Sector 3, except for one sighting location in Sector 4.

Big game fishing boats use mainly Sector 3.

Fishings boats

Considering the fishing boats' general distribution, Sector 3 is the most used, followed by Sectors 5 and 8. Sector 2 is the least used sector, followed by Sector 1 (Table 1 and Fig. 5). There were found no significant differences among the sectors during the winter season. Traffic activity seems to drop in Sector 4 during the summer season (Mann-Whitney test significant results for $p < 0.05$).

Based on these results it is possible to identify a 'higher use corridor' composed by Sectors 3 and 6, both sectors of higher activity in most traffic distributions across the inshore study area, as further described below.

Cetaceans data collected during shipboard surveys

The descriptive statistics data (mean and standard deviation) for the general sighting rate distribution, for all cetaceans and cetaceans groups with calves, for all sectors, are presented in Table 2.

Table 2

Mean and standard deviation (SD) of the general sighting rates distribution maps, for overall cetaceans and cetacean groups with calves, according to sectors.

	Cetaceans		Cetacean groups with calves	
	Mean	SD	Mean	SD
Sector 1	0.39	0.40	0.07	0.15
Sector 2	0.25	0.45	0.07	0.26
Sector 3	0.46	0.47	0.12	0.19
Sector 4	0.26	0.29	0.02	0.08
Sector 5	0.32	0.33	0.08	0.15
Sector 6	0.36	0.38	0.09	0.18
Sector 7	0.31	0.46	0.06	0.13
Sector 8	0.34	0.38	0.09	0.20

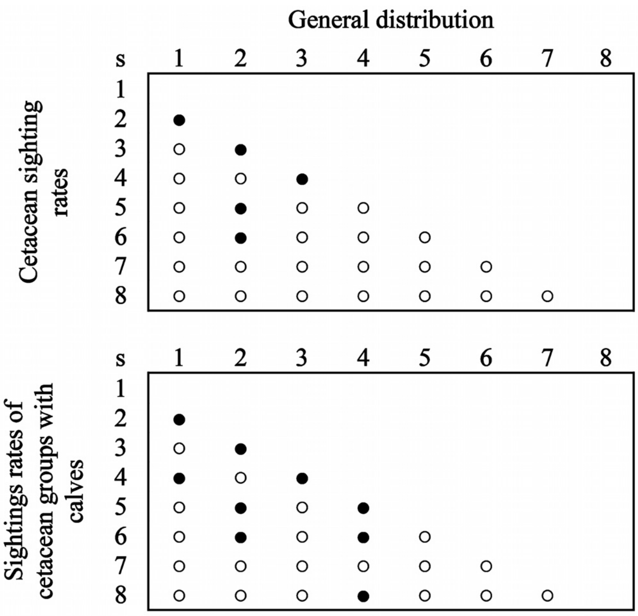

Fig. 7. Results of the Mann-Whitney tests for the cetacean distributions. Matrix comparing cetacean sighting rates distributions (overall and of groups with calves) across the sectors of the study area. Key: Black circles P ≤ 0.05; White circles P > 0.05.

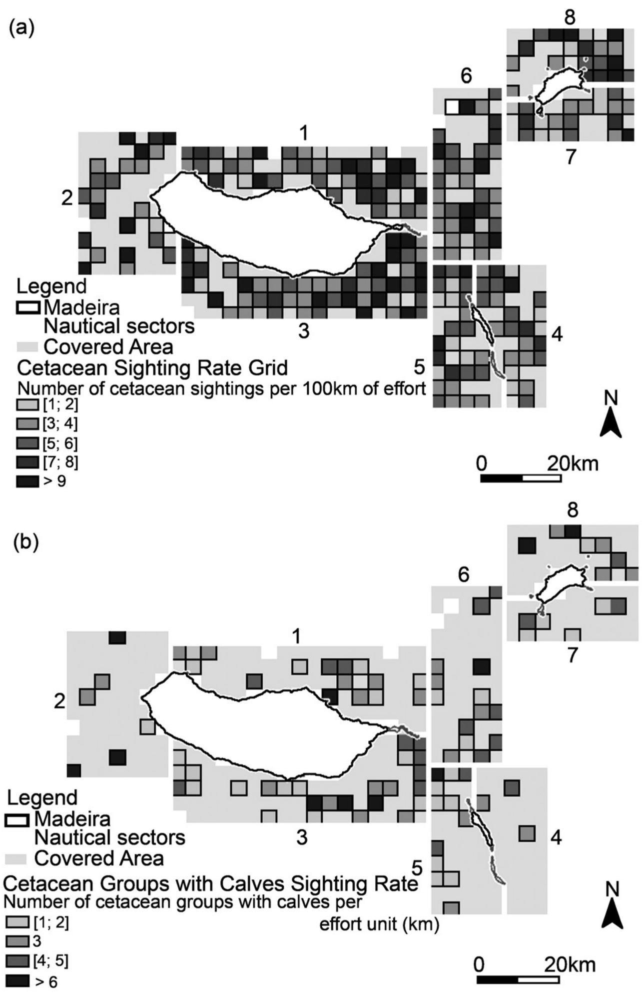

Fig. 8. Inshore cetacean sighting rates distribution maps: (a) general cetacean sighting rates distribution map (each cell value corresponds to the number of sightings per 100km of effort); (b) cetacean groups with calves sighting rates distribution map (each cell value corresponds to the number of sightings where calves were present per 100km of effort).

All cetaceans

According to the Mann-Whitney test results (Table 4), Sectors 2 and 4 presented the lowest cetacean presence. Sector 2 is significantly different ($p < 0.05$) from all sectors, except Sectors 4, 7 and 8. Sector 3 has the highest cetacean presence, being significantly different from Sectors 2 and 4, followed by Sectors 1, 6 and 5.

Cetacean groups with calves

According to the Mann-Whitney test results (Fig. 7), Sectors 2 and 4 have the lowest presence of groups with calves, while Sectors 3, 5 and 1 have the highest, followed by Sector 6. In Fig. 8b it is possible to see that most cells in Sector 5 marked with cetacean presence are in the upper part of that sector, between Sectors 3 and 6.

DISCUSSION

AIS Data

Traffic distribution

Even though some cargo ships are headed to Caniçal or Funchal, the study area seems to be mostly crossed by cargo ships heading to different destinations such as the North Sea, Middle East, the North and South America or the Mediterranean region. Cruises/ferries on the other hand cross the area usually to reach Funchal Port, one of the traditional cruise ship stops in this region of the Atlantic.

An exceptional event or combination of events, that the authors could not identify may have led to a much higher than normal traffic of vessels of the ‘other type of vessels’ category in May 2008.

Madeira EEZ maritime traffic level, though less intensive, is still considerable when compared with some of the busiest waterways in the world. The Baltic Sea, with a surface area of approximately 392,978km^2 (Lepparanta and Myrberg, 2009), corresponding to approximately 86% of Madeira EEZ, is crossed by an average of 1,319 vessels per seven day period (0.0034vessels km^{-2}) (Eiden and Martinsen, 2010) and the Madeira EEZ corresponds to approximately 12% of its traffic. The North Sea, with approximately 750,000km^2 (Lepparanta and Myrberg, 2009), is crossed by an average of 1,335 per seven days period (0.0018vessels/km^2) (Eiden and Martinsen, 2010). Madeira EEZ corresponds to 61% of the North Sea area and to 22% of its traffic. However, Eiden and Martinsen (2010) reported that the presented number of vessels crossing the North Sea is underestimated.

To put this into perspective, the inshore study area should be compared with other coastal areas with similar surface areas. The Strait of Gibraltar is located between the southern coast of Spain and the northern coast of Morocco (58km long and approximately 13km at shorter distance between shores) and is an important shipping route since it is the only connection between the Atlantic Ocean and the Mediterranean Sea. Its surface area is roughly 1,914km^2 (considering the strait’s western extreme 43km wide, between Barbate and Tanger and the eastern extreme 23km wide, between Rock of Gibraltar and Ceuta Canyon) corresponding approximately to 43% of the Madeira inshore study area and is crossed by an average of 1,975 vessels per week (IWC, 2011), i.e. approximately 1.03 vessels km^{-2}. The inshore traffic of the study area is about 0.8 % of the Strait of Gibraltar’s traffic.

Vessel speeds

A closer look at the average traffic speed in inshore cells indicates that 'low' speeds are common (green and yellow coloured cells) near Madeira and Porto Santo Islands ports (Funchal, Caniçal and Porto Santo ports), which are mostly associated with vessels approaching and leaving harbours or mooring places (Sectors 3 and 7). However, 'high' speeds cells are the most common in these two sectors (Fig. 4b). In Sectors 4 and 5 (East and West Desertas) the 'low' speed cells closest to the shore are from small vessels, as ships would not be able to moor there. Desertas Islands are frequently sought out for touristic purposes, by local recreational and commercial boats and foreign recreational boats. Cargo and cruise ships also use these sectors, passing farther away from the coast to different destinations at cruising speed. The same happens in Sector 6 (the passageway between Madeira and Porto Santo island) and Sector 2 (West of Madeira), where 'low' speeds are rare (Fig. 4b).

AIS data limitations

Though this kind of data has revealed itself to be very useful and accurate, it has some limitations. The AIS transmission range is limited and can vary depending on the transmitting and receiving aerial heights as well as meteorological conditions that can affect the spatial coverage (dependent on the VHF signal range from the coast). This is particularly true for the greater distances from Funchal (Eiden and Martinsen, 2010; Mou *et al.,* 2010), as shown in Fig. 3 where large gaps can be found between points from the same route.

The original database files were large and hard to manage, so file converters were used to reduce their sizes. The discontinuity and heterogeneity of AIS data available for each of the sampling units throughout the study period was also a problem. Data was unavailable for some months of a particular year or some months were integrally represented while others only had data covering a few days.

Even though AIS covers a great variety of vessel types, smaller recreational boats may not have such devices (Eiden and Martinsen, 2010; Evans *et al.,* 2011; IWC, 2011; Mou *et al.,* 2010). Nevertheless, the percentage of smaller recreational boats should still be smaller than cargo or cruise ships, as they tend to be either local boats navigating mostly inshore waters or they are sailing boats crossing the Atlantic or passing through Madeira on their way to the Canary Islands or the Caribbean. This type of traffic is more frequent during the autumn season (October to December), when they can take advantage of the trade winds.

The number of vessels given here is also certainly underestimated as no AIS data on fishing vessels was available.

Traffic data collected in inshore shipboard surveys

Considering the inshore traffic composition (Fig. 6c), Sector 3 stands out as the zone with the higher traffic level, used by every type of vessel, as expected. The south of Madeira Island, with calmer waters sheltered from the trade winds (NE), is the most populated coast and is where most of the small harbours and main ports are located in the archipelago. These characteristics justify why this is the sector with higher traffic both in summer and winter. Sector 6 follows, with an important amount of movement between the two main islands, frequently done by recreational boats, fishing boats and ships, especially in summer time.

Though Sectors 3, 5 and 6 appear to be the most frequently used sectors, when crossing these data with the available AIS data for the same area (Fig. 3b), mainly composed of ships, Sector 5 is rarely crossed. This may be justified by the associated discrepancy of some recorded positions of observed bigger vessels, as explained in the methodology section.

The Madeira fishing fleet is 89% composed of vessels less than 12m in length (Direcção-Geral das Pescas e Aquacultura, 2007), carrying out demersal fishing and operating near the harbours. The most profitable are the tuna and black scabbard fishing fleets, which together accounted for 84% of the total landings and 87% of 2012 economic revenue of the fishing activity in the region (Instituto Nacional de Estatistica, 2013), also operate offshore, away from the area covered by the inshore shipboard surveys. These fleets may be underrepresented in the traffic sighting rates maps, especially during the summer period. The black scabbard fishery usually runs May–December and the tuna fishery usually runs between April and October.

Potential impact towards cetaceans

Comparing the distributions of traffic and cetaceans (all groups and groups with calves) with the inshore study area it can be seen that the traffic 'higher use corridor' (including Sectors 3 and 6) overlaps a substantial part of the cetaceans' preferential distribution area, where the encounter rates are higher. Therefore, this corridor can be considered a 'potential danger zone'. According to previous studies, Sectors 3 and 6 include a critical area for cetaceans in general, where these are more frequently sighted (Freitas *et al,* 2014).

Cetaceans may be disturbed by vessels in different ways, such as (eco)tourism, ship strikes or water noise and pollution produced by boats (Bejder and Samuels, 2003; Laist *et al.*, 2001; Weilgart, 2007). However, some types of vessels are associated with specific cetacean interactions that should be considered independently. Likewise, some species are more prone to traffic interactions, than others.

The interactions between cetaceans and whalewatching vessels have been previously investigated in the study area when short term effects were observed among the Delphinidae (Ferreira, 2007). Stress responses have also been reported for short-finned pilot whales when followed by whalewatching boats, especially when these encounters were not conducted following the voluntary guidelines (Freitas *et al.,* 2004a).

Unfortunately, there are no data available on underwater noise or water pollution in the Madeira archipelago. Therefore, the following discussion will be mainly focused on ship strikes.

Potential ship strike risk in inshore waters

The incidences of ship strikes in a certain area are not easy to quantify. Their probability depends on different variables such as the level of traffic activity, the number of cetaceans and their behaviour within that area. The amount of time whales spend underwater away from watercraft and their ability to detect and consequently avoid them are related to the probability of ship strikes within a certain area.

Every type and size of vessel can strike whales, but the more serious or lethal cases registered occurred with ships with a length of 80m or more, travelling at speeds over 14 knots (Evans *et al.*, 2011; Laist *et al.*, 2001), usually ferries, cargo and cruise ships. In previous studies focused on the collisions between vessels and Mediterranean fin whales (Panigada *et al.,* 2006), ferries and cargo ships were the type of vessels with the highest number of strikes, accounting for 62.5% and 16.7% of cases, respectively.

The probability of a ship strike being fatal increases from 20% to 80% as ship speed increases from 8.6 to 15knots. At speeds below 11.8 knots, the likelihood of lethal injury is less than 50%, while at speeds over 15 knots, the probability rises from 80% to 100% (Vanderlaan and Taggart, 2007).

Even though in Sector 3 ships tend to reduce speed or slowly pick up speed as they get close to or away from the ports, temporarily giving time and space for whales to avoid them, cells with average speed over 15 knots are still present (Fig. 4), specially away from the shore and at higher depths where the presence of whales is more likely. In Sector 6, also part of the 'higher use corridor', speeds over 10 knots are the most frequent. This means that if a ship strike takes place within this area there is a high probability it will be fatal.

Fin whales (*Balaenoptera physalus*), short-finned pilot whales (*Globicephala macrorhynchus*), Cuvier's beaked whales (*Ziphius cavirostris*) and sperm whales (*Physeter macrocephalus*) are the species present in the study area (Fig. 9) and are among the species known to be more frequently involved in ship strikes (Carrillo and Ritter, 2008; Laist *et al.*, 2001; Panigada *et al.*, 2006).

All the species mentioned above are present in Sectors 3 and 6 (Figs. 9 and 10). The short-finned pilot whale stands out from the remaining species due to its localised distribution (adults and calves), which overlaps the 'higher use corridor', making it potentially more vulnerable to ship strikes (Fig. 8). Baleen whales, sperm whales and beaked whales were sighted in the same area, especially across Sector 6 (Freitas *et al.*, 2004b; Freitas *et al.*, 2014).

Vessel strikes involving small cetaceans are more frequently associated with small vessels and in many cases the animals show evidence of vessel propeller cuts (Waerebeek *et al.,* 2007). 'Small vessels are here defined as fast small to medium size planing craft powered by inboard or outboard engines, where most of the recreational, whalewatching and big game fishing boats are included. Considering these three vessel types all together, they represent almost 40% of the Madeira inshore traffic fleet. Recent reports also refer to cases of vessel collisions with cetaceans caused by sailing boats (Ritter, 2012).

Bottlenose dolphins (*Tursiops truncatus*), Atlantic spotted dolphins (*Stenella frontalis*) and common dolphins (*Delphinus delphis*) are some of the species globally reported

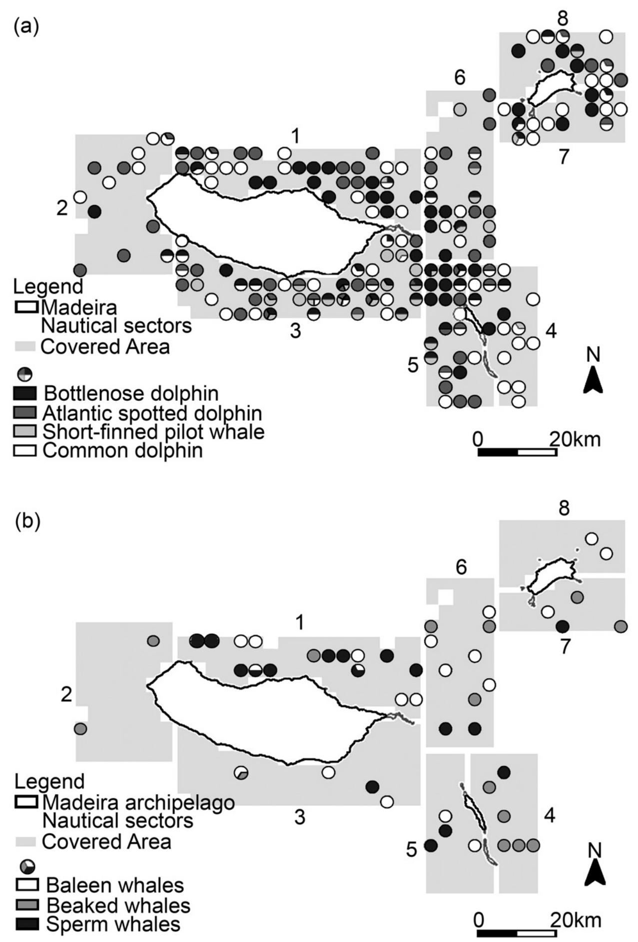

Fig. 9. Distribution of cetacean species presence represented through a pie chart where each pie represents the proportion of each species sighted within each grid cell through the period 2001 until 2012: (a) dolphin presence distribution pattern; (b) whale presence distribution pattern.

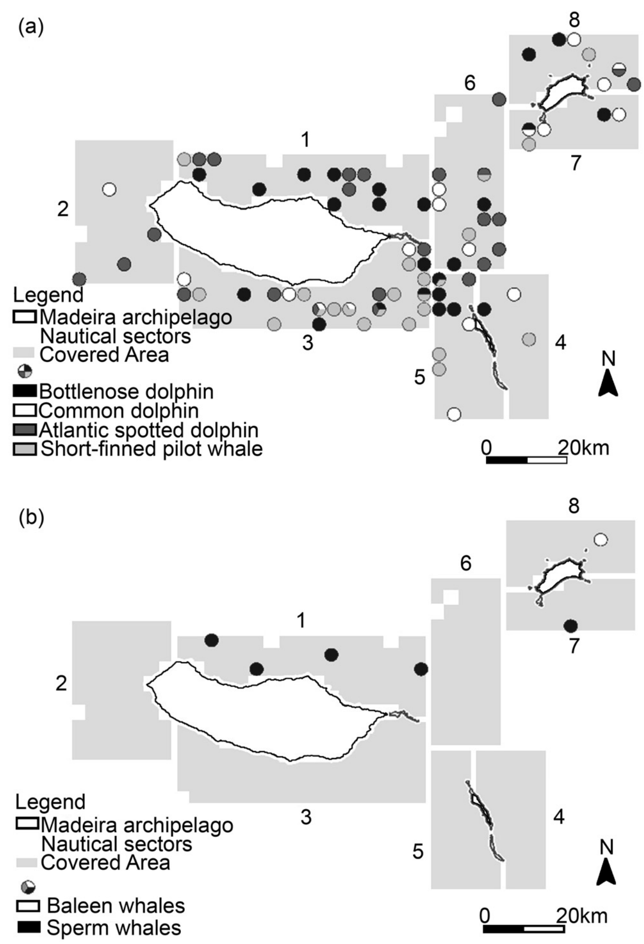

Fig. 10. Distribution of cetacean species presence represented through a pie chart where each pie represents the proportion of each species sightings with calves within each grid cell through the period 2001 until 2012: (a) dolphin presence distribution pattern; (b) whale presence distribution pattern.

as casualties of small vessel strikes. Both adults and calves are present in the sectors most intensively used by recreational boats (Sectors 3, 6 and 7), whalewatching boats (Sector 3) and big game fishing boats (Sector 3), and thus subject to its potential impact.

In the MWM strandings database (1986–2012) there are three deaths associated with ships strikes out of the 136 stranded animals recorded: a possible ship strike with Gervais' beaked whale (*Mesoplodon europaeus*) and two confirmed ship strikes, one with a Cuvier's beaked whale (one out of five recorded standings of this species) and another with a common dolphin. These species were previously reported as more vulnerable to traffic incidents (Laist *et al.*, 2001; Waerebeek *et. al.*, 2007).

Although not many strandings associated with vessel strikes have been reported so far in the Madeira islands, these might have been overlooked, since most carcasses usually sink to deep waters before stranding or refloating due to decomposition. Some animals may be hit in the open ocean or may drift away from the islands' coast never to be detected (Laist *et al.*, 2001; Silber *et al.*, 2012; Weilgart, 2007). Also, carcasses in advanced states of decomposition may mask signs of possible causes of death (Laist *et al.*, 2001; Silber *et al.*, 2012) and blunt trauma impacts may not show any external signs (Evans *et al.,* 2011; Silber *et al.,* 2012).

Madeira is expected to have far less ship strikes than continental coastal areas due to the oceanic nature of most marine traffic (lower cetacean densities in open ocean) in the archipelago and the relatively small coastal traffic, namely ferries, when compared with, for example, the Canary Islands. Madeira has one ferry (20 knots) connecting the two main Islands travelling at most twice a day, while the Canary Islands have several fast ferries (≥30 knots) and regular ferries connecting all the islands with several trips per day.

The 'higher used corridor' thus stands as a potential vessel strike risk area (Fig. 11) in the context of the Madeira archipelago marine traffic.

Potential ship strike risk in offshore waters

Unfortunately, there are no data on cetacean distribution (e.g. sightings rates per cell) in the offshore waters of the Madeira EEZ making it impossible to compare both cetaceans' and vessels' distribution patterns to identify overlapping areas of higher cetacean numbers and traffic presence. Nevertheless, cetaceans' densities are expected to be lower in oceanic open waters, both because of the expected lower food availability and the huge areas involved. However, the months with higher level of traffic activity correspond to the summer period, where the presence of calves is more likely, increasing the possibility then of being hit by a ship.

As expected, there is very little evidence of ship strikes in Madeira offshore waters, mainly because it is a large area with little human presence and a relatively small nearby coast line where carcasses may come ashore. Difficulties in gathering ship strike evidence have been reported in most other related studies (IWC, 2011; Laist *et al.,* 2001; Waerebeek *et al.,* 2007), even in areas where ship strikes are a serious concern (Carrillo and Ritter, 2008). Some of the most intensive studies on the subject, have focused not only on stranding archives but also on historical and anecdotal records, and still, only a few of the total number of ship strikes were revealed (IWC, 2011; Laist *et al.*, 2001). This type of archival data was not collected in the present study.

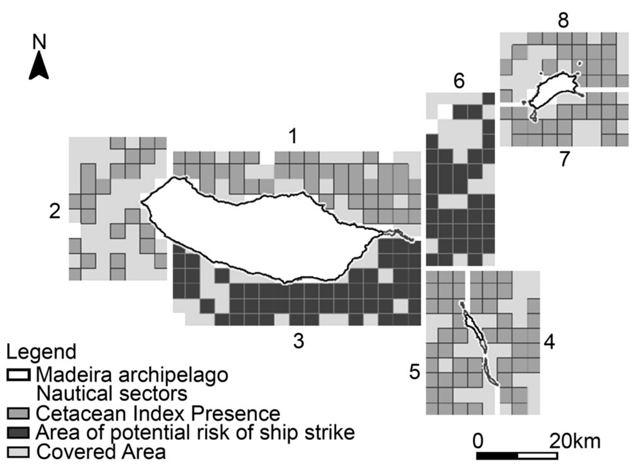

Fig. 11. The 'potential danger zone'. The darker cells represent the cetacean index presence that intersected Sectors 3 and 6, the 'higher use corridor', a preferential area for both cetaceans and ships, where the latter often cross the area moving at speeds over 10 knots , i.e. a potential ship strike area.

CONCLUSION

The marine traffic in the Madeira EEZ, while not so alarming as in other areas of higher traffic level, is still a concern and may have an important impact in the surrounding environment that should not be ignored.

A 'higher use corridor' in Madeira inshore waters used by both vessels and cetaceans was identified, standing as a potential ship strike risk zone. Even so, based on the available evidence, the marine traffic impacts are not apparently high and the animals continue to use the area, indicating that at the present impact level it is, at least, tolerable.

It is important that studies of the spatial and temporal characterisation of the maritime traffic in Madeira EEZ continue, in order to identify specific routes and produce traffic density maps for this area. To obtain real positions of sighted vessels a radar should be used during the inshore shipboard surveys run by the MWM around Madeira inshore waters.

The potential impact regarding ship strikes and water noise on cetaceans should be quantified for the present study area.

In order to infer the probability of a ship strike in the study area, some of the ASCOBANS (IWC, 2011) recommendations on the subject could be followed. Among other measures, a dedicated trained observer should be placed on board cargo and cruise ships to register cetacean presence and interactions/behaviour towards marine traffic in the vicinity (Correia *et al.,* 2015). The available species photo-identification catalogues should also be used to detect possible signs of blunt trauma, such as propeller cuts, in either adults or young cetaceans.

It is recommended that fast ferries in the Madeira EEZ should not be permitted as it has already been proven that these are responsible for several ship strike incidents with cetaceans elsewhere (Carillo and Ritter, 2008).

It is too soon to understand the real impact of marine traffic in the Madeira EEZ based on these initial results. It is important to keep track of the traffic expansion and ascertain how it is impacting cetacean populations so that, if required, mitigation measures may be implemented in time.

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