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Spatial and temporal characterization of the exposure of island-associated cetacean populations to whale-watching in Madeira Island (NE Atlantic)

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ABSTRACT

The whale-watching industry can represent a critical anthropogenic stressor for the targeted populations. Identifying and characterizing the individual exposure to wildlife tourism in island-associated cetacean communities is especially relevant in small, remote oceanic regions relying on tourism. This study characterized the spatial and temporal variation of the whale-watching pressure on common bottlenose dolphins (*Tursiops truncatus*) and short-finned pilot whales (*Globicephala macrorhynchus*) in Madeira Island and identified the most exposed portion of the population, making use of diverse long-term datasets (i.e. sighting data, photographic data and vessels' tracks) obtained year-round from platforms of opportunity (whale-watching operators) and proposing a new descriptive index which estimates the cumulative exposure rates. Core areas of encounters with the whale-watching vessels were identified off the capital city of Funchal. A daily average of 6.5 (±2.2 SD) vessels were concurring in this area, with a significantly higher number recorded between May and October and a peak of 14 vessels in August. From a total of 367 identified bottlenose dolphins and 536 pilot whales, a minimum of 6% and 10%, respectively, were identified as island-associated individuals. Cumulative exposure rates for these individuals could reach levels over two times higher than the general trend for both species. A higher proportion of island-associated bottlenose dolphins were recorded in the winter season. In contrast, island-associated pilot whales were predominant (over 50%) or in a high proportion (over 40%) year-round. The present study highlights the importance of using data from platforms of opportunity to investigate anthropogenic stressors, as tourism-based cetacean observation. It also provides insights into the whale-watching pressure on island-associated individuals occurring in oceanic areas and calls attention to the need of monitoring the fitness and well-being of these wildlife populations in Madeira Archipelago, an outermost European region.

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1. Introduction

Individual repeated exposure of wildlife populations to anthropogenic disturbance is an issue of growing interest, as forms of wildlife tourism are constantly increasing in popularity (Vinding et al., 2014; Christiansen et al., 2015; Tyne et al., 2018). The whale-watching industry (commercial activity of whale and dolphin watching) is exponentially increasing worldwide in the last 40 years as a form of eco-tourism (Hoyt, 2001; O'Connor et al., 2009; Higham et al., 2014). However, controversially, it represents one of the stressors of major concern for the targeted animals as it often consists of repeated, close-up encounters with specific cetacean communities (Parsons, 2012; Wearing et al., 2014; Senigaglia et al., 2016). Short-term effects in the targeted animals have been widely reported as a response to whale-watching activity, including changes in surface behaviour, activity and energy budgets, which can comprise reduction of resting and foraging bouts (e.g. Lusseau, 2003; Visser et al., 2011; Clemente et al., 2018; Schuler et al., 2019; Chalcobsky et al., 2020). Although more challenging to identify, long-term consequences

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have also been reported to affect individuals' reproductive success, population size or emigration patterns (Lusseau, 2004; Bejder et al., 2006a,b; Lusseau and Bejder, 2007; Pérez-Jorge et al., 2016). Cetacean communities displaying strong site-fidelity to areas where anthropogenic stressors (such as whale-watching) occur, are potentially more exposed and vulnerable to disturbance. Bejder et al. (2006a) demonstrated that resident indo-pacific bottlenose dolphins (*Tursiops aduncus*) in Shark Bay moved to a different resting area to avoid the repeated disturbance produced by the dolphin-watching tour boats. By doing so, these animals expended higher amounts of energy, while the birth rate of those that stayed in dolphin-watching areas significantly decreased. Thus, studies assessing the exposure of animals with strong site fidelity to whale-watching areas are critical and can produce essential contributions towards local eco-tourism regulations and consequent wildlife welfare (Bejder et al., 2006a; Gonzalvo et al., 2014; Fumagalli et al., 2019). Nevertheless, most studies focused on the population-level and short-term behavioural responses (e.g. Magalhães et al., 2002; Constantine et al., 2004; Bejder et al., 2019; Schuler et al., 2019; Sprogis et al., 2020; Chalcobsky et al., 2020; Kassamali-Fox et al., 2020). Assessing individual exposure rates from human-induced stressors, especially from tourism impacts, is a way to assess which part of the population might be more vulnerable, and it is vital for proper environmental management. These studies can be achieved in individually identifiable cetacean populations, where individuals can be distinguished by naturally occurring marks (Hammond, 1990). The common bottlenose dolphin *Tursiops truncatus* (Montagu, 1821), hereafter bottlenose dolphin, and the short-finned pilot whale *Globicephala macrorhynchus* (Gray, 1846), hereafter pilot whale, are two examples of cetacean species exhibiting high proportions (ca. 60%–70%) of naturally marked animals (Shane and McSweeney, 1990; Wilson et al., 1999; Quick et al., 2017) and that have been widely studied at the individual level (e.g. Mahaffy et al., 2015; Kendall-Bar et al., 2016; Milmann et al., 2017; Hill et al., 2019; Estrade and Dulau, 2020).

The oceanic waters around Madeira Island (northeast Atlantic) host a high cetacean diversity (ca. 30 species; Ferreira et al., 2017; Freitas et al., 2012) and support a relatively recent (from early '00s) but well-established whale-watching industry (Sequeira et al., 2009). The southern Madeiran waters, sheltered from predominant winds and in proximity to the capital (Funchal) harbour, constitute an area of interest for the local whale-watching activity, with five species representing the majority (87%) of sightings. The bottlenose dolphin and the pilot whale are among the most frequently encountered species throughout the year (Alves et al., 2018). Photographic-identification (hereafter photo-id) studies based on naturally well-marked animals in both species in Madeira Archipelago revealed heterogeneity in capture probabilities, indicating the presence of island-associated individuals, with some individuals showing long-term site-fidelity (Alves et al., 2013, 2015; Dinis et al., 2016a). The whale-watching is concentrated in areas used by both species for vital activities like foraging, reproducing, socializing and resting (Alves et al., 2018). Repeated interruptions of these activities by the approach of tour vessels can cause short- to long-term consequences on the population fitness, as observed in other regions (Lusseau and Bejder, 2007). Coastal populations can compensate for the overlapping of spatial use by anthropogenic stressors by moving to other nearby locations. In contrast, island-associated populations inhabiting oceanic environments (especially on small remote islands, as is the case of Madeira) might be forced to travel long distances to find other suitable habitats. Individuals from both species have been found capable of long-ranging movements among Archipelagos (i.e. Madeira - Canary Islands $\approx$ 460 km apart) (Alves et al., 2019; Dinis et al., 2021). However, travelling long distances expends a considerable amount of energy and certain individuals might ultimately choose to endure the repeated disturbance instead (Gill et al., 2001; Lusseau et al., 2006; Tyne et al., 2018).

The whale-watching industry has been exponentially growing in Madeira Island during recent years (Krasovskaya, 2018). Although a regional legislation was implemented to protect the cetacean communities inhabiting these waters (Portaria n° 46/2014 and Decreto Legislativo Regional 15/2013/M), the long-term site fidelity and the year-round presence of bottlenose dolphins and pilot whales in this area, together with the high encounter success rates in the whale-watching trips ($\sim$90%, Alves et al., 2018) and the rise of the touristic activity, suggest that these populations might still be exposed to an increasing disturbance (Alves et al., 2013; Gonzalvo et al., 2014; Dinis et al., 2016a). Nevertheless, to date, there is no quantification and characterization of the exposure of these island-associated animals to the whale-watching activity in Madeira at the individual level.

The present study analyses 13 years of photo-id data collected on platforms of opportunity (whale-watching operators) to provide a first insight into the exposure rates of island-associated bottlenose dolphins and pilot whales to touristic activities in Madeira. Using a long-term dataset collected throughout the year, it is possible to obtain individual temporal patterns on the long-term exposure and assess the individual cumulative exposure for the two populations. The specific goals are to (i) characterize the pressure, i.e. the whale-watching vessels operating in the area, both temporally and spatially, (ii) identify the proportion of the populations regularly exposed (i.e. more vulnerable) to the activity, and (iii) estimate the observed exposure in the different populations. This study aims to provide knowledge about one of the main anthropogenic disturbances to cetaceans in an island that relies on tourism as its primary source of economic income and highlights the importance of monitoring individual exposure in wildlife populations using opportunistic platforms.

2. Material and methods

2.1. Study area

The study was carried out in the southern waters of Madeira Island (Fig. 1), the main island of the warm-temperate Archipelago of Madeira (Portugal), where the principal harbours hosting the whale-watching fleet are located (in the towns of Funchal and Calheta, see Fig. 1). Surrounded by the abyssal plain of Madeira to the west and the African Continent to the east, the island is characterized by a pelagic and oligotrophic environment, with a narrow continental shelf and deep submarine canyons (Longhurst, 1995; Geldmacher et al., 2000; Narciso et al., 2019). A high mountain ridge (ca. 1800 m) in the island's interior creates an obstruction to the dominant northeast trade winds, leading to warmer and sheltered waters in the south of Madeira (Tomczak and Godfrey, 2013; Caldeira et al., 2002; Caldeira and Sangrà, 2012).

2.2. Characterization and quantification of the whale-watching activity

The number of whale-watching vessels operating simultaneously in the area was recorded with an *ad-hoc* method based on visual counts of the number of vessels from a trained operator on-board one of the whale watching vessels. The spatial variability of the area of operation was estimated recording Global Positioning System (GPS) tracks (60 s intervals with a GPS Garmin), on-board different boats, covering all the three types of vessels composing

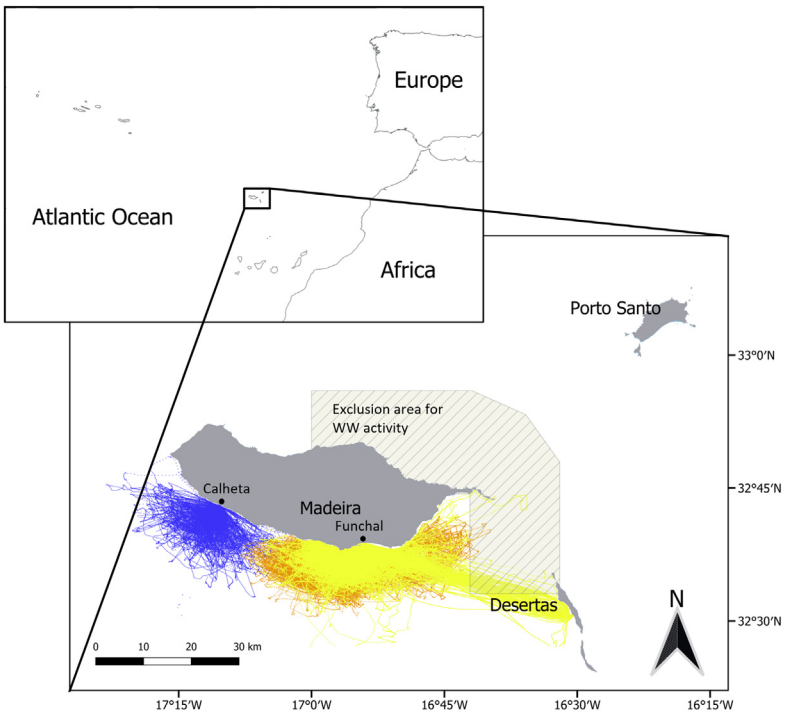

Fig. 1. Location of the study site and spatial characterization of the whale-watching activity in Madeira Island, indicated by GPS tracks recorded by vessels from three whale-watching companies (different colours) between 2014 and 2017, in a total of 1617 trips (593, 696 and 328). The exclusion zone for the whale-watching activity is displayed as the grey area with diagonal lines.

the whale-watching fleet (i.e. catamaran, sailing, and Rigid Inflatable Boat). GPS data were collected from three whale-watching companies, two operating in Funchal and one in Calheta (Fig. 1), throughout the year between 2014 and 2017. The recorded tracks were considered representative of the trips made by the majority of the whale-watching vessels operating in the study area. The trips to Desertas, not operated by all vessels and with no specific focus on whale and dolphin watching, were an exception. Nevertheless, cetacean sightings were frequent during these trips and were included to give a more realistic scenario of the area of exposure.

GPS positions of sightings of any cetacean species recorded between 2003 and 2018 from three companies from Funchal and one company from Calheta were also analysed to characterize the main area of encounter of the whale-watching vessels with cetaceans. For bottlenose dolphin and pilot whale, 50% kernel density estimate of encounter (50% KDE) was calculated using a bivariate normal kernel with a reference bandwidth (h = "href", as suggested in Calenge, 2019) using the KernelUD function from the adehabitatHR package (Calenge, 2006) in R software (R Core Team, 2021).

To assess seasonal variation in the whale-watching pressure, the intra-annual variability of the number of whale-watching vessels was quantified by registering the total number of whale-watching vessels observed during an entire trip (from harbours' departure to arrival). Data were collected by observers on-board one of the whale-watching vessels in the area of Funchal (Fig. 1) during 2015 and 2016. The mean number of vessels operating simultaneously in the area was calculated for each month. A Kruskal–Wallis test with Bonferroni post-hoc correction and Tukey's pairwise comparison was applied to test for significant differences in the number of boats between months as implemented in the R agricolae package (Mendiburu, 2020).

2.3. Photographic data collection and analysis

Photographs of bottlenose dolphins and pilot whales were taken with different digital cameras and zoom lenses on board eight whale-watching vessels (see 'Acknowledgements') between 2003 and 2016. A photo-id catalogue based on the dorsal fins of naturally well-marked animals (i.e. comprising nicks and notches, Auger-Méthé and Whitehead, 2007) and a dataset of capture histories was compiled for each species, according to Würsig and Jefferson (1990). The selection and processing of photographs were based on Alves et al. (2013) and Dinis et al. (2016a). More permanent natural marks such as nicks and notches on the trailing edge of the dorsal fin were used for long-term photographic individual recaptures (years); whereas less permanent and superficial marks such as scratches, tooth rake marks, and scars were used for short- (days) to medium-term (weeks to months) recaptures (Auger-Méthé and Whitehead, 2007; Rowe and Dawson, 2009).

2.4. Individual exposure analysis

Each photographic capture (defined as an individual identification within an encounter) was considered an exposure event to the whale-watching activity. For all the individuals captured more than once, we described temporal patterns of exposure within the population, defined as cumulative exposure rate. This was calculated as the relation between the number of recaptures and the number of recaptured individuals (individual exposure rate) in function of time (consecutive numbers, corresponding to number of days, going from 0 to the value corresponding to the longest interval between two consecutive recaptures of the same individual, for that population). Cumulative exposure rates were thus calculated as follows:

$$e = \frac{r_d}{l_d} \quad (1)$$

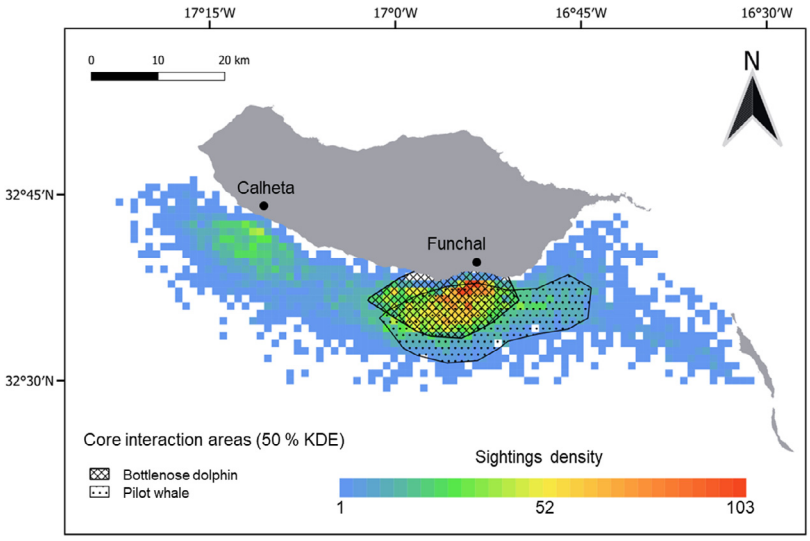

Fig. 2. Cetacean sightings (all species) recorded between 2003–2018 from three whale-watching companies departing from Funchal and one departing from Calheta (n = 10341), represented in raster visualization as number of sightings per km^2 and core areas of encounters with bottlenose dolphins and pilot whale represented by 50% KDE.

where:

e = cumulative exposure rate

d = number of days

r_d = number of recaptures within intervals $< d$, during the study period

I_d = number of individuals recaptured within intervals $< d$, during the study period

This index gives an indication of the exposure pressure on the analysed population, reporting an average number of recaptures per individual, which cumulatively increases with the increase of the considered interval length between recaptures, if the same individuals are being recaptured. Seasonal and annual patterns have also been considered in the analysis. Individuals captured a minimum of five times in three seasons within a year and at least three years (non-consecutive) were considered island-associated individuals, prone to long-term exposure (adapted from Alves et al., 2013; Dinis et al., 2016a). Seasons were defined, considering winter as January to March, spring as April to June, summer as July to September, and autumn as October to December. The monthly distribution of captures for all and island-associated individuals was examined, merging data from all years together. Cumulative exposure rates were calculated separately for all individuals and for island-associated individuals and compared (raw data and calculations in Supplementary Material MMC S1).

3. Results

3.1. Whale-watching activity

Tracks were recorded from a total of 1617 trips (Fig. 1) covering 1043 days. The spatial characterization shows that the whale-watching vessels from both main harbours of Madeira Island operated mainly up to 10 km off the coast (except trips to the Desertas Islands) in an area of approximately 1500 km^2, encompassing depths up to 2000 metres (Fig. 1). GPS positions from a total of 10 341 sightings were recorded to visually represent sighting densities (as number of sightings per squared km). Sighting densities were higher in the proximity of the departing harbours, with the highest numbers recorded off the capital city of Funchal (Fig. 2). The core area (KDE 50%) of encounters with bottlenose dolphins (~150 km^2) reflects this general trend, while the core area for pilot whales (~260 km^2) was located slightly more to the east and offshore (Fig. 2).

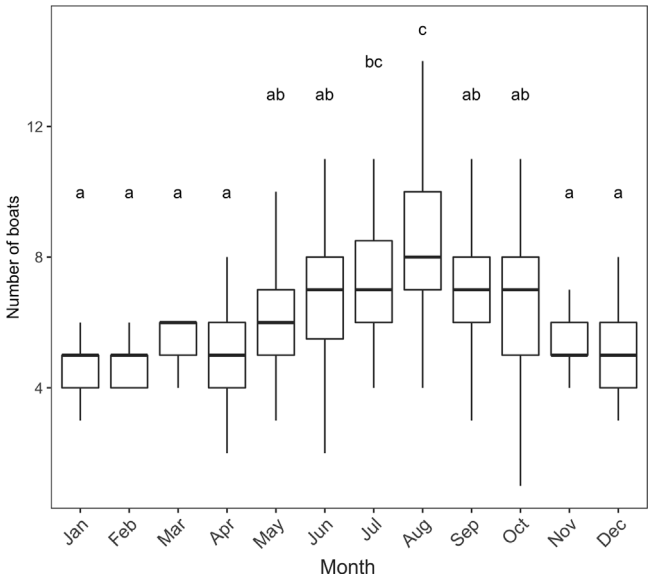

Fig. 3. Monthly number of whale-watching boats operating in the South-Southeast of Madeira (i.e. departing and arriving from Funchal, where most of the whale-watching fleet is located) at the same time. Box represents the upper and lower quartiles, horizontal line inside each box indicates the median, whiskers reach to maximum and minimum values. Common letters indicate means that are not significantly different (Tukey's pairwise comparison at level of significance $\alpha = 0.05$).

The number of whale-watching vessels operating simultaneously during the same trip was quantified from 330 trips during 2016 (n = 13, 17, 24, 16, 27, 44, 46, 46, 33, 31, 22, 11, respectively for January to December). A daily average of 6.5 (± 2.2 SD) whale-watching vessels used the area of Funchal (core area) simultaneously throughout the year. There was a significant intra-annual variability in the number of boats using the area, (Kruskal–Wallis test with Bonferroni post-hoc correction, p-value < 0.05), with significantly higher values recorded between May and October (Tukey's pairwise comparison, results represented in Fig. 3). The highest absolute number (14) was recorded in August.

Table 1
Summary table of individual photographic captures collected by whale-watching boats off the south coast of Madeira Island over the study period (Bottlenose dolphin: 2004 to 2016; Pilot whale: 2003 to 2015).

Species	Number of captured individuals	Total number of captures	Number of recaptured individuals	Total number of recaptures	Recaptures per individual (mean ±SD)
Bottlenose dolphin	367	954	167	587	3.5 ± 3.7
Pilot whale	536	1959	181	1423	7.9 ± 10.7

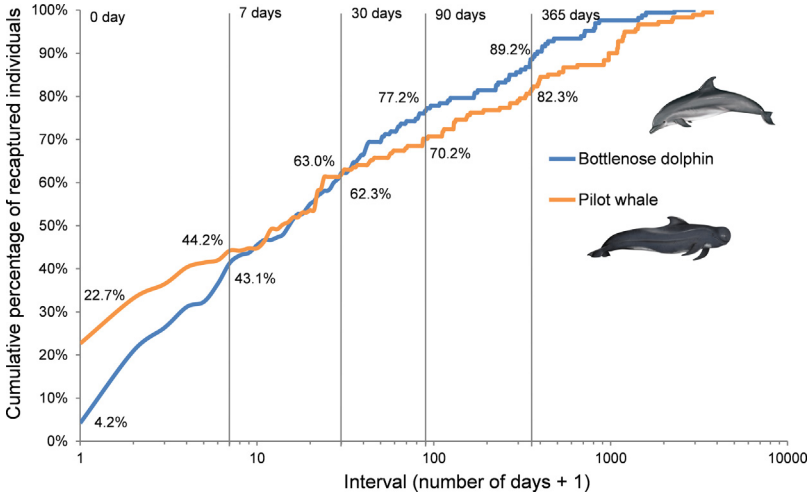

Fig. 4. Cumulative percentage of individual bottlenose dolphin and individual pilot whales recaptured within each interval (defined as number of days between two consecutive captures of the same individual). Maximum X-values corresponds to the longest interval between two consecutive captures for an individual of that species. Values are shown as the % of individuals recaptured within the same day, 1 week, 1 month, 1 season (90 days) and 1 year (365 days). *X*-axis is log-scaled. Illustrations by E. Berninsone ©ARDITI.

Table 2
Summary table of intervals distribution, where an interval corresponds to the number of days between two consecutive exposures (i.e. photographic recapture) of the same individual to whale-watching boats off the south coast of Madeira Island, between 2003 and 2016.

Species	Shortest interval (days)	Longest interval (days)	Median value (days)	Central inter-quartile range (days)	Median annual rate (captures yr^{-1})	Inter-quartile annual rate (captures yr^{-1})
Bottlenose dolphin	0	3017	41	12.5–192.5	8.9	1.9–29.2
Pilot whale	0	3832	48	15–246	7.6	1.5–24.3

3.2. Photographic data collection

Surveys and data collection were performed heterogeneously throughout the years (Figure S1, available online in Supplementary Material). Photographic captures of bottlenose dolphins were collected in 418 trips (covering 356 days), whereas pilot whales were in 547 trips (406 days). A total of 954 captures of the former species allowed identifying 367 individuals, and 1959 captures of the latter species allowed identifying 536 individuals (Table 1).

3.3. Individual exposure rates

During the entire study period, 167 bottlenose dolphins and 181 pilot whales, corresponding to 45.5% and 33.8% of the total number of identified individuals, were exposed more than once to whale-watching vessels. The maximum number of captures for one individual was 18 for the former species and 54 for the latter (Figure S2, available online in Supplementary Material). An individual bottlenose dolphin has been repeatedly exposed for a maximum of six (non-consecutive) years, whereas the maximum number of years for a pilot whale was 12, i.e. nearly every year of the study period (Figure S3, available online in Supplementary Material).

The distribution of time between two consecutive exposure events (i.e. intervals) of an individual bottlenose dolphin and an individual pilot whale shows a similar trend for the two species. The median, maximum and minimum intervals and interquartile ranges are shown in Table 2. Along the study period, 4% of the individual bottlenose dolphins and 23% of the individual pilot whales were recaptured at least once within the same day, 43% and 44% within seven days, 62% and 63% within 30 days, 77% and 70% within 90 days, and 89% and 82% within 365 days, respectively (Fig. 4). Twenty-one bottlenose dolphins and 51 pilot whales were identified as island-associated individuals, representing respectively 6% and 10% of the total number of identified individuals. The captures of these individuals represent 24% of the total number of captures for bottlenose dolphins and 52% for pilot whales. Cumulative exposure rates were calculated for all individuals and for island-associated individuals. For the island-associated bottlenose dolphin and pilot whale individuals, the overall cumulative exposure rate was 10.1 and 18.9, respectively (average number of recaptures per individual), against 3.5 and 7.9 for all individuals. For any given interval length, pilot whales presented higher cumulative exposure rates than bottlenose dolphins, and island-associated individuals presented higher rates than all individuals in both species (Fig. 5). Monthly analysis of the captures showed that bottlenose dolphins had the highest number of captures in summer. Still, higher percentages of island-associated individuals (> 40%) were recorded in winter and early spring, between November and March. On the contrary, individual pilot whales were mainly captured in late summer and autumn, and island-associated individuals represented over 50% of the captures in every month except June, November and December (Fig. 6).

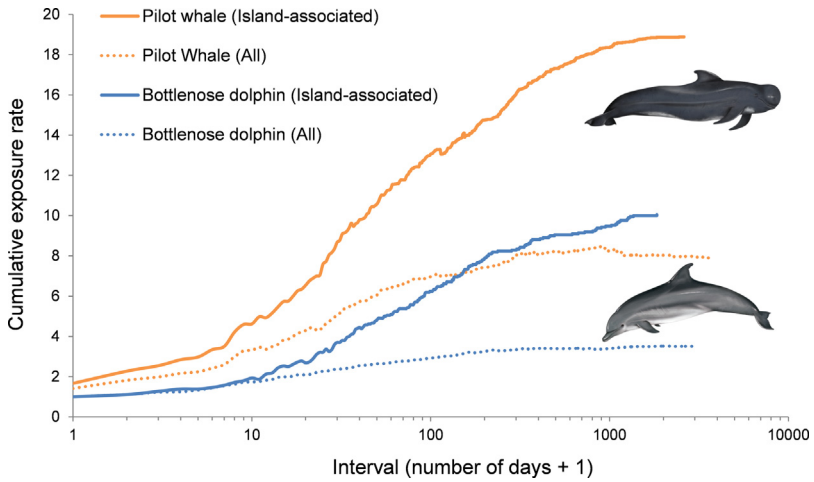

Fig. 5. Cumulative exposure rates of individual bottlenose dolphins and individual pilot whales to whale-watching boats off the south coast of Madeira Island. Rate correspond to the ratio between the number of recaptures and the number of recaptured individuals within each interval (see Methods) along all the study period (2003–2016). Increasing the interval time, it increases the number of recaptures per individuals if the same individuals keep coming back to the study area. Comparison between all the individuals (captured more than once) and the island-associated ones is shown. X–axis is log-scaled. Illustrations by E. Berninsone ©ARDITI.

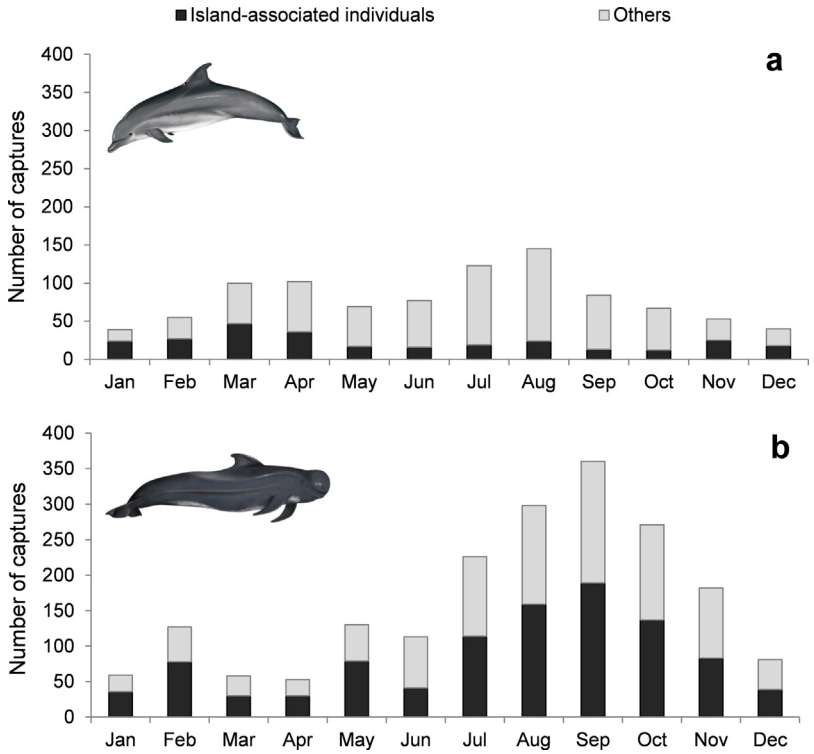

Fig. 6. Monthly distribution of the number of photographic captures of all individuals and of the island-associated individuals of bottlenose dolphins (a) and pilot whales (b), collected along all the study period (2003–2016) off the south coast of Madeira Island. Data from different years have been merged given the heterogeneous nature of the data and the impossibility to consider each year as an independent statistical unit. Despite the unequal effort, the probability of capture of island-associated individuals or any other one was equal in each encounter. The number of captures does not reflect the seasonal abundance of the two species. Illustrations by E. Berninsone ©ARDITI.

4. Discussion

This study presents the first spatial and temporal analysis of the whale-watching pressure on cetacean populations in Madeira Island and characterizes the long-term exposure of island-associated bottlenose dolphin and pilot whale individuals, using mark-recapture analysis based on 13 years of photo-id data collected on platforms of opportunity. The exposure rates described in this study suggests that individual pilot whales are more exposed to whale-watching disturbance on the long-term when compared to individual bottlenose dolphins, with a higher percentage of individual pilot whales showing long-term site fidelity to the study area (10% pilot whales vs. 6% bottlenose dolphins). Moreover, the higher frequency categories of recaptures (over 18) for this species belong exclusively to 18 individuals, contributing to 44.5% of the total number of recaptures (Figure S2, available online in Supplementary Material). Therefore, results suggest that this small portion of the pilot whale population, constituted by the island-associated individuals, is subject to intense exposure to the whale-watching vessels.

Recent findings from the same study area indicated poorer eco-physiological conditions in resident pilot whales when compared with visitors (Alves et al., 2020). The hypothesis of long-term exposure to whale-watching contributing to those findings should not be discarded. The disruption of feeding or resting activities by non-lethal human activities has been linked to a decrease in the rate of energy acquisition (Williams et al., 2006; Christiansen et al., 2013, 2014; Srinivasan et al., 2018), which can lead to long-term negative consequences for individuals and their populations (Foote et al., 2004; Bejder et al., 2006a,b; Lusseau et al., 2006; Williams et al., 2006).

We found that most of the encounters of tourism boats with bottlenose dolphins and pilot whales occurred in two partially overlapped areas, with bottlenose dolphins being found closer to the coast and pilot whales in deeper waters and more on the east side of the island. Other studies carried out in oceanic habitats also found that some individual bottlenose dolphins and pilot whales spend most of their time in relatively small areas, with sporadic wide-ranging movements (e.g. Baird et al., 2009; Hill et al., 2019). These "core" areas are usually characterized by specific bathymetric features, such as steep canyons for pilot whales (Abecassis et al., 2015; Thorne et al., 2017; Fernandez et al., 2021) and shallow waters for bottlenose dolphins (Dinis et al., 2016b; Fernandez et al., 2021; Silva et al., 2008), and they likely constitute preferential foraging habitats.

Recent studies also showed bottlenose dolphins and pilot whales moving between Madeira and Canaries and between Azores and Madeira (Alves et al., 2019; Dinis et al., 2021). In both species, most of the individuals that carried out such wide-ranging movements were captured only once or twice in Madeira, suggesting that they belong to an offshore population with more extensive home ranges. Data derived from satellite-linked bio-loggers recently deployed on four island-associated pilot whales off Madeira showed that the main area of the whale-watching activity seems to represent their preferred area, where they spent about 80% of their time (out of a total of 170 days covering three seasons; own data, unpublished). On the contrary, bottlenose dolphins in Madeira have been encountered more often in a different area than the main whale-watching one (i.e. in the exclusion area for the whale-watching activity, in the northeast of Madeira; Dinis et al., 2016a), which can help to explain the lower individual exposure rates when compared to pilot whales.

Even though these animals are capable of ranging widely for feeding or breeding purpose, these findings suggest a differentiation in foraging strategies and habitat preferences between the island-associated and the offshore populations, with a clear strong fidelity of the former for a small suitable area. In this area, individuals will manage disturbances as another ecological variable. They will assess its costs related to other energetic trade-offs associated with the occupancy of the habitat in which the disturbance occurs, and individuals who stay in such habitat might have reduced fitness, leading to reduced reproductive success (Lusseau et al., 2006; Lusseau and Bejder, 2007).

Seasonality is one of the main variables to consider when assessing anthropogenic disturbance derived from tourism-based activities. Whale-watching activity is performed year-round in Madeira Island. However, we showed an increase in the number of vessels between May and October, which can be identified as the touristic "high season" (Fig. 3). This also results in a higher number of photographic captures during summer (Fig. 6), which is therefore not associated with seasonal abundance variation. Dinis et al. (2016a) found no strong seasonal fluctuation in the presence of bottlenose dolphins in the Madeira Archipelago, while higher sighting rates have been observed in pilot whales during autumn (Alves et al., 2019). Higher proportions of island-associated bottlenose dolphins were captured during the winter months in the present study. Coherently, Dinis (2014) observed larger groups from June to October in Madeira Archipelago, suggesting an influx of transients and visitors moving into the study area in this period and a slightly higher number of residents during winter, indicating that they might move out of the area in the remaining seasons. Whether this is a natural phenomenon driven by environmental and biological factors or an effect of the anthropogenic pressures during the high touristic season is not clear, and further investigation is required. The proportion of island-associated pilot whales was always high (always over 50%, except in June, November and December that was over 40%) and showed little monthly variation throughout the year. The summer period might represent a major exposure risk for the pilot whale population, given the high capture probability of island-associated individuals and the increase of the whale-watching activity. Seasons dominated by the presence of island-associated individuals represent critical periods in which they can be exposed to a great number of repeated approaches by touristic boats, which can affect their regular activity budget (Parsons, 2012; Senigaglia et al., 2016). For example, in this study, in one winter season (January, February, March 2016), 126 captures of 66 individual bottlenose dolphins were recorded from whale-watching boats, with one individual being captured up to seven times. In one summer season (July, August, September 2011) 292 captures of 112 individual pilot whales were recorded, with some individuals being captured up to nine times.

In the present study, a higher number of individual pilot whales than bottlenose dolphins were photographically captured, despite the equal length of the study period (13 years) and the no-specific interest of the touristic operators in encountering one species instead of another. Alves et al. (2018) showed that sightings of bottlenose dolphins are more frequent than sightings of pilot whales in Madeira Island, and that the average group size for the two species is quite similar. A likely reason for this incoherence might be the unbalanced capture probability for the two species, due to different dorsal fin sizes and different inter-specific surface behaviours. In Madeira Island, travelling is the most common behavioural pattern found in bottlenose dolphins, while pilot whales are more frequently found in resting behaviour (Alves et al., 2018). Bottlenose dolphins typically briefly show the dorsal fin in faster movements, resulting many times in poor quality photographs. On the contrary, pilot whales perform slower movements on the surface and have a considerable larger dorsal fin which facilitate the photographic capture and the individual identification. Therefore, individual exposure of bottlenose dolphins is most likely underestimated.

The exposure estimation here reported, especially when considering short-term intervals, can only describe the minimum observed exposure for both species since our data only comprises opportunistic captures. However, the consistency of our long-term results regarding the spatial and temporal variation of such exposure is supported by studies where systematic data have been used (Alves et al., 2013, 2015; Dinis, 2014; Dinis et al., 2016a,b). The calculation of cumulative exposure rate, as proposed in this study, could be considered a new cost-effective and valuable approach to assess the whale-watching pressure on different cetacean populations, making use of opportunistic photo-id data collected by touristic operators. Therefore, the use of data and photographs collected by whale-watching operators should be promoted and encouraged worldwide, as it can provide meaningful inputs that could be beneficial in future impact assessment studies.

The whale-watching industry in Madeira has grown strongly in the last years. The number of whale watchers recorded in this region passed from almost zero, in 1998 (Hoyt, 2001), to 59731, in 2008, with a 72.9% annual average growth rate (O'Connor et al.,

2009). In 2018, Krasovskaya estimated that 129158 whale watchers visited the island, documenting another exponential growth of the industry, which reflected an increase in whale-watching vessels (Krasovskaya, 2018).

In the last 20 years, studies to monitor the growth of the industry and the cetaceans' occurence were conducted to implement conservation measures (Ferreira, 2008; Sequeira et al., 2009). As a result, the regional government established in 2014 an exclusion area for the whale-watching activity of ∼1000 km^2 in the North-East waters of Madeira Island (Portaria n° 46/2014, Fig. 1), identified as a preferential habitat for bottlenose dolphins (Dinis et al., 2016b). In 2016, the Madeira Regional Government also proposed a Site of Community Importance (SCI) for the bottlenose dolphin within the European Union Habitats Directive framework. This SCI covers the coastal waters around Madeira, Desertas and Porto Santo Islands between 1 mile off the coast and the 2500 m depth line. Our findings suggest that the island-associated pilot whale population might be exposed to higher levels of disturbance compared to the bottlenose dolphin and that the main area of encounter with this species, shifted to the east of Funchal, might represent a preferential area of occurrence for this species. Further studies are needed to confirm such hypothesis, however, as it has been the case for the bottlenose dolphin, the constitution of an exclusion zone for the whale-watching in a preferential habitat for the pilot whale could be highly beneficial for the conservation and protection of this population. The whale-watching activity in Madeira already benefits from several mitigation measures, legally implemented in 2013, such as limitations in the number of authorised vessels and in the sightings time (Decreto Legislativo Regional 15/2013/M; Portaria 13/2015). Such sustainable tourism practices can be highly effective, however, to our knowledge, no evaluation of the whale-watching impact on the cetacean population is ongoing in the area. Monitoring the effects of the activity on these species is crucial, as much as ensuring the compliance of the regulation by the tourist boats.

CRediT authorship contribution statement

Annalisa Sambolino: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Filipe Alves:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing – review & editing. **Marc Fernandez:** Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – review & editing. **Anja Badenas Krakauer:** Data curation, Investigation, Writing – review & editing. **Rita Ferreira:** Data curation, Investigation, Resources, Writing – review & editing. **Ana Dinis:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

Additional data are included in the supplementary material files. All data generated and analysed for the present study are available upon request from the corresponding author.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2021.102084. The online version contains supplementary material available on the publisher's website.

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