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Analysis of occurrence patterns and biological factors of cetaceans based on long-term and fine-scale data from platforms of opportunity: Madeira Island as a case study

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Abstract

Management and conservation issues are addressed through the identification of areas of particular importance, which requires the acquisition of baseline information on species distribution and dynamics. These types of data are particularly difficult to obtain at high resolution for large marine vertebrates like cetaceans, given that dedicated surveys are complex and logistically expensive. This study uses daily presence–absence sighting data of cetaceans collected year-round from whale-watching boats to support the theory that fine-scale data obtained from platforms of opportunity can provide valuable information on species occurrence and group dynamics. Data from 7,551 (daily) sightings comprising 22 species were collected from 3,527 surveyed days over 11 years (mean of 321 days per year, *SD* = 17) in the pelagic environment of Madeira Island. Cetaceans were observed on 92% of the surveyed days, and a mean of 15.4 (*SD* = 1.5), 8.2 (*SD* = 2.0) and 2.1 (*SD* = 1.2) species were recorded per year, month, and day, respectively. There were significant differences in the number of species per month ($p < .001$), with the highest diversity recorded in June. At least nine species, comprising 96% of all sightings, were found to use the Madeiran waters on a regular basis, such as the Atlantic spotted dolphin (*Stenella frontalis*), the short-beaked common dolphin (*Delphinus delphis*), the bottlenose dolphin (*Tursiops truncatus*), and others featured in the Red List of the International Union for Conservation of Nature as Endangered, Vulnerable, and Data Deficient. In addition, 10 species were found to use the Madeiran waters for travelling, feeding, resting, socializing and calving, which suggests that the southern and southeastern waters of Madeira Island constitute an area of interest for cetaceans. This study characterizes the cetaceans' community structure (occurrence, aggregation sizes, behaviours, proportion of calves, and inter-specific relationships) of a poorly studied region, providing important information for managers. Finally, the advantages and limitations of using fine-scale data from a type of platform of opportunity that is increasing along coastlines globally are discussed.

KEYWORDS

behaviour, calving, community structure, group dynamics, inter-specific relationships, management, marine mammals, NE Atlantic, temporal diversity, whale-watching vessels

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1 | INTRODUCTION

Addressing basic ecological issues, such as the relationship between diversity and ecosystem function, is essential for proper ecosystem-based management (Borja, 2014; Hooper et al., 2005). This requires the acquisition of information at the community ecology level, preferentially including high-resolution species distribution data (Soulé, Estes, Miller, & Honnold, 2005; Tobeña, Prieto, Machete, & Silva, 2016). Such data are particularly difficult to obtain for most pelagic predators given their highly dynamic nature in a vast marine ecosystem, both in terms of the geographical range and the use of the water column, and the logistical and financial constraints normally associated with surveying oceanic habitats (Evans & Hammond, 2004; McClellan et al., 2014).

Cetaceans (whales, dolphins and porpoises) comprise the majority of marine mammal species (Hoyt, 2011). As most species are apex predators, they play an important role in maintaining the structure and functioning of marine ecosystems and may be useful indicators of ecosystem health and productivity (Estes, 2009; Katona & Whitehead, 1988). Dedicated cetacean surveys are difficult to achieve owing to their complex and expensive logistics, and few institutions are capable of undertaking them on a regular basis (Moura, Sillero, & Rodrigues, 2012). Nowadays, the increasing access to platforms of opportunity allows researchers to use these as an alternative and collect scientific data on a daily basis at a low cost. This has been done mainly from three types of platforms of opportunity, namely, ferries or cargo ships with established regular routes, i.e. surveys with constant linear effort routes (e.g. Arcangeli, Marini, & Crosti, 2013, 2016; Correia, Tepsich, Rosso, Caldeira, & Sousa-Pinto, 2015), fishing vessels with non-regular routes (e.g. Prieto, Tobeña, & Silva, 2017; Silva et al., 2014; Tobeña et al., 2016) and whale-watching boats with targeted observational efforts (e.g. Hauser, VanBlaricom, Holmes, & Osborne, 2006; Hupman, Visser, Martinez, & Stockin, 2015; Stockin, Binedell, Wiseman, Brunron, & Orams, 2009). Generally, all types are suboptimal and have inherent procedural limitations (Moura et al., 2012), but can provide large data sets of fine-scale data covering long-term periods that would otherwise be unavailable. Moreover, the collection of sighting information from platforms of opportunity may be the first step in providing a broader overview of cetacean diversity and occurrence, and therefore in reporting an area of interest that could be further investigated using a more refined survey methodology (Evans & Hammond, 2004; Hupman et al., 2015; Pérez-Vallazza, Álvarez-Vázquez, Cardona, Pintado, & Hernández-Brito, 2008).

The pelagic waters of the archipelago of Madeira are amongst the most isolated oceanic habitats of the North Atlantic. Although cetaceans are a marine megafauna group of socio-economic importance in Madeira, knowledge on their occurrence comes mostly from qualitative studies confirming the presence of 26 species for the region (Ferreira et al., 2017; Freitas, Dinis, Nicolau, Ribeiro, & Alves, 2012). As for many regions worldwide, in Madeira cetaceans are also likely to constitute a key component of the marine ecosystems. Yet, here, ecological and biological studies exist only for specific species (e.g. Alves, Dinis, Cascão, & Freitas, 2010; Alves, Dinis, et al., 2013; Alves, Quérouil, et al., 2013; Dinis, Carvalho, et al., 2016; Dinis, Alves, et al., 2016; Quérouil et al., 2010, 2013), and therefore information on cetacean community structure remains widely unknown. In addition, there is an increasing number of anthropogenic activities in Madeira with potential impacts on cetaceans, in particular the whale-watching industry (Alves, Dinis, et al., 2015; Ferreira, 2007) and marine traffic (Cunha et al., in press). Therefore, appropriate distribution studies, to describe cetacean occurrence patterns and evaluate trends, are needed to support conservation measures. For this purpose, a baseline for managers is the identification of species occurrence patterns across time and of species' biological factors (Cañadas & Sagarminaga, 2000; Hoyt, 2011), preferably when based on long-term data sets as in the case of the present study. The reduced (almost absent) continental shelf in the archipelago of Madeira, together with a whale-watching industry operating bidaily trips year-round, offers a privileged location to study the ecology of cetaceans in a truly pelagic environment from platforms of opportunity.

The present study analyses 11 years of cetacean sighting data from nautical surveys conducted onboard platforms of opportunity on a daily basis throughout the year in the archipelago of Madeira. Here, using the species' occurrence rate, the aim is to characterize cetacean diversity and to investigate these species' biological factors, such as aggregation size, behaviour, proportion of calves, and inter-specific relationships. This study provides the first assessment of the occurrence patterns of cetaceans in Madeira, contributing to filling in a gap in knowledge of the ecology of this important taxonomic group in a poorly documented region of the Atlantic. Finally, it also explores the advantages and limitations of using fine-scale data from a type of platform of opportunity that is increasing along coastlines globally.

2 | MATERIAL AND METHODS

2.1 | Study area

The study area encompasses the southern and southeastern waters of Madeira Island (west of Desertas Islands), in the warm-temperate Archipelago of Madeira (Portugal), which lies approximately 1,000 km off the European continent and 500 km off the West African coast (Figure 1). The area covers approximately 800 km^2, up to 20 km off the coast. It is characterized by a narrow continental shelf, steep submarine canyons and deep waters (*c*. 1,500 m; Geldmacher, Bogaard, Hoernle, & Schmincke, 2000). The oceanographic patterns are influenced by the Portuguese, the Azores and the Canary Currents, as well as by African filaments and regional dynamics (Caldeira & Sangrà, 2012; Caldeira, Groom, Miller, Pilgrim, & Nezlin, 2002; Sala, Caldeira, Estrada-Allis, Froufe, & Couvelard, 2013). These oceanographic conditions lead to productive cyclonic eddies and fronts (Caldeira et al., 2002), resulting in high salinity, high temperature and low-nutrient regime waters (Johnson & Stevens, 2000). The obstruction caused by a high mountain

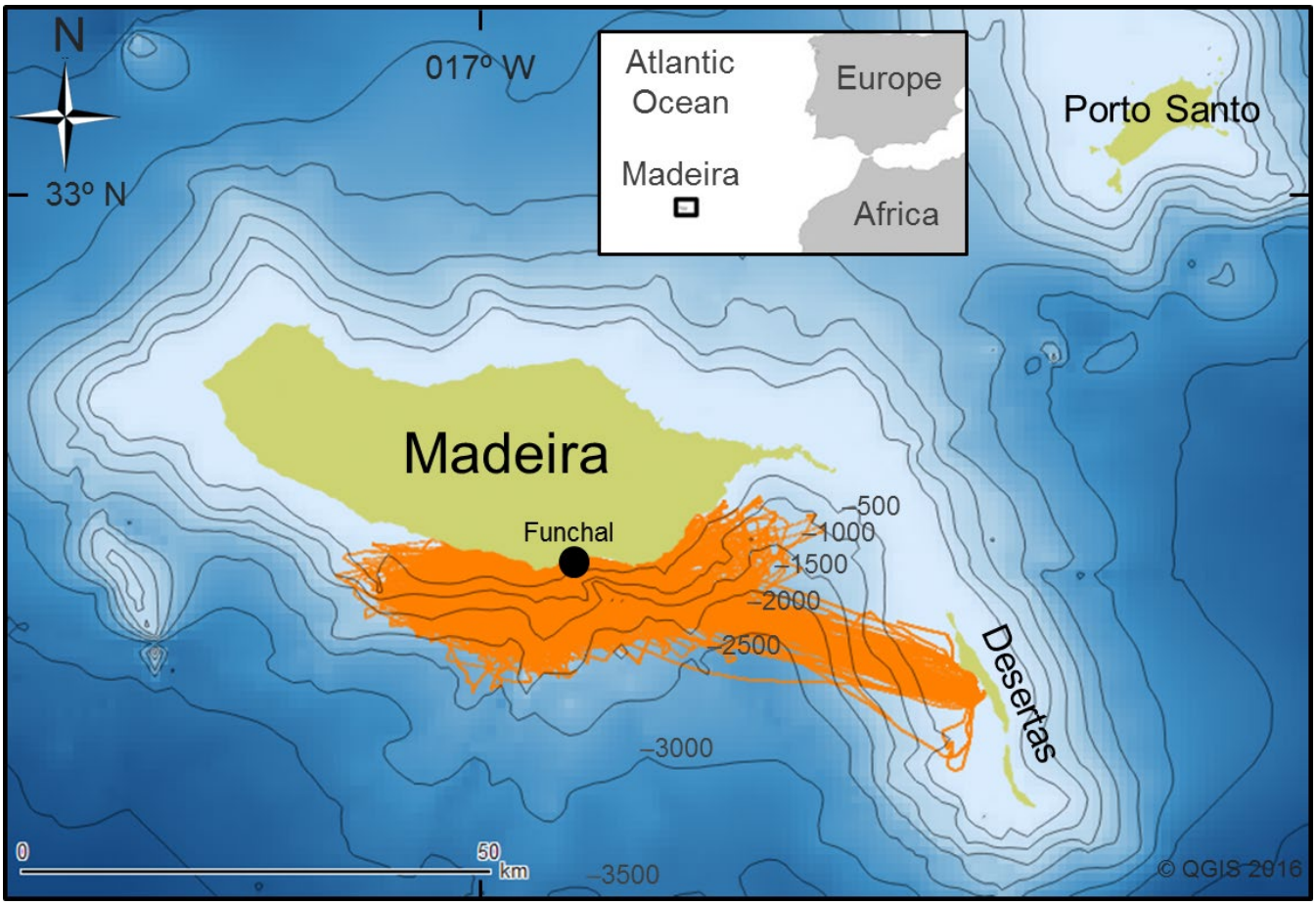

FIGURE 1 Location of the study area in the NE Atlantic showing the bathymetry (shown by different levels of blue shading, with isobaths in m) of the Archipelago of Madeira, and the search effort track-lines (orange) along the south and southeast of Madeira Island

ridge (*c*. 1,800 m altitude) to the prevailing northeast trade winds (Tomczak & Godfrey, 1994) leads to calmer sea state conditions to the south of Madeira Island, which coincides with the main whale-watching operation area.

The Archipelago of Madeira relies on tourism as its main source of economic income, and the development of marine tourism activities has increased during the last decade, such as legally regulated whale-watching activity. From a conservation viewpoint, the Madeira Regional Government recently approved a proposal for a Site of Community Importance for the bottlenose dolphin (*Tursiops truncatus*) around the waters of the main islands of the Archipelago of Madeira (Madeira, Porto Santo and Desertas; Figure 1), within the framework of the European Union Habitats Directive.

2.2 | Data collection

Sighting data of cetaceans were collected year-round between 1 January 2005 and 31 December 2015 from whale-watching boats operating in the study area (Figure 1). Two platforms were used instead of one given that it increased the spatio-temporal coverage of the area and sample size, thus allowing for a higher resolution of the data (i.e. fine-scale) and a better representativeness of the study area. Data from a third platform were also collected for 2 years, but a preliminary data analysis (discovery curve; not shown) revealed no advantage in continuing given that this did not add significant data (i.e. no increase in the number of species/sightings presence, nor in the spatio-temporal coverage), entailed extra logistics and was time consuming (e.g. in eliminating duplicates). Therefore, to address the goals proposed in this study, the optimal balance was to use the combined data from two platforms. The platforms used were the tour boats *Ventura do mar* and *Seaborn*. The former is a 15-m ketch powered by a 200 hp (horsepower) and the latter is a 23 m Taiti catamaran powered by a twin 160 hp. Both depart and arrive at the same time from Funchal harbour (Figure 1) and operate bidaily trips that last 3 hr (from 10:30 to 13:30 and from 15:00 to 18:00) in day light, irrespective of the season. The trips search for cetaceans, without focusing on any species in particular, and use one experienced observer who scans the area up to the horizon assisted by 7 × 50 binoculars. While both boats operate within a similar general area (south and southeast of Madeira Island, Figure 1), they frequently cover different subareas (e.g. offshore versus inshore, south versus southeast). Observers onboard *Ventura do mar* search for cetaceans at an eye-height of 4 m above the sea level at a cruise speed of 7 knots, whereas for *Seaborn* these values are 5 m and 10 knots, respectively.

TABLE 1 Summary statistics per year, showing the occurrence rate of each taxon per year between 2005 and 2015 and the overall mean with *SD*, based on a total of 3,527 surveyed days and 7,551 (daily) sightings

Taxa	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Mean ± *SD*	Relat. contr. (%)
Stenella frontalis	45.7	46.9	52.6	59.1	49.7	51.6	42.8	42.3	41.5	57.1	50.1	49.04 ± 5.87	22.88
Tursiops truncatus	28.6	27.9	36.8	39.0	51.6	51.2	64.0	58.3	45.8	38.0	46.9	44.38 ± 11.55	20.71
Delphinus delphis	24.1	31.6	35.3	34.8	30.0	22.4	27.4	27.5	27.7	34.6	46.0	31.04 ± 6.56	14.59
Balaenoptera brydei	26.4	32.2	44.4	40.6	32.3	24.9	13.5	10.3	4.9	39.5	16.4	25.94 ± 13.23	12.09
Globicephala macrorhynchus	12.5	20.2	29.7	14.7	23.2	26.7	26.2	26.0	30.8	26.9	34.6	24.68 ± 6.65	11.59
Physeter macrocephalus	7.7	5.8	8.5	8.0	10.0	6.4	6.5	7.6	12.6	11.4	9.7	8.56 ± 2.16	4.01
Stenella coeruleoalba	6.4	10.4	10.0	5.4	14.8	5.3	4.9	10.3	7.4	6.2	8.2	8.13 ± 3.02	3.81
Ziphiidae	2.3	2.8	2.9	3.8	10.0	2.8	8.0	6.3	5.8	1.5	2.1	4.40 ± 2.76	2.05
Balaenoptera sp.	13.2	11.0	5.6	3.2	5.2	1.1	1.2	0.9	0.9	3.7	2.1	4.37 ± 4.20	2.04
Balaenoptera physalus	6.1	1.8	0.6		2.9	2.5	4.9	5.4	1.8	6.5	8.2	3.71 ± 2.66	1.75
Steno bredanensis	0.6	0.3	2.4	3.5	5.5	2.1	1.5	2.1	1.5	2.8	0.9	2.12 ± 1.46	0.98
Delphinidae	4.5	4.9	2.9	3.2	1.9	0.4	0.6	0.6	0.9	0.9		1.90 ± 1.73	0.89
Grampus griseus	1.0	0.3	2.4	1.6	1.6	4.6	1.8	2.1	2.5	0.3	1.5	1.79 ± 1.19	0.82
Mesoplodon densirostris	0.3	0.6	0.9	1.0	1.6	0.7	3.1	0.6	1.5	0.9	0.9	1.10 ± 0.76	0.52
Kogia breviceps	0.3	1.8	0.6	0.6	1.0	0.4	0.3	0.6	0.6	0.6	1.5	0.76 ± 0.49	0.36
Balaenoptera borealis	1.6	2.5	0.3	0.3						1.9	0.6	0.65 ± 0.89	0.30
Pseudorca crassidens	0.3	0.9				0.4	0.3	0.3		0.9	0.9	0.36 ± 0.38	0.17
Orcinus orca	0.3			0.3	0.3		0.6		0.3		0.6	0.22 ± 0.24	0.11
Megaptera novaeangliae		0.3			0.3						0.9	0.14 ± 0.28	0.07
Ziphius cavirostris		0.3				0.4	0.6					0.12 ± 0.21	0.05
Balaenoptera acutorostrata	0.3								0.3	0.6		0.11 ± 0.21	0.05
Lagenodelphis hosei	0.3		0.3	0.3							0.3	0.11 ± 0.16	0.05
Hyperoodon ampullatus			0.3	0.3					0.3			0.08 ± 0.14	0.04
Balaenoptera musculus					0.3						0.6	0.08 ± 0.19	0.04
Peponocephala electra	0.3											0.03 ± 0.10	0.01
No. of species	18	16	15	15	15	14	15	13	15	15	18	15.36 ± 1.50	
No. of surveyed days	311	326	340	313	310	281	325	331	325	324	341	320.64 ± 16.76	
No. of days with sightings	253	292	318	295	299	258	305	300	300	302	329	295.55 ± 22.45	
Daily sighting rate (%)	81.4	89.6	93.5	94.2	96.5	91.8	93.8	90.6	92.3	93.2	96.5	92.13 ± 4.16	

The occurrence rate was calculated as the number of days with sightings divided by the number of surveyed days (multiplied by 100). Taxa are ranked by decreasing order of their relative contribution (Relat. contr.). Blanks represent zeros.

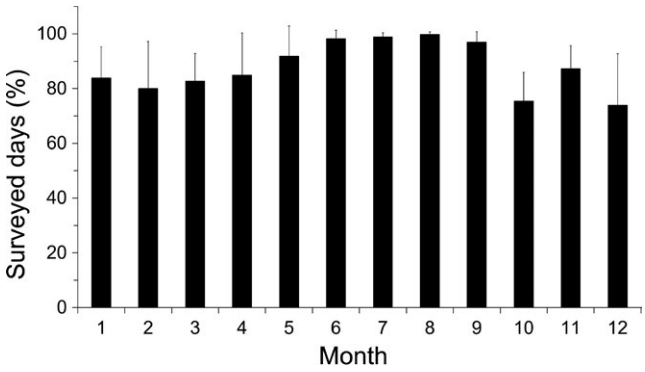

FIGURE 2 Monthly effort, expressed as the mean percentage of the surveyed days in each month. *SD* indicates inter-annual variability (2005–2015)

The trips covered different distances and depths within the most intensively surveyed area, i.e. off the south and southeast coasts of Madeira Island (Figure 1). The track lines of trips were recorded using a Global Positioning System (GPS) for the two latest years of the study. This adequately elucidates the sampled area used by these platforms (i.e. comparable during the years of the study), given that they used the same harbour and schedules throughout the study period, and corroborated by personnel observations during the surveys. The search effort started when leaving the harbour, and finished only when at the coastline, irrespective of the number of sightings during the trip. During the trips, the boats searched for the highest number of species possible. The legal permits allow for boats to be near the cetaceans for a maximum of 10 min, which means that in general most of each trip's duration was spent on effort, i.e. searching for cetaceans. At each sighting of cetaceans, the route was modified in order to approach the animals, which allowed collecting confident sighting data. Given that sightings could be shared with other boats via tips from radio calls, the number of whale-watching boats operating in the area was recorded during each trip in order to determine whether this affected cetaceans' seasonal occurrence. Sighting data and Beaufort sea state were recorded on printed data forms.

The sighting data included co-ordinates (the closest to the group or individual), date, initial and end time, species, best estimate of group size, initial behaviour pattern, best estimate of number of calves, and inter-specific relationships. Species were identified to the lowest taxonomic level possible at sea, but also from photographs. A group was defined as all individuals within 250 m distance of each other and exhibiting similar behaviour (Heimlich-Boran, 1993), except in the case of sperm whales (*Physeter macrocephalus*) displaying foraging behaviour (fluke-up followed by long-dive; Whitehead, 1989), which are known to disperse over a wider area (Drouot, Gannier, & Goold, 2004; Whitehead, 1989). Therefore, all foraging/dispersed *P. macrocephalus* sighted within a 1-hr period were considered a group. This period started from the first individual sighted, and was restricted to 1 hr in order to avoid repeated counts given the typical long dive duration of these animals (Aoki et al., 2007), which in the study (and neighbouring) area are mainly composed of females with immatures (Correia-Fagundes & Romano, 2013; Matthews, Steiner, & Gordon, 2001). Behaviour patterns were ranked in four categories: (i) travelling – moving animals, normally on a steady course, independent of whether slowly, moderately or fast, (ii) resting – stationary in one place, almost without movement, (iii) socializing – clear and constant interaction between the animals in the group, normally stationary in the area, and (iv) feeding or foraging – non-synchronized movements and very active animals, normally involving the visualization of prey or aggregation of birds, or when showing the fluke in the case of *P. macrocephalus* (which, when followed by a long dive, as assessed in most cases during this study, is known to involve large energetic costs mainly associated with foraging activity; Irvine, Palacios, Urbán, & Mate, 2017; Watwood, Miller, Johnson, Madsen, & Tyack, 2006); adapted from Evans (1982), Drouot et al. (2004) and Cañadas and Hammond (2006). A calf was defined as an immature individual that was <⅔ the length of the adult individual that it was in close association with (<5 adult body lengths) and had a lighter colour; adapted from Yonekura, Matsui, and Kasuya (1980), Whitehead (1996) and Perrin, Würsig, and Thewissen (2009). The exception to this definition was *P. macrocephalus*, whose calves, in contrast to other cetacean species, are not consistently accompanied closely by a single adult, and therefore, in the present study calves of this species comprised mainly the easily distinguishable first-year calves (4–5.5 m in length), following Whitehead (1996). Inter-specific relationships were considered as when two or more species were observed in close association and exhibiting similar behaviour during the entire duration of the encounter.

2.3 | Data analysis

For the analysis of the occurrence patterns, as consecutive observations were collected close together in space and time, all sightings of a cetacean species made during the same day were pooled and considered only as presence. This binomial (presence–absence) approach minimized the introduction of potential spatial and temporal correlation into the data analysis (de Stephanis et al., 2008; Panigada et al., 2008), as well as eliminated bias caused by simultaneously using two platforms (i.e. avoided repeated sightings). The occurrence rate of each species was calculated on a temporal basis, as the number of days with sightings divided by the number of surveyed days (multiplied by 100), thus obtaining the percentage of days each species was sighted in the area. For this analysis each year was treated individually and was analysed statistically for the number of species, number of surveyed days, number of days with sightings and for the daily sighting rate. The relative sighting frequency of each species was also determined to help assess the cetacean community structure.

Intra-annual variation in cetacean diversity was assessed by analysing the number of species sighted per month, given the high and homogeneous effort (expressed as the number of surveyed days) across years and months (Table 1, Figure 2). One-way analyses of variance (ANOVAs), followed by post-hoc Tukey's tests, were used

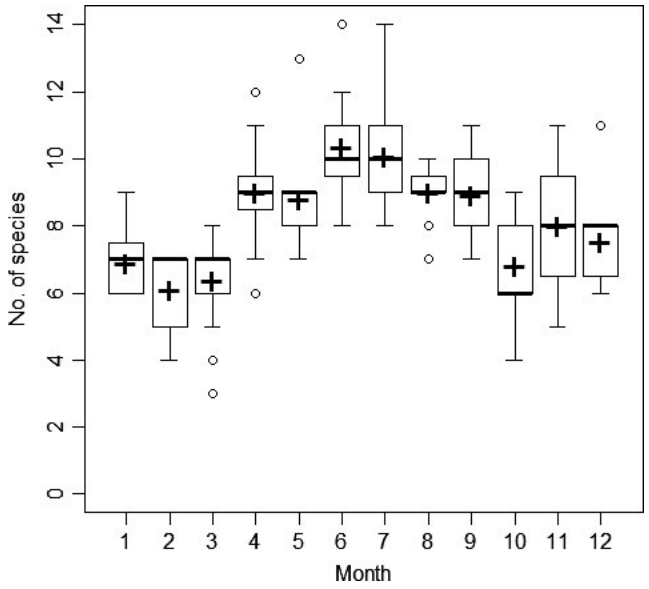

FIGURE 3 Boxplot of the number of species sighted per month between (1—January, etc.) 2005 and 2015 (n = 132; 12 months across 11 years). Middle bold lines indicate median values, + shows the mean, upper and lower lines of boxes encompass the spread of data from the first to the third quartile, and upper and lower horizontal bars show minimum and maximum group sizes unless outliers are present (o), in which case the horizontal bar is defined as the third quartile plus 1.5. Significant differences in the number of species per month (p < .05) occurred mainly between June–July and the autumn–winter months, as well as between February–March and most of the spring–summer months (Appendix S4)

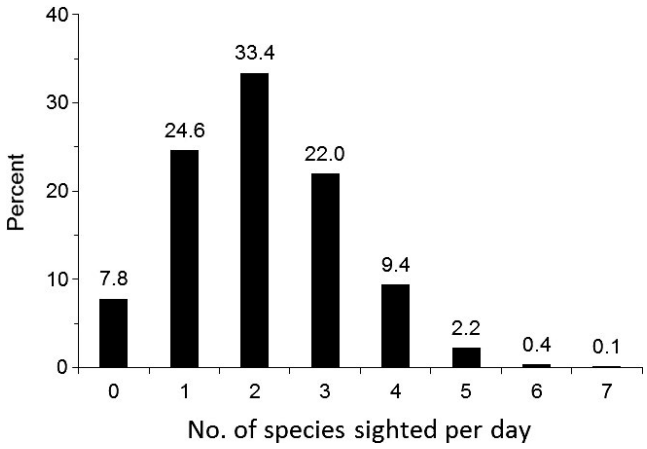

FIGURE 4 Relative frequency histogram of the number of species sighted per day, based on 3,527 surveyed days carried out year-round between 2005 and 2015

to assess if the number of species sighted per month was significantly different (α = .05). For this analysis all years were combined given the absence of significant differences in the number of species sighted within years (one-way ANOVA, p > .9). At a higher resolution (daily analysis), the number of species sighted per day was also calculated. The factors causing variations in the effort and the associated biases are discussed later (Discussion).

The analysis of the species' biological factors addressed the aggregation size, species behaviour, proportion of calves, and inter-specific relationships. Prior to this analysis, data were cross-checked to remove duplicates. These were considered as any sighting of the same species collected from different boats during the same trip within the same hour or 3-km range. When duplicates were detected, the group with the largest size was retained, as it is probably the most accurate representation (Hupman et al., 2015). In addition, to minimize bias, this analysis considered only the sightings collected by the most experienced observers (all authors of the present study, who have extensive experience in marine mammal identification), and the ones collected at a close distance to the animals. The analysis of the proportion of calves was restricted to the two latest years of the study given that the definition of calf was only established for this period. One-way ANOVAs, followed by post-hoc Tukey's tests, were used to assess if the percentage of calves in groups with calves was significantly different between species; this inferential analysis was restricted to the six most sighted species (see Table 1). All the analyses were carried out using the R 3.3.1 statistical package (R Core Team, 2016), and the search tracks were mapped using the QGIS 2.14 Essen programme.

TABLE 2 Statistics for group sizes. Frequency histograms are presented in Appendix S1. Caution should be taken when interpreting the results with low n

Species	Mean ± *SD*	Range	*n*
Delphinus delphis	29.4 ± 29.4	1–330	863
Stenella frontalis	40.9 ± 33.7	1–250	1,448
Stenella coeruleoalba	27.9 ± 15.5	1–95	115
Steno bredanensis	20.9 ± 13.3	1–60	42
Tursiops truncatus	18.9 ± 17.1	1–150	1,156
Globicephala macrorhynchus	17.8 ± 10.5	1–120	707
Grampus griseus	15.3 ± 12.3	3–50	27
Pseudorca crassidens	23.5 ± 23.6	1–75	13
Orcinus orca	7.5 ± 8.2	3–24	6
Lagenodelphis hosei	67.5 ± 10.6	60–75	2
Peponocephala electra	12.0	12–12	1
Mesoplodon densirostris	3.7 ± 1.7	1–8	47
Ziphius cavirostris	2.8 ± 1.9	1–7	8
Hyperoodon ampullatus	6.0	6–6	1
Physeter macrocephalus	3.7 ± 3.5	1–30	235
Kogia breviceps	1.4 ± 0.5	1–2	13
Balaenoptera brydei	1.5 ± 0.7	1–6	719
Balaenoptera borealis	1.4 ± 0.8	1–4	51
Balaenoptera physalus	1.8 ± 1.4	1–7	84
Balaenoptera musculus	1.5 ± 0.7	1–2	2
Balaenoptera acutorostrata	1.0 ± 0.0	1–1	4
Megaptera novaeangliae	1.0 ± 0.0	1–1	7

n, number of sightings.

3 | RESULTS

3.1 | Effort

A total of 3,527 days were surveyed during the 11 years, with an annual mean of 321 (*SD* = 17) surveyed days (Table 1). The mean monthly coverage was 27 days (*SD* = 3) (Figure 2). This coverage corresponded to 88% of the study period, with the remaining days mainly being associated with rough weather. Data collected corresponded to 13,942 sightings, with a reduction to 7,551 sightings after pooling (to daily presences). The latter were the only data used in the analysis of the occurrence patterns. The biological factors were assessed from a total of 6,353 sightings (after eliminating duplicates). The majority of the data were collected at Beaufort sea state ≤ 3 (94.0%) or ≤ 4 (99.3%).

3.2 | Occurrence patterns

A total of 25 taxa were recorded, comprising at least 22 species (Table 1). There were inter-annual variations in each species' occurrence rate (assessed from visual inspection, Table 1), but the rank of these values remained similar between species across the 11 years. The five most frequently observed species (i.e. sighted on ≥ 25% of the surveyed days) were, by decreasing order of the mean occurrence rate, the Atlantic spotted dolphin (*Stenella frontalis*), *Tursiops truncatus*, the short-beaked common dolphin (*Delphinus delphis*), Bryde's whale (*Balaenoptera brydei*) and the short-finned pilot whale (*Globicephala macrorhynchus*). These were followed by *Physeter macrocephalus*, the striped dolphin (*Stenella coeruleoalba*), Ziphiidae [most sightings likely to be Blainville's beaked whale (*Mesoplodon densirostris*) given that this was the most sighted species of the beaked whales], *Balaenoptera* sp. (mainly either *B. brydei* or the sei whale, *Balaenoptera borealis*, but most sightings are likely to have been the former species) and the fin whale (*Balaenoptera physalus*); these taxa had mean occurrence rates of between approximately 9% and 4%. Three other species had a mean occurrence rate between approximately 2% and 1%, and the remaining species were sighted only on < 1% of the surveyed days (Table 1).

The mean number of species recorded per year was 15.4 (*SD* = 1.5, range 13–18), and in general, cetaceans were sighted on > 92% of the surveyed days (Table 1). The combined relative sighting frequency of the five most sighted species comprised 82% of the total daily sightings, of the seven most sighted species comprised 90% and of the 10 most sighted taxa (including at least nine species) comprised 96% (Table 1).

The number of species per month was lowest in February and March, with a minimum of three species, and highest in June and

TABLE 3 Relative percentage (in relation to total *n*) of each of the natural behaviours recorded per species. Caution should be taken when interpreting the results with low *n*

Species	Trav.	Rest.	Feed.	Soc.	*n*
Delphinus delphis	61	8	25	6	602
Stenella frontalis	64	8	15	13	1,165
Stenella coeruleoalba	80	2	9	9	88
Steno bredanensis	48	24	9	18	33
Tursiops truncatus	81	8	4	7	826
Globicephala macrorhynchus	73	24	1	2	469
Grampus griseus	70	30	0	0	20
Pseudorca crassidens	67	11	0	22	9
Orcinus orca	83	0	17	0	6
Lagenodelphis hosei	100	0	0	0	1
Mesoplodon densirostris	84	11	0	5	37
Ziphius cavirostris	80	0	0	20	5
Hyperoodon ampullatus	100	0	0	0	1
Physeter macrocephalus	47	21	19	12	154
Kogia breviceps	17	83	0	0	6
Balaenoptera brydei	82	2	11	4	486
Balaenoptera borealis	85	0	3	13	39
Balaenoptera physalus	64	14	8	14	36
Balaenoptera acutorostrata	100	0	0	0	3
Megaptera novaeangliae	50	50	0	0	2

Feed., feeding; *n*, number of sightings; Rest., resting; Soc., socializing; Trav., travelling.
Although feeding is difficult to record in the deep-feeders *G. macrorhynchus* and *M. densirostris*, such behaviour is expected in these species in Madeira based on deep dives recorded for the former species (Alves, Dinis, et al., 2013) and on the high site fidelity of the latter species (Dinis, Baird, Mahaffy, Martín, & Alves, 2017; Dinis, Marques, et al., 2017).

July, with a maximum of 14 species (Figure 3). The mean number of species was at its minimum in February (6.1, *SD* = 1.3), and maximum in June (10.4, *SD* = 1.6), with an overall monthly mean of 8.2 (*SD* = 2.0). In general, the mean number of species was lower between October and March, and higher between April and September (Figure 3). There were significant differences in the number of species per month ($p < .001$), with the post-hoc tests presented in Appendix S4. The mean number of species sighted per day was 2.1 (*SD* = 1.2), which occurred on 33.4% of the surveyed days, and ranged between zero (7.8%) and seven (0.1%) (Figure 4).

3.3 | Biological factors

Group sizes were attributed to 5,551 sightings from all species, and are summarized in Table 2. Frequency histograms of the number of individuals for the species with > 40 sightings (11 species) are presented in Appendix S1.

Behavioural patterns were attributed to 3,988 groups from 20 species, and the statistics on the animals' natural behaviours per species are presented in Table 3. All four of the behaviour categories were recorded in 10 out of the 20 species for which behavioural patterns were analysed. Travelling was the category with the highest relative percentage in all species except for the pigmy sperm whale (*Kogia breviceps*). There was intra-annual variability in the animals' natural behaviour in the five most observed species (Figure 5).

The proportion of calves was attributed to 2,426 groups from 13 species, with the proportion of groups with calves ranging from 10% in *Balaenoptera physalus* to 64% in *Globicephala macrorhynchus* (Table 4). Apart from the latter species, four others [namely *Delphinus delphis*, *Stenella frontalis*, the false killer whale (*Pseudorca crassidens*) and *Mesoplodon densirostris*] presented groups with calves in > 30% of the sightings. In these sightings, the mean percentage of calves represented between 9% and 29% of the group (Table 4), being significantly different between species ($p < .001$). The post-hoc test showed that the larger whales (*Physeter macrocephalus* and *Balaenoptera brydei*) had significantly higher percentages of calves in their groups than in the groups of the remaining four delphinid species used in this analysis (Appendix S5).The analysis of the intra-annual variability of the proportion of calves in the four most represented delphinid species showed that calves were recorded throughout the year in *G. macrorhynchus*, and for most months in *D. delphis*, *S. frontalis* and *Tursiops truncatus* (Figure 6).

Based on 4,591 sightings, 357 (7.8%) were involved in inter-specific relationships. Of these, 340 sightings (95.2%) involved two species, 16 (4.5%) involved three species and one (0.3%) involved four species. A total of 12 species were involved in mixed groups, but only four were commonly sighted in such types of associations, summing 87.2% of the relative frequency of the contribution of each species to the total sightings of mixed groups. These were *T. truncatus* (30.5%), *G. macrorhynchus* (24.0%), *S. frontalis* (17.1%) and *B. brydei* (15.6%). Adding the contributions of *D. delphis* (5.3%) and *Stenella coeruleoalba* (3.4%), the total increased to 95.9% (Appendix S3).

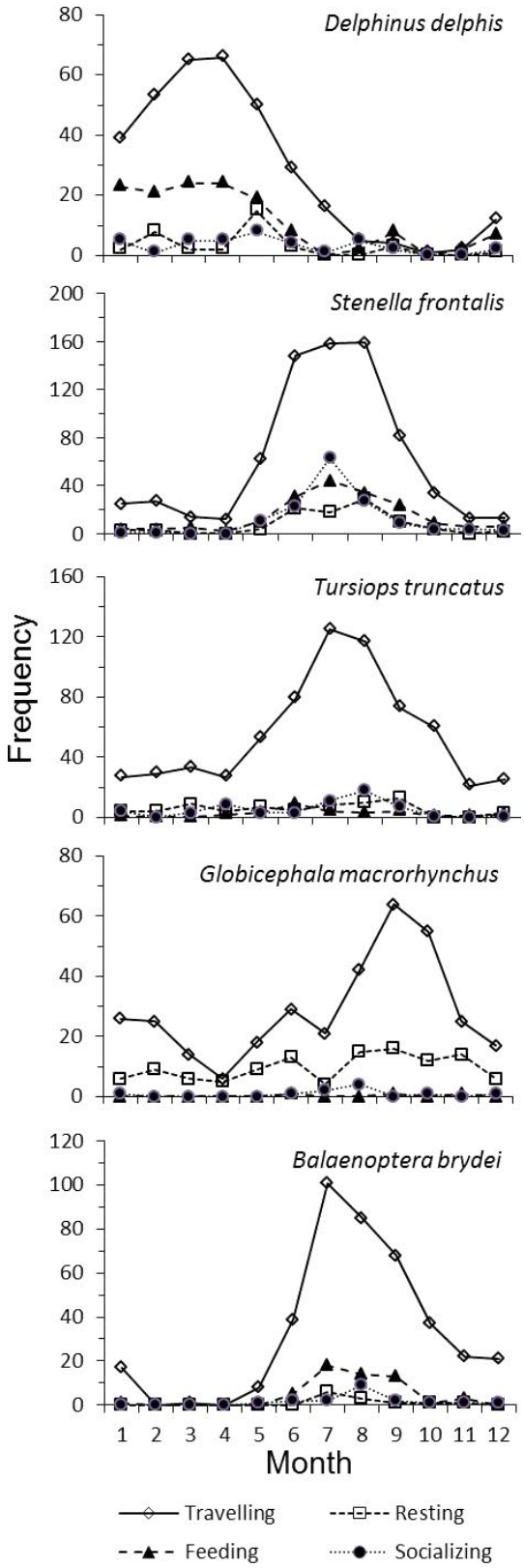

FIGURE 5 Intra-annual variability in the animals' natural behaviour for the five most observed species in Madeira

4 | DISCUSSION

This study presents 11 years of effort-related sightings based on opportunistic nautical surveys conducted from whale-watching platforms on a daily basis, providing new information on the occurrence and group dynamics of cetaceans around Madeira Island mainly using a descriptive approach. The high intra- and inter-annual homogeneous coverage, with a mean of 27 (*SD* = 3) surveyed days per month and 321 (*SD* = 17) per year (see Figure 2 and Table 1), and the high number of sightings (*n* = 6,353) from which biological data were collected by experienced observers under good weather conditions (according to Evans & Hammond, 2004) indicate that this type of platform can provide large amounts of fine-scale data that would be unfeasible to collect from dedicated research vessels. The whale-watching industry is increasing worldwide, along with the number of qualified staff (in many cases the presence of a biologist is required onboard), thus offering excellent platforms for researchers to establish collaborations. The large data sets that can be obtained from several types of platforms of opportunity can therefore balance possible biases associated with such types of data, which can include restrictions in the spatial and temporal coverage (Kiszka, Macleod, Canneyt, Walker, & Ridoux, 2007), in the time spent with a focal group (Wall, O'Brien, Meade, & Allen, 2006) and/or in the data quality (e.g. species identification; reviewed in Hupman et al., 2015). The quality and limitations of the data obtained from platforms of opportunity will therefore differ according to the nature of each platform and region. In the case of the present study, the fine-scale data allowed us to make reliable inferences on cetacean occurrence and to characterize the species' biological factors.

This study presents new knowledge on the ecology of cetaceans in Madeiran waters, a region where multi-species studies on this taxonomic group were previously limited to a single checklist (Freitas et al., 2012) and to grey literature. By addressing species occurrence and diversity across different temporal scales, and the species' group sizes, behaviour patterns, proportion of calves and inter-specific relationships, this study presents important baseline information on the community patterns and biological factors of these large marine apex predators. For instance, it shows that a high number of cetacean species uses these waters, as observed in the neighbouring archipelagos of the Azores (Silva et al., 2014) and Canaries (Carrillo, Pérez-Vallazza, & Álvarez-Vázquez, 2010), supporting the importance of the Macaronesian waters for cetaceans. Moreover, some species were found to use the Madeiran waters on a regular basis, with five species being present between approximately 25% and 50% of the year and five taxa between approximately 4% and 9%. These include species featured in the IUCN (International Union for Conservation of Nature) Red List (IUCN, 2016) as Endangered (like *Balaenoptera physalus*), Vulnerable (like *Physeter macrocephalus*) and Data Deficient (like *Balaenoptera brydei*, *Globicephala macrorhynchus* and *Mesoplodon* spp.).

Stenella frontalis and *B. brydei* were amongst the species with the highest mean occurrence rate across the 11 years of the present study, and yet these species were only first recorded in Madeira in 1997 and 2003, respectively (Freitas, Dellinger, & Reiner, 1998; Freitas et al., 2012). The study also found that *Tursiops truncatus* and *G. macrorhynchus* were amongst the most sighted species, which is in accordance with the existence of island-associated populations in Madeira (Alves, Dinis, et al., 2013; Dinis, Alves, et al., 2016). Together with *Delphinus delphis*, these five species comprise the majority (87%) of the sightings in Madeira, contrasting with Tenerife (Canary Islands, which lies about 300 km south of Madeira) where *T. truncatus* and *G. macrorhynchus* together comprise 82% of all sightings (Carrillo et al., 2010). This, along with the overall annual mean of 15 species and monthly mean of eight species observed in this study,

TABLE 4 Statistics for the presence of calves, based on 2,426 groups observed during 2014–2015

Species	No. of groups observed	% of groups with calves	Mean ± *SD* of the % of calves in groups with calves
Delphinus delphis	452	33	9 ± 8
Stenella frontalis	629	43	9 ± 8
Stenella coeruleoalba	54	15	6 ± 3
Steno bredanensis	12	17	5
Tursiops truncatus	552	24	9 ± 8
Globicephala macrorhynchus	344	64	12 ± 9
Grampus griseus	11	27	14 ± 12
Pseudorca crassidens	9	44	23 ± 24
Mesoplodon densirostris	20	40	29 ± 13
Physeter macrocephalus	93	25	28 ± 11
Kogia breviceps	6	17	50
Balaenoptera brydei	192	15	47 ± 7
Balaenoptera physalus	52	10	43 ± 16

See Figure 6 for the proportion of calves throughout the year and Appendix S5 for inferential statistics for the percentage of calves in groups with calves.

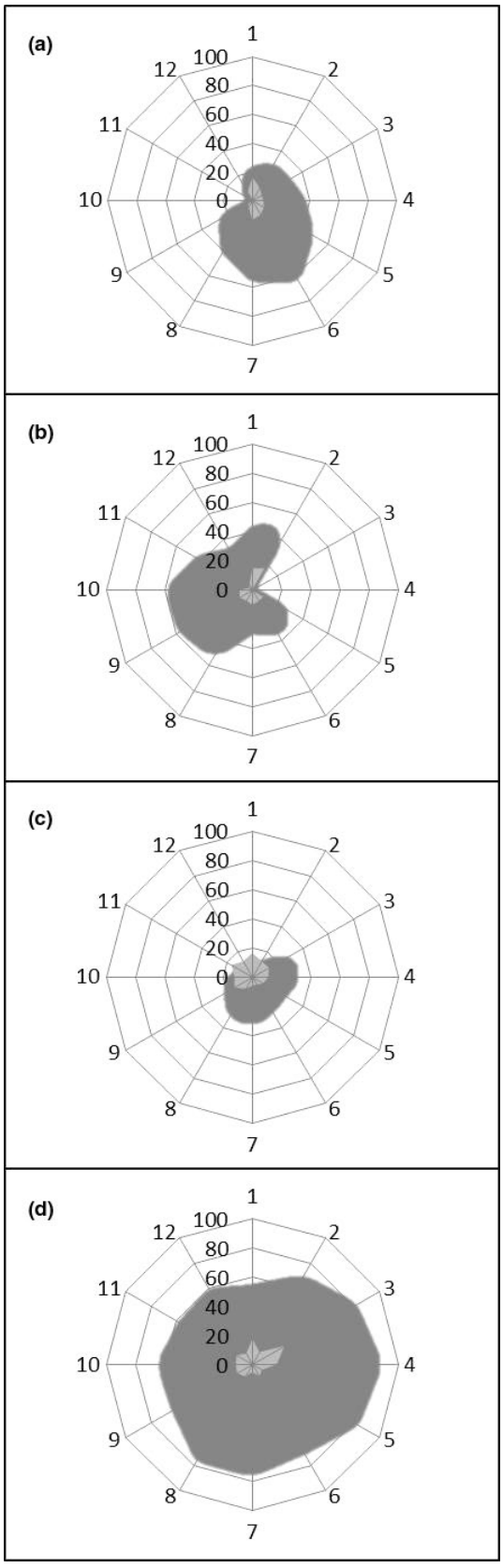

FIGURE 6 Proportion of groups with calves (dark grey area) and mean percentage of calves in these groups (light grey area) per month for (a): *Delphinus delphis*, (b): *Stenella frontalis*, (c): *Tursiops truncatus* and (d): *Globicephala macrorhynchus*. The number of sightings is presented in Table 4

suggests that the community structure of cetaceans in Madeira is more diverse/balanced than the community in Tenerife, which is mainly dominated by two species.

In addition, the study also shows that the vital activities of feeding, resting, socializing and calving are conducted in Madeiran waters by at least nine species (Table 3), corresponding to the ones with the highest mean occurrence rates (see Table 1, where species are ranked by decreasing order of their relative contribution). In particular, *S. frontalis* and the deep-diver species *Mesoplodon densirostris* and *G. macrorhynchus* were observed with calves in a high percentage (>40%) of the groups, and in the latter case the calves were present throughout the year, which is consistent with another study (Alves, 2013). Similar results for the proportion of groups with calves in *T. truncatus* were also found between this (24%) and an independent data set from a similar period and region (26.4%, Dinis, Alves, et al., 2016). The importance of this area as a calving ground is also supported by the observation of births/neonates in Madeiran waters for some of these species, such as *S. frontalis* (Alves, Nicolau, Dinis, Ribeiro, & Freitas, 2015), *G. macrorhynchus* (Reggente et al., 2016) and *P. macrocephalus* (Correia-Fagundes & Romano, 2013).

Taking into consideration that management and conservation issues are best addressed by providing a preliminary identification of areas of particular importance for specific species (Panigada et al., 2008), the findings described here should be taken into consideration by managers. It is thus suggested that the south and southeast of Madeira Island constitute an area of interest for cetaceans in terms of travelling, resting, socializing, feeding and calving. Including this information in governmental management plans would be of major importance especially because the study area coincides with the main area of marine traffic in Madeira Island (Cunha et al., in press) and with the main area of operation of whale-watching vessels (this study, supported by Figure 1). Moreover, it also provides information on the target species (*T. truncatus*, owing to being listed in the Annex II of the Habitats Directive) of the recently approved proposal for a Site of Community Importance, which will certainly benefit all remaining species. A more in-depth modelling analysis of both the spatial and temporal distribution of cetaceans around Madeira is in preparation and will be published elsewhere, thus complementing the baseline information obtained in the present study.

Sightings per unit of effort are commonly reported in the literature, including from platforms of opportunity (e.g. Arcangeli, Campana, Marini, & MacLeod, 2016; Correia et al., 2015), as the number of sightings per 100 km surveyed. Yet, this is more appropriate when obtaining data from ferries or cargo ships given that these platforms use established transect lines and do not change their course according to the animals' presence. In the case of whale-watching boats, sightings can easily be influenced by tips from sources such as radio calls and look-out posts. In order to minimize such bias, studies from this type of platform commonly use the number of sightings per total surveys conducted (e.g. Hupman

et al., 2015) or per surveyed day (e.g. Pérez-Vallazza et al., 2008). Here, in order to minimize potential spatial and temporal correlation caused by using two platforms conducting two trips per days within a small area, the daily presence–absence approach was the selected method to represent the animals' temporal occurrence patterns. Although the obtained values are not comparable with sighting frequencies per 100 km, they are less biased and can be compared with other studies using the same method. Nevertheless, caution should be taken when comparing values from different regions given that the surveys that collected these data will usually have variations in detection probability (both inter- and intra-study; Matthiopoulos & Aarts, 2010) owing to different types of vessel, types of survey/search (e.g. dedicated, opportunistic, acoustic, visual, help of lookout post), number of whale-watching boats in the area, number of observers, eye-height, etc. In the present case, such variations could be caused by using boats with observers at different eye-heights or by variations in the number of surveyed hours (trips) between seasons. The number of other whale-watching boats in the area was relatively homogeneous across months (Appendix S2), yet even such small levels of variation could have affected the observed diversity of cetaceans.

5 | CONCLUSIONS

The present study supports previous literature (e.g. Arcangeli et al., 2013; Hupman et al., 2015) by demonstrating that despite their limitations, platforms of opportunity, and specifically whale-watching vessels, constitute highly cost-effective tools and valuable vehicles that can provide robust data sets. The similarity of the values presented in this study to those from dedicated surveys for the proportion of calves, group sizes, and inter-specific relationships in *Globicephala macrorhynchus* and *Tursiops truncatus* in Madeira (Alves, 2013; Dinis, Alves, et al., 2016) supports the reliability of the results obtained from platforms of opportunity. These vehicles should be used to collect baseline information on species occurrence, diversity, and group dynamics, which can help to answer numerous questions regarding the conservation of marine mammals.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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