

Spatial and temporal distribution of bottlenose dolphins, *Tursiops truncatus*, in the Madeira archipelago, NE Atlantic

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One of the first steps in understanding the relationships between populations and their habitats is to determine which areas they use with higher frequency. This study used systematic and non-systematic survey data from 2001-2002 and 2004-2012 to determine encounter rates and investigate temporal and spatial distribution of bottlenose dolphins around Madeira, Desertas and Porto Santo islands. A total 24,914 km of search effort was carried out and 199 sightings were recorded. Highest encounter rates were found off the east coast of Madeira and off Porto Santo. Moreover, higher encounter rates occurred over bathymetries ranging between 500-1,000 m during systematic surveys whereas in non-systematic surveys relative high encounter rates were found in depths of 2,000-2,500m. Most dolphins were found to be distributed in depths <1,000m and at no more than 10 km offshore indicating a preference for shallower waters. Dolphins were sighted during the whole year and there were no significant differences in encounter rate between months. These results suggest the existence of preferential areas for this species based on static bathymetric features. The fact that the dolphins prefer inshore areas that are more exposed to anthropogenic activities should be taken into account when discussing bottlenose dolphin conservation measures in the Madeira archipelago.

Key words: Bottlenose dolphins, conservation, nautical surveys, physiographic variables, spatio-temporal occurrence

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INTRODUCTION

Effective conservation of wild populations requires an understanding of the relationship between populations and their habitats and for that the first step is to determine which habitats are used with higher frequency (Cañadas et al. 2005). Physiographic, oceanographic and biological variables can be used as proxies for prey availability

(known to determine cetacean distribution patterns as a predator response) (de Stephanis et al. 2008), which often are not available at the required spatial resolution to be used for habitat use analysis (Redfern et al. 2006). Foraging cetaceans are known to concentrate over areas of abrupt topography, such as shelf breaks, steep slopes, canyons, shallow banks and seamounts (Baumgartner et al. 2001; Yen et al. 2004; Cañadas et al. 2005). These habitats are

characterized by higher productivity, as a result of upwelling-driven nutrient availability (Genin 2004).

The bottlenose dolphin, *Tursiops truncatus* Montagu, 1821, occurs in populations ranging from far offshore waters to coastal waters, along the continents or around islands (Forcada et al. 2004). In Madeira archipelago the bottlenose dolphin is one of the most common species (Freitas et al. 2004; Dinis et al. 2009) and one of the most sighted species by the whale-watching activity (Ferreira 2007; Vera 2012).

In Madeira archipelago, the range of anthropogenic activities is yet unknown with the exception of the whale-watching industry (Ferreira 2007; Vera 2012) and marine traffic (Cunha 2013). In the last years the demand for marine activities has increased, and the whale-watching industry has grown in the same proportion. Marine tourism operators began undertaking sightseeing trips where they also advertised whale-watching. Nowadays, there are companies exclusively dedicated to whale-watching, including 'swimming with dolphins' activities (Vera 2012). In 2013 the whale-watching activity was legally regulated imposing limits to the number of companies operating and, in 2014 limited areas of operation were established. Moreover, Cunha (2013) identified an inshore common "high used corridor" for both vessels and cetaceans, standing as a potential conflict zone.

One of the most common approaches to marine conservation is the establishment of marine protected areas (MPAs) and although their effectiveness is the subject of much debate, they are considered an important tool for conservation (Cañadas et al. 2005). In Madeira archipelago MPAs cover only the coastal waters down to 100 m depth (Menezes et al. 2011), which is hardly effective for a highly mobile species such as the bottlenose dolphin. These animals usually have ranges too large to be included within a single MPA, but addressing areas where threatening human activities significantly overlap with the population range or important habitat can contribute effectively to the species' conservation (Silva et al. 2012). Designing protected areas requires knowledge of the spatial-temporal distribution and habitat requirements of the

population interest, in order to adjust the size of the management area to the biological needs of the target population (Silva et al. 2012). In addition, the large habitat area usually required for a species like the bottlenose dolphin can protect many other species (Hoyt 2011). Thus, these dolphins can simultaneously act as an umbrella and a flagship for the preservation of the marine environment.

This study uses long-term data to calculate encounter rates and to investigate temporal occurrence and spatial distribution of bottlenose dolphins around Madeira, Desertas and Porto Santo islands.

MATERIAL AND METHODS

STUDY AREA

This study was conducted in the archipelago of Madeira, Portugal. The archipelago is located in the warm-temperate waters of the northeast Atlantic Ocean, at approximately 1,000 km from the European continent and 500 km from the West African coast (Figure 1). The overall study area is characterized by a narrow continental shelf, with steep submarine canyons and deep waters (ca. 1,500 m) (Geldmacher et al. 2000).



Fig. 1. Map of the Madeira archipelago in the NE Atlantic

FIELD METHODS

The Madeira Whale Museum has conducted systematic and non-systematic surveys for cetaceans within the scope of different research projects. Sightings and search effort from these

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dedicated surveys conducted between 2001 and 2012 (excluding 2003) were used in the analyses. Systematic nautical surveys were carried out from R/V ZIPHIUS (12 km/h) over eight established sectors (Figure 2) that covered the waters around the islands of Madeira, Desertas and Porto Santo (4,637 km²). Three observers searched the area up to the horizon, equipped with 7x50 binoculars, at an eye-height of 5m above the sea level. Non-systematic surveys were carried out mainly from the 6.5m rigid inflatable research boat ROAZ (25 km/h), and also from R/V ZIPHIUS. These were

conducted over four pre-established sectors (Figure 2), covering the south and northeast of Madeira Island and Porto Santo. An attempt was made to cover all distances and depths within that area. An average of three observers (min. two, max. four) scanned the area by naked eye, at an eye-height of 2 m above the sea level. The track lines were registered using a Global Positioning System (GPS), and Beaufort Sea State, effort and sighting data were collected.

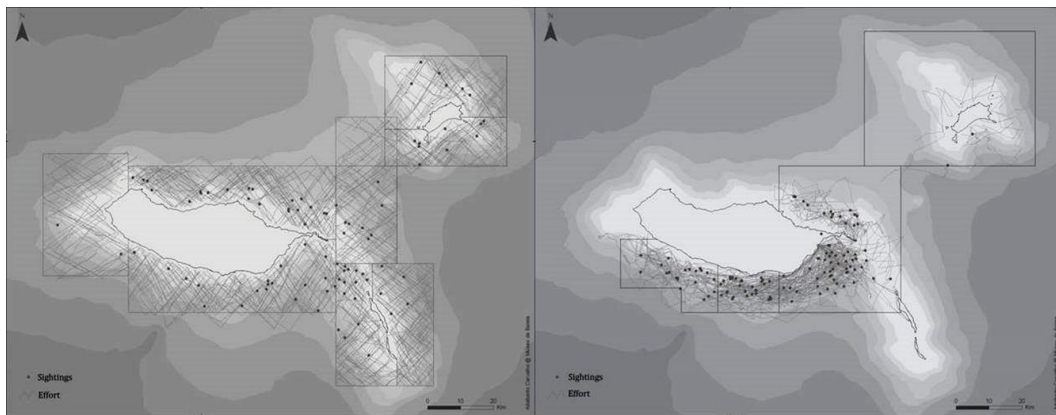


Fig. 2. Map representing the different sectors, effort tracks and sightings for systematic surveys (left) and non-systematic surveys (right). Surveys are represented by the grey tracks, and sightings by the black dots.

DATA ANALYSIS

Search effort was quantified as the number of km covered on effort mode under Beaufort Sea State ≤ 3 . In order to reduce bias, sightings from radio calls from other vessels were excluded. Effort and sighting data were then transferred into ArcView 9.3.1 (ESRI, Inc.), which was used for data processing.

SPATIAL DISTRIBUTION

Search effort, sighting data, and static variables such as mean depth, mean slope and minimum distance to coast were associated with each grid cell using Geographic Information System (GIS) tools. Spatial distribution was investigated by dividing the study area into a 2' x 2' grid of cells and calculating an encounter rate for each grid cell. Encounter rate was calculated as the number of sightings by 100 km surveyed in each grid cell. Data analysis was independent for each type of

survey due to different methodologies, and grid cells with < 5 km of search effort were excluded from the analysis to avoid small sample biases (Panigada et al. 2005; de Stephanis et al. 2008; Alves 2013).

For the analysis of the encounter rate in relation to physiographic variables these were categorized into bins. Depth and distance from the coast were categorized into bins. Depth and distance from the coast were measured in metres and kilometres respectively, while slope was expressed in degrees.

TEMPORAL DISTRIBUTION

Monthly encounter rate was calculated using inter-annual data of each type of survey, after verifying there were no significant differences between years (not shown). Encounter rate was pooled by month.

The Kruskal-Wallis test was used to explore if there were significant differences in the encounter rate between months for both systematic and non-systematic survey data. The Shapiro-Wilk and Levene's tests were carried out for the ANOVA assumptions ($\alpha=0.05$). All the analyses were made in R 3.0.2 software (R Development Core Team 2012).

RESULTS

EFFORT AND SIGHTINGS

Eighty nine sightings were registered along 14,318 km of effort during systematic surveys and 110 groups of bottlenose dolphins were recorded along 10,596 km of search effort during non-systematic surveys adding up to 199 sightings and 24,914 km of search effort from 2001-2012 (Table 1).

Table 1. Kilometres (km) surveyed number of groups and encounter rate (ER) of bottlenose dolphins sighted per year and type of survey, from 2001-2002 and 2004-2012.

Year	Non-systematic surveys			Systematic surveys			Total	
	km	Groups	ER	km	Groups	ER	km	Groups
2001	-	-	-	2,577	7	0.27	2,577	7
2002	-	-	-	1,943	7	0.36	1,943	7
2004	455	17	3.74	652	7	1.07	1,107	24
2005	1,853	17	0.92	-	-	-	1,853	17
2006	2,005	11	0.55	-	-	-	2,005	11
2007	649	6	0.92	919	6	0.65	1,568	12
2008	-	-	-	2,274	15	0.66	2,274	15
2009	-	-	-	500	4	0.80	500	4
2010	953	13	1.36	1,551	10	0.64	2,504	23
2011	3,266	26	0.80	2,510	17	0.68	5,776	43
2012	1,415	20	1.41	1,392	16	1.15	2,807	36
Total	10,596	110		14,318	89		24,914	199

SPATIAL DISTRIBUTION

Search effort during surveys was not homogeneous in all sectors mainly due to weather conditions and distance from the port (Figure 2). The exclusion of the cells with ≤ 5 km of search effort resulted in the elimination of 288 km of transect line from non-systematic surveys, and of

109 km from systematic surveys. No sightings were eliminated by this truncation.

Dolphins were encountered in 75 of the surveyed grid cells (16%) during systematic surveys and in 56 of the surveyed grid cells (21%) during non-systematic surveys (Figure 3).

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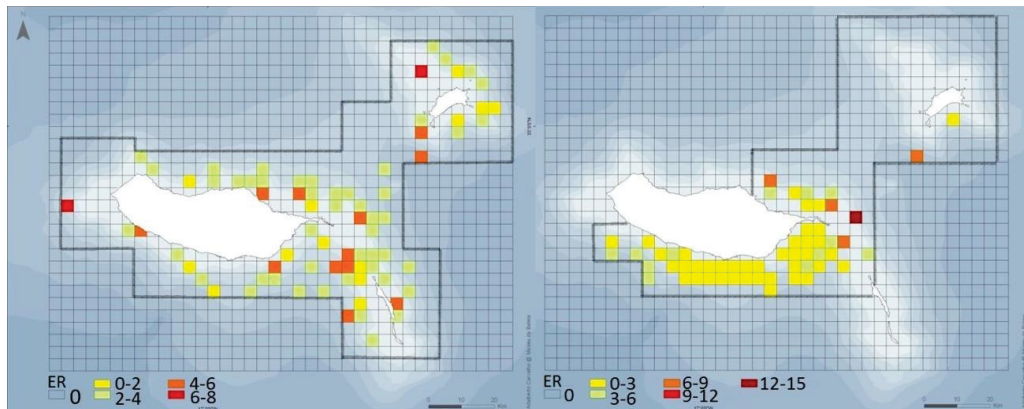


Fig. 3. Encounter rate (groups per 100 km) (ER) by grid cells for systematic surveys (left) and non-systematic surveys (right) over the study area.

With the exception of one grid cell in the southwest coast of Madeira, cells with highest

encounter rates were found on the east side of Madeira and in Porto Santo.

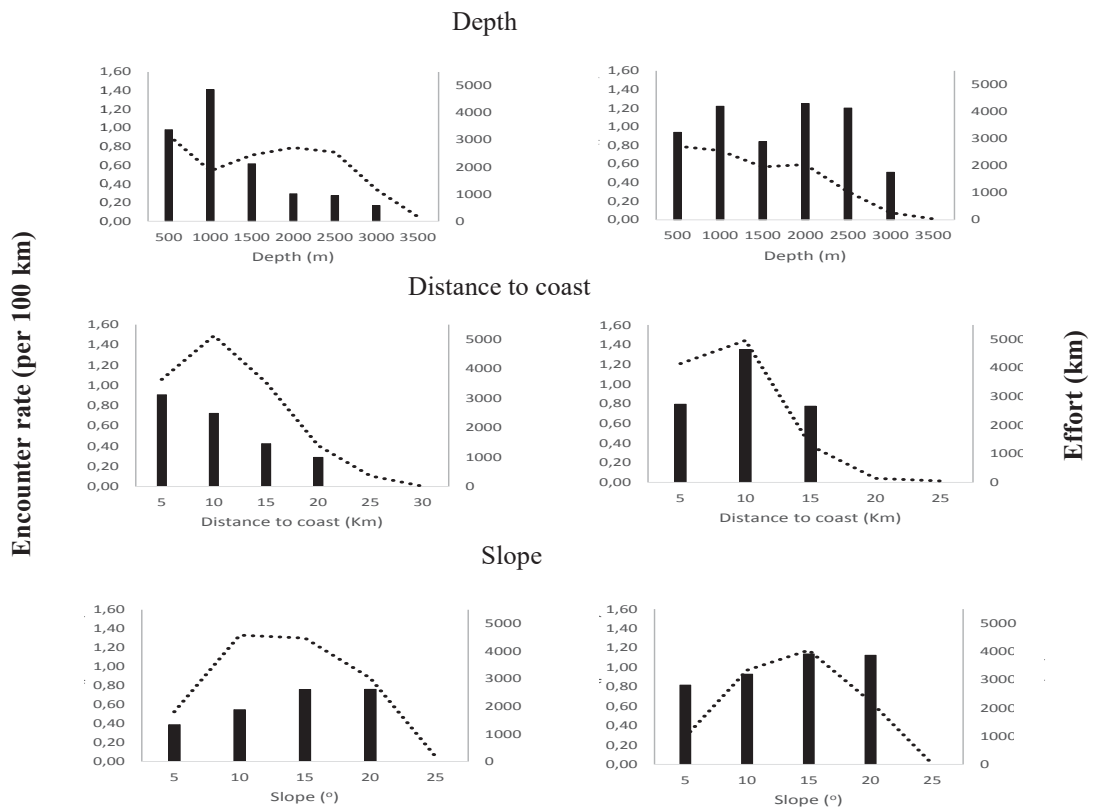


Fig. 4. Distribution of encounter rate (bars) and search effort (•) in relation to depth, distance to coast and slope, per type of survey: left- systematic surveys; right - non-systematic.

The northeast of Madeira presented the cell with the highest encounter rate (ER=13.5; effort=7km) in non-systematic surveys, followed by a grid cell in the north of Porto Santo during systematic surveys (ER=7.5; effort=13km). The encounter rate distribution in relation to physiographic covariates revealed different values for systematic and non-systematic surveys for all variables, except for slope where the tendency was similar (Figure 4). Higher encounter rates occurred over bathymetries ranging between 500 and 1,000m during systematic surveys whereas in non-systematic surveys high encounter rates were also found in depths of 2,000 and 2,500m. Encounter rates decreased with distance from the coast in

systematic surveys while in non-systematic surveys the 5-10 km class showed the highest value. Lastly, encounter rate in relation to slope ranged between 5 and 20° with the highest values appearing in 5-10° and 10-15° slopes, for both types of surveys

TEMPORAL DISTRIBUTION

Effort was distributed throughout the year in both types of surveys. In systematic surveys April was the most surveyed month, and August was the month with less effort. In non-systematic surveys effort was more concentrated in spring and summer (May to September), and there was less effort in December (Figure 5).

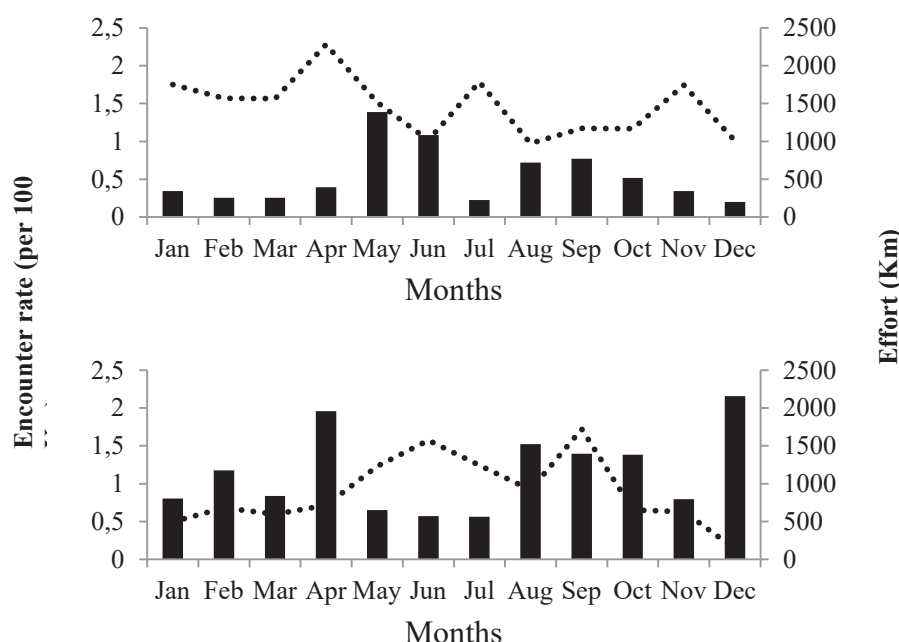


Fig. 5. Monthly distribution of encounter rate (bars) and search effort (•) per type of survey. Top: systematic surveys; Bottom: non-systematic surveys.

In systematic surveys, encounter rate was higher in spring (May-June) and, in non-systematic surveys April and December were the months with highest values. Late summer (August-October) presented high values for both types of surveys. Despite the heterogeneous results in encounter rate by months, the Kruskal-Wallis test showed no significant differences in encounter rate

between months for neither systematic ($p=0.443$) nor non-systematic surveys ($p=0.172$).

DISCUSSION

Using a combination of long-term (11 years) data collected during dedicated surveys (systematic and non-systematic) this study provides the first

baseline information about the spatial and temporal occurrence of bottlenose dolphins in Madeira archipelago. The systematic surveys were designed as part of a wider project using Distance 5.0 (Thomas et al. 2010). Transects from systematic surveys were designed in such a way that every point in the study area had the same probability of being sampled. The probability of detecting cetaceans is known to decline as a function of distance from the observation platform, and so perpendicular distance is used to fit a detection function which is then used to adjust the estimated encounter rate (Hammond 2010). In this study those distances were not considered, so encounter rate was not adjusted making it impossible to infer about the overall density of dolphins in the area. Factors influencing detectability were also likely to differ between types of survey, thus affecting the comparison of encounter rates across seasons or geographic area (Silva et al. 2014). By analysing data from each survey separately and restricting effort to Beaufort Sea State ≤ 3 bias introduced by the factors mentioned above was reduced within and between surveys. Although sighted in every sector of the study area, bottlenose dolphins showed an overall higher encounter rate to the east of Madeira, particularly in the northeast and around Porto Santo (with the exception of one grid cell in Madeira West). When analysing probabilities of bottlenose dolphins moving within and between different sectors of the study area based on photo-identification, Dinis (2014) found dolphins had higher probabilities of remaining in the same sectors mentioned above (east of Madeira and all around Porto Santo), supporting the hypothesis that they are important for the studied population. Despite this apparent heterogeneous distribution the bottlenose dolphin is one of the most frequently sighted species of cetaceans on board whale-watching trips (Ferreira 2007) that operate mainly in the south of Madeira. This area, especially in the southeast should be carefully monitored as it is one of the areas where dolphins can be more exposed to the whale-watching activity.

The distribution of dolphins related with some physiographic variables provided some important information. The majority of dolphins was found

in depths $< 1,000\text{m}$ (for systematic surveys) and at no more than 10 km offshore (for both surveys) indicating a preference for shallower waters. In Madeira archipelago, the absence of a broad continental shelf, limits this kind of physiography to areas closer to the coast and to the channel between Madeira and the Desertas. This explains why the majority of sightings were closer to shore, despite the larger spatial coverage provided by the surveys. These findings are in accordance with what Silva et al. (2014) found in the neighbouring archipelago of Azores, and also with Baird et al. (2003; 2009) in the Hawaiian islands where bottlenose dolphins were typically found in depths of $< 700\text{m}$. Nevertheless, there were sightings over deep bathymetries (2,000-3,000m) corresponding to associations with short-finned pilot whale, *Globicephala macrorhynchus* Gray 1846. Alves (2013) reported that one third of the sightings of short-finned pilot whales in the study area were in association with bottlenose dolphins, and these whales were distributed mainly over bathymetries of 2,000 to 2,500m. This suggests prey availability may play an important role in dolphin distribution (Fortuna 2006). While bottlenose dolphins inhabiting inshore and coastal waters feed mainly on benthic and demersal fish species (Barros & Odell 1990; Cockcroft & Ross 1990), dolphins occurring in offshore waters forage on a wide variety of prey relying mainly on epipelagic and mesopelagic schooling fish and cephalopods (González et al. 1994; Mead & Potter 1995; Barros et al. 2000). The dolphins occurring in offshore waters seem to exhibit both strategies. Silva (2007), referring to the neighbouring archipelago of the Azores, indicated that the preference of the dolphins for shallower areas (between 100 and 600 m) in these oceanic environments is likely due to the fact that those areas provide a more suitable habitat, where dolphins can prey on demersal fish species in addition to schooling pelagic prey on open waters. Bottlenose dolphins commonly associate with environmental features known to increase biological productivity and/or promote prey aggregation (Baumgartner et al. 2001; Cañadas et al. 2002), however a full understanding of the oceanographic processes influencing the Madeiran waters is still missing (Caldeira &

Sangrà 2012). As mentioned before there is no information on the distribution of potential prey species of bottlenose dolphins in the study area, and habitat preferences of bottlenose dolphins in relation to oceanographic variables as well as other explanatory physiographic variables, that are known to influence biological productivity (and consequently prey distribution), should be further investigated.

No significant difference was found for any of the surveys in monthly encounter rate, suggesting bottlenose dolphins use the research area similarly year-round. Dinis (2014) found larger groups observed in the summer and autumn, mainly due to the presence of transient pelagic bottlenose dolphins, although there were no significant differences in group sizes across months.

Assessment of seasonality in this study seems to indicate that there is no strong seasonal fluctuation in the presence of bottlenose dolphins in Madeira archipelago waters.

CONCLUSIONS

In this study, bottlenose dolphins were regularly found in shallow areas closer to shore, suggesting the existence of biological processes influenced by bathymetry, as proposed by Silva (2007) with reference to the archipelago of the Azores. These results suggest the existence of preferred areas of habitat for this species based on static bathymetric features. This should not be interpreted as an isolated influence, as cetacean distribution is known to be affected also by hydrographic processes not dependent on local bathymetry. The preferred areas found in this study should be further investigated while monitoring the anthropogenic activities here is crucial to protect the population of bottlenose dolphins occurring in Madeira. The exposure of the near shore areas to anthropogenic activities like marine traffic or whale-watching and the presence of dolphins in these areas, should be taken into account when discussing bottlenose dolphin conservation measures in Madeira archipelago, or when discussing future MPAs for this species in this archipelago.

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