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**The Spatial Distribution of the Common dolphin, *Delphinus delphis*,  
along the Portuguese Mainland Coast and their Interaction with the  
Purse Seine Fishery**

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This thesis is submitted by Sarah Brouder to the Università di Bologna, Italy in partial fulfilment of the requirements for the Erasmus Mundus Master's in Water and Coastal Management (WACOMA), in conjunction with the Universidade do Algarve, Portugal and the Universidad de Cádiz, Spain.

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CONFIRM THAT:

This Masters dissertation titled “The spatial distribution of the common dolphin, *Delphinus delphis*, along the Portuguese mainland coast and their interaction with the purse seine fishery” prepared by Sarah Brouder summarizes her Masters thesis and considering that it meets all legal requirements, authorize its presentation and defence to qualify for the degree of MSc. in Water and Coastal Management.

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## Index of Abbreviations

AIS	Automatic Information System
CODA	Cetacean Offshore Distribution and Abundance
DGPM	Direção-Geral de Política do Mar
DSM	Density Surface Models
ESAS	European Seabird at Sea
EU	European Union
ICES	International Council for the Exploration of the Sea
IPMA	O Instituto Português do Mar e da Atmosfera
IUCN	The International Union for Conservation of Nature
MSFD	Marine Strategy Framework Directive
MPA	Marine Protected Area
MSP	Marine Spatial Planning
PPSF	Portuguese Purse Seine Fishery
PSF	Purse Seine Fishery
SCANS	Small Cetaceans in European Atlantic Waters and the North Sea
SDM	Species Distribution Maps
SPEA	Sociedade Portuguesa para o Estudo das Aves

## Abstract

The common dolphin, *Delphinus delphis*, is the most abundant cetacean species along the Portuguese mainland coast and are faced with many anthropogenic threats. Over the past decade, intense fishing practices have contributed to a decline in the availability of their main prey, the sardine. Furthermore, the high Purse Seine Fishing (PSF) activity has raised concern over the level of by-catch along the coast.

The purpose of the study is to (i) investigate the distribution of the common dolphin along the Portuguese mainland coast, and (ii) to estimate the overlap between the PSF effort and the common dolphin's distribution. The study uses sighting data from 2005-2020 to identify dolphin hotspot areas. In addition, the study analyses changes in their offshore distribution across different time periods. Finally, the study overlaps Automatic Information System data of the PSF with common dolphin distribution data, in order to identify high by-catch risk areas.

The outputs of the study identify major common dolphin hotspots along the central and southern Portuguese mainland coast, which coincide with important fishing ports and geographic features. Furthermore, the common dolphin was found to occur significantly further from the coast during from 2013-2016 ( $p$ -value  $< 0.05$ ), which corresponds with a period of particularly low sardine biomass. Finally, the by-catch risk assessment reported high risk areas off the western Algarve, particularly near important fishing grounds.

The study highlights the major common dolphin hotspots and potential conflict areas with the PSF. These results can be used by managers to inform conservation measures and for the sustainable management of PSF fleet along the Portuguese mainland coast.

**Keywords:** Common dolphin; By-catch risk assessment; Distribution maps; Purse seine fishery; Sardine.

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# 1. Introduction

Marine conservation efforts are often based upon the knowledge of where species are distributed in space and time. This knowledge can provide key information about priority seasons and areas for protection, therefore informing cetacean conservation management plans. In marine and coastal management, the use of Species Distribution Maps (SDM) can be used to inform Marine Spatial Planning (MSP) initiatives, by providing insight into potential areas of conflict between different users of the maritime space. For instance, cetacean SDM can be used to assess where a species' habitat overlaps with anthropogenic activities, such as fisheries (Jog *et al.*, 2022), marine traffic ways (Pennino *et al.*, 2017), physical and acoustic disturbance (Erbe *et al.*, 2019), seismic activities (Kavanagh *et al.*, 2019), touristic operators (Parsons, 2012), and offshore development (Bailey *et al.*, 2010; Nichols *et al.*, 2020; Sahri *et al.* 2021). Understanding how anthropogenic activities overlap and interact with marine mammals' distribution is fundamental for decision making regarding the allocation of no-take zones in important migratory routes or breeding and foraging sites (Wade *et al.*, 2021). Furthermore, SDM can be used to understand temporal changes in habitat preference. For instance, it is possible to identify whether there is a seasonal shift in the distribution of cetaceans, thereby guiding the implementation of restrictions on human activity during certain times of the year

Cetaceans are important umbrella species and therefore they have strong effects on ecosystem structure, dynamics, and functions (Kiszka *et al.*, 2022). However, these top predators are often impacted by human activity such as whaling, ship strikes, marine contamination, and habitat degradation (Nichols *et al.*, 2020). Moreover, they are particularly vulnerable to human activity because of their large size, low reproductive potential, and occurrence in areas with strong human activity (Lettrich *et al.*, 2019). Cetacean conservation is a top priority for marine management plans because their protection can have positive effects on the overall ecosystem health (Zacharias and Roff, 2001). A number of international frameworks have been established to address the conservation of cetaceans and their habitats (e.g., the Convention on the Conservation

of Migratory Species of Wild Animals; the International Convention for the Regulation of Whaling) (Ripol and Zupan, 2021). Within Europe, the European Union (EU) Habitat Directive (1992/43/EC) strictly protects and sets out to bring back Favourable Conservation Status for all cetacean species in EU Waters. Furthermore, Member States are required to implement a monitoring system for the incidental by-catch and killing of cetaceans (Ripol and Zupan, 2021). In addition, the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) requires the assessment of the population status of cetaceans in EU waters, through the use of indicators such as abundance and distribution estimates and to report on Good Environmental Status. The Common Fisheries Policy (EU no. 1380/2013) was also established for the conservation and sustainable exploitation of fishery resources and requires strict protection for marine mammals and the implementation of mitigation measures to reduce bycatch.

Accurate abundance and distribution estimates are needed to address the requirements of the MSFD and EU Habitats' Directive (Hammond *et al.*, 2017). To date, there has been a number of studies which provide abundance and distribution estimates within the northeast Atlantic waters. In 1994, the European Commission launched the first large scale aerial survey, SCANS (*Small Cetaceans in European Atlantic waters and the North Sea*), which has since been repeated in 2005 and 2016 (Hammond *et al.*, 2017). From the third SCANS survey, there was an estimated abundance of 473,000 common dolphins in the North-East Atlantic (Hammond *et al.*, 2017). Abundance estimates for the common dolphin were also obtained from the CODA (Cetacean Offshore Distribution and Abundance) ship-based surveys. From this survey, there was an estimated abundance of 116,709 (CV=0.34) common dolphins (Hammond *et al.*, 2009). For the Portuguese coast, the LIFE+ MarPro project estimated an increase in the abundance of the common dolphin from 17,067 to 52,632 individuals from 2010 to 2015 (Vingada and Eira, 2018). Other smaller studies have been conducted to provide abundance and distribution estimates for cetaceans. For instance, Waggitt *et al.*, (2019) provided a large compilation of distribution maps for cetaceans and seabirds in order to inform by-catch risk assessments along the northeast Atlantic. The purpose of these studies was to identify risk areas between marine animals and anthropogenic activity, thereby adding knowledge to future marine conservation and management actions.

The common dolphin, *Delphinus delphis*, is one of the most abundant cetacean species in the North-East Atlantic and is considered to have an “Unfavourable-Inadequate” conservation status for EU waters (Murphy *et al.* 2019). However, for its global distribution, *D. delphis*, has most recently been assessed for The IUCN Red List of Threatened Species in 2020 and was listed as Least Concern (Braulik *et al.*, 2021). They are widely distributed and occur in waters from Scotland to southern Portugal, between 35°N and 55°N and are most commonly sighted in offshore waters deeper than 180 m and over the continental shelf (Murphy *et al.*, 2013; Reid, 2003). Studies have shown that they specialize on high energy small pelagic fish, in order to satisfy their energetically expensive lifestyle (Silva 1999; Spitz *et al.*, 2010; Marçalo *et al.*, 2018). In the North-East Atlantic, seasonal shifts in the dolphin’s distribution have been reported, with dolphins occupying more northerly distributions during the summer months in response to changes the availability of their primary prey, the sardine *Sardina pilchardus* (Culik *et al.*, 2011; Silva *et al.*, 2014).

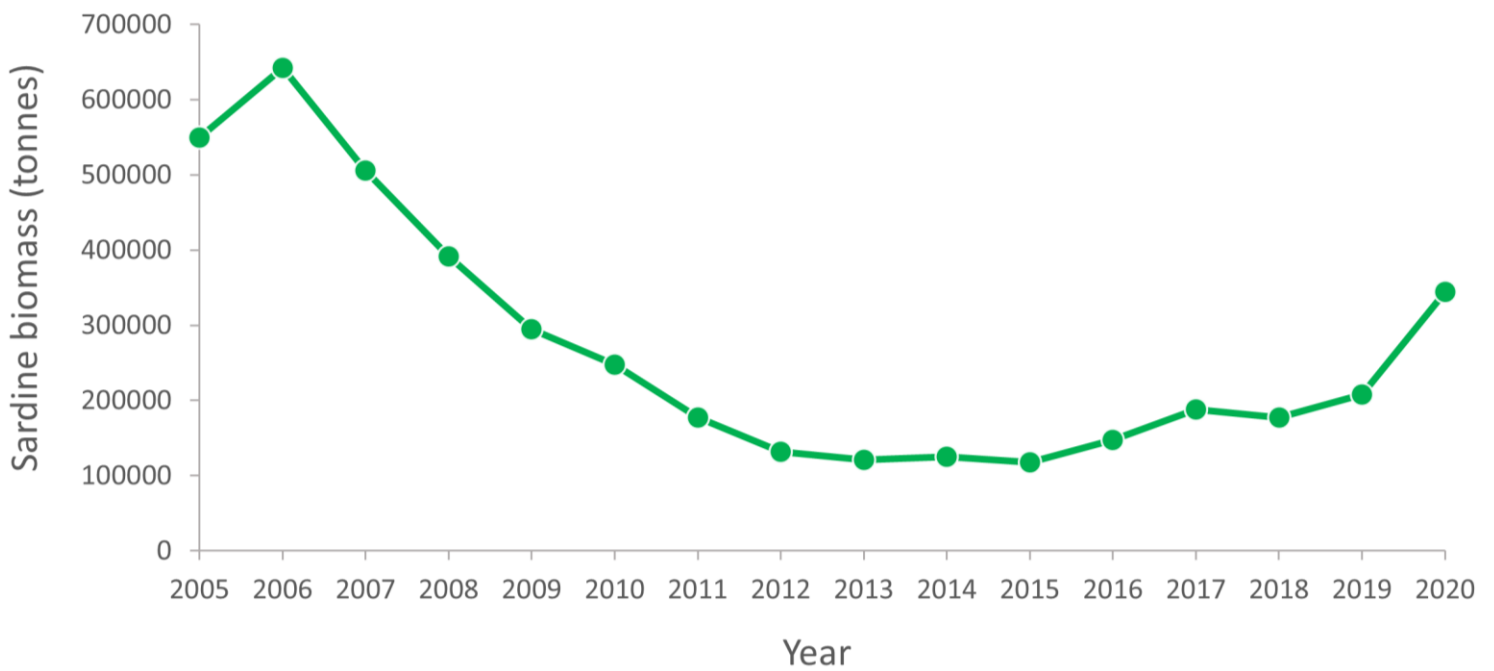
The common dolphin is often negatively impacted by fishing activities through fishing entanglement, habitat degradation and reduced prey availability (Kirkwood *et al.*, 1997; Bearzi *et al.*, 2004, Bearzi *et al.*, 2008; Marçalo *et al.*, 2021). Within the northeast Atlantic, there has been an unsustainable level of by-catch, with thousands of common dolphins caught each year (Mannocci *et al.*, 2012; Peltier *et al.*, 2014; Peltier *et al.*, 2016). In particular, the Portuguese mainland coast represents an area of high concern because of the strong fishing activity and high abundance of common dolphin, particularly along the continental shelves and submarine canyons (Brito *et al.*, 2009; Vingada and Eira, 2018). In fact, studies have shown that the common dolphin is the most frequently stranded species along the Portuguese mainland coast and have the highest number of recorded mortalities associated with fisheries (Silva and Sequeira, 2003; Vingada and Eira, 2018; ICES, 2019).

The most important fishery along the Portuguese mainland coast is the Portuguese Purse Seine Fishery (PPSF), which contributes to approximately 50% of the total fish catch landings (Silva *et al.* 2015; Feijó *et al.* 2018; DGRM, 2019). The fishery consists of 192 vessels, most which exclusively target the sardine *Sardina pilchardus* (INE, 2020). In

total, the PPSF is responsible for 98% of the total sardine national landing (Monteiro, 2017). Indeed, there has been shown to be a strong interaction between the common dolphin and PPSF activities along the Portuguese mainland coast (Wise *et al.*, 2007, 2018; Marçalo *et al.* 2015; Dias *et al.*, 2022). In fact, the common dolphin was found to be the most frequently sighted cetacean species within the operational zone of the PSFF (Wise *et al.* 2007, Marçalo *et al.* 2015, Dias *et al.*, 2022). This strong common dolphin-PPSF association is due to the fact that they both target the sardine, the common dolphin's favourite prey and the target of the fishery (Silva 1999; Marçalo *et al.*, 2018), mainly from late spring to early Autumn (Silva *et al.*, 2015; Feijó *et al.*, 2018). The strong resource overlap has raised concern, most notably the risk of by-catch, which has been responsible for a significant amount of common dolphin mortality (Silva and Sequeira, 2003; Marçalo *et al.* 2015; Dias *et al.* 2022).

As well as the risk of by-catch, there are other threats associated with the interaction between the PPSF and the common dolphin, such as declines in prey availability. Along the Portuguese mainland coast, there have been significant reductions in sardine stock levels as a result of overfishing and environmental changes (Malta *et al.*, 2016; Rodríguez *et al.*, 2017; Szalaj *et al.*, 2021). Since 1986, there had been a continuing decline in Iberian sardine stocks, mainly caused by a lack of recruitment, while the resource continued to be exploited due to the high market and cultural demand (Silva *et al.*, 2015). Based on a stock assessment from the International Council for the Exploration of the Sea, there was a pronounced breakdown in sardine recruitment in 2005 (ICES, 2017). Furthermore, in 2016 the sardine biomass and recruitment reached its lowest recorded level in 40 years (ICES, 2017; Figure 1.1). In response to the significant decline in sardine stock biomass, a multi-annual management plan was introduced in 2012 known as the "*Sardine Fishery Management Plan (2012-2015)*" (henceforth "Sardine Ban"). The Sardine Ban put forward limitations on the annual catch, sardine catch prohibition periods, limits on the catches of juveniles, and regulated technical measures to reduce by-catch in PSFF (Monteiro, 2017; Silva *et al.* 2018). As part of the Management plan, there was also a fishery closure introduced during the sardine spawning in winter and spring, and annual catch limits were reduced from 55,000 tonnes in 2010 to less than 15,500 tonnes in 2014 (Feijó *et al.*, 2018; ICES, 2021a). The Sardine Ban has resulted in a noticeable

recovery in sardine stocks, with there being a 30% increase in biomass from 2015 to 2016 alone (ICES, 2020). However, despite some increase in sardine biomass, in 2017 stock numbers were still below the Biological Limits (Blim) as defined by ICES and a long way from economic and ecological stability (ICES, 2020).



**Figure 1.1:** Sardine biomass (thousands of tonnes) from 2005-2020 in Portuguese waters (ICES, 2021b).

## 2. Scope of Study

The purpose of the study is to map the distribution of the common dolphin along the Portuguese mainland coast in order (1) improve our knowledge about the spatial distribution of this charismatic species and (2) contribute to a better understanding of the potential impact of the purse seine fisheries on their habitat use. Currently, there is a lack of long-term distribution estimates of the common dolphin along the Portuguese mainland coast, which is particularly concerning when considering the high common dolphin abundance and fishing activity in this area. Without adequate knowledge of the distribution of cetaceans along the Portuguese coast, it is difficult to implement effective management strategies for their protection.

Furthermore, the study intends to understand how changes in prey availability has influenced the habitat use of the common dolphin. The research aims to understand whether the implementation of the Sardine Ban of 2012 corresponds to changes in the common dolphins' distribution, which may signify a response to changes in sardine stock levels. Despite the recovery in sardine stock numbers since the "Sardine Ban" (Silva et al. 2018; ICES 2020), there is little knowledge about the overall effects on the distribution of the common dolphin. Marçalo *et al.*, (2018) showed that there were slight changes in the common dolphin's diet, with some fish species occupying a greater proportion of their diet than they previously did (Silva, 1999). Although sardine was still the primary prey and seems to be able to satisfy the dolphin's energetic demands, even after declines in stock numbers, it is not known if there were changes in their feeding locations or behaviours (Marçalo *et al.* 2018). It is possible that the dolphins have shown responsive movements in order to compensate for the decline in food sources in their usual habitats. The study uses heatmaps and grid maps to identify the distribution of the common dolphin over different time periods. These distribution maps are to be used as a tool for better understanding the true potential impact of changes in prey availability and the PPSF activity on the dolphins' habitat use.

Finally, the study addresses the urgent need for a by-catch risk assessment along the Portuguese mainland coast, by providing a case study for the southern Portuguese

mainland coast (Algarve), where there is significant purse seining activity. This information will contribute to by-catch risk assessments by identifying high risk areas for the dolphins. Ultimately, the study intends to inform conservation measures for the reduction of conflict between the common dolphin and anthropogenic pressures along the Portuguese mainland coast.

## 2.1. Objectives

The following objectives are to be achieved in the thesis:

- 1) To map the spatial distribution of the common dolphin, *Delphinus delphis*, along the Portuguese mainland coast between the years 2005-2020 and to understand temporal and spatial changes that correspond to periods that delimited management and conservation strategies to recover the sardine stock biomass, namely from 2012 onwards.
- 2) To understand the potential overlap between the Portuguese Purse Seine Fishery and common dolphin along the Southern Portuguese coast (Algarve) in order to contribute to a by-catch risk assessment.

## 3. Material and Methods

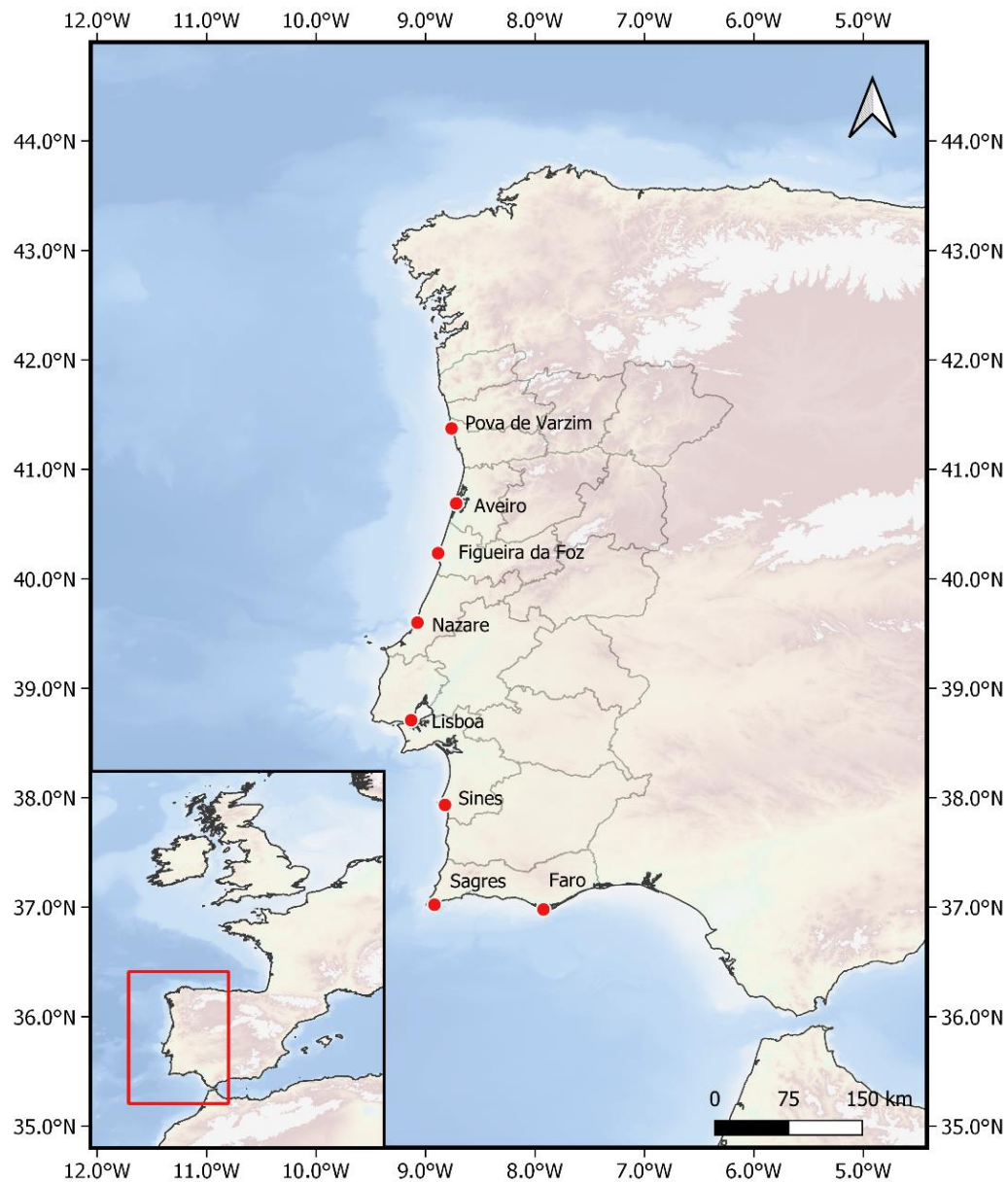
### 3.1. Study Area

#### 3.1.1. Portuguese mainland coast

Portugal is located in the western part of Europe and includes three main biogeographical areas (i.e., Azores, Madeira, and the mainland) (Figure 3.1). The coast is 1,214 km and has an Exclusive Economic Zone (EEZ) of 237,521 km<sup>2</sup>, making it one of the largest in Europe (European Commission, 2015; DGRM, 2021). The studied area lies within the ICES (the International Council for the Exploration of the Sea) division 9a, which represents the Bay of Biscay and Iberian Coast ecoregion (ICES, 2019). Furthermore, the study area covers the Portuguese mainland coast, extending 860 km from Caminha (41° 50' N, 8° 50'W) to Vila Real St. António (37° 12' N, 7°25'W).

There exist important topographic and bathymetric features along the Portuguese coast, which facilitate high biological productivity. The largest submarine valley, the Nazaré canyon, is 230 km long and extends from depths of 5000 m to the coast. To the south, there are three other important submarine canyons, the Lisboa, Setúbal and São Vicente canyon (Alves *et al.*, 2000). These canyons are responsible for the upwelling of nutrient rich water to the surface, therefore facilitating high biodiversity and productivity for sardine and dolphins. In addition, the two major estuaries, the Tejo and Sado, are important for the transport of nitrogen and phosphorous to the coastal areas. This high nutrient load from the estuarine flow is also responsible for high productivity in the area (Brito *et al.*, 2009). In addition, there is an interaction between the north-easterly trade winds and atmospheric high-pressure (Azores High), which are responsible for seasonal variations in mesoscale oceanic eddies. Furthermore, the coast represents a transition between the warmer lower latitudinal waters of the Mediterranean Sea and the cooler higher latitude waters of the north-eastern Atlantic (Álvarez-Salgado *et al.*, 2003). These oceanographic and topographic conditions offer favourable habitats for cetaceans. In total there are 28 species of cetaceans found within the Portuguese coast, which

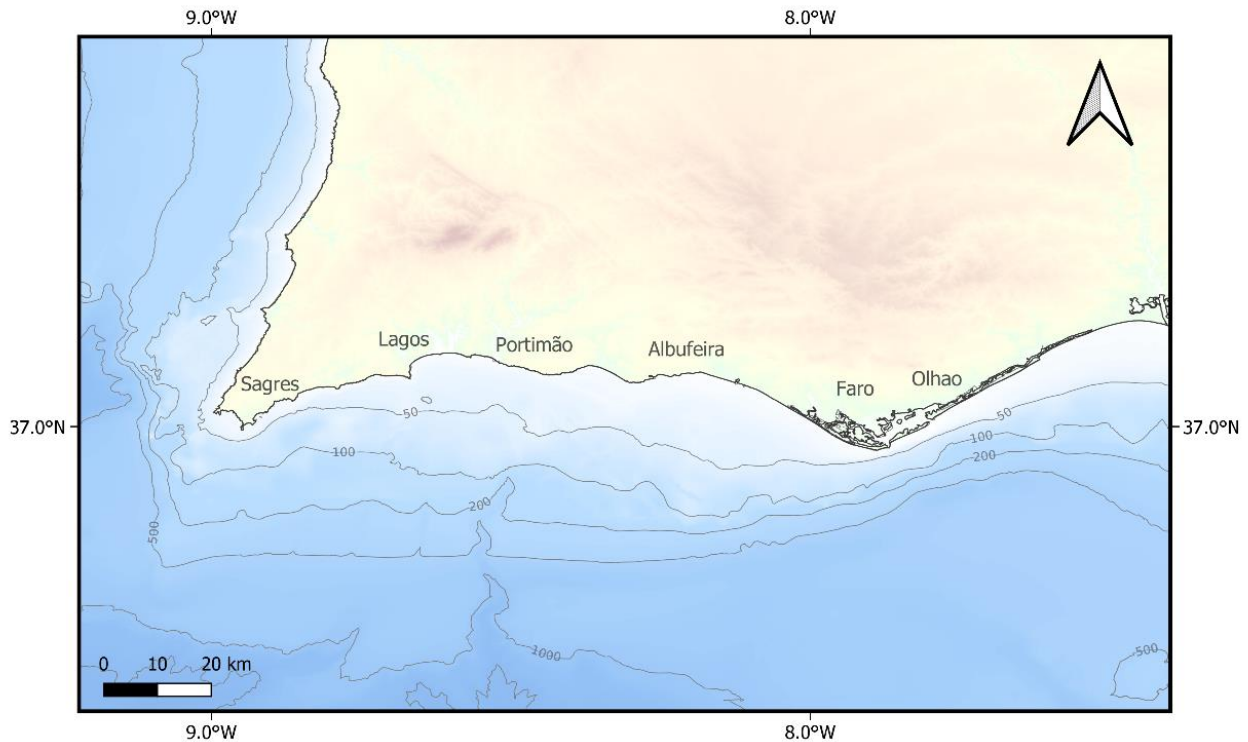
represents the highest cetacean species richness in northern Europe. The most frequently observed species are the common dolphin, *Delphinus delphis*, bottlenose dolphin, *Tursiops truncatus*, striped dolphin, *Stenella coeruleoalba*, and minke whale, *Balaenoptera acutorostrata* (Vingada and Eira, 2018).



**Figure 3.1:** Map of Portuguese mainland coast for objective one of the thesis. Map was created using QGIS (Version 3.10.0).

### 3.1.2. Southern Portuguese mainland coast

The Algarve (37° 1' 4.634" N, 7° 55' 51.002" W) is located in the south of continental Portugal (Figure 3.2). It is 5,000 km<sup>2</sup> wide and has a length of 155 km along the southern coast and 50 km along the western coast. It ranges from Cape St. Vincent in the west to the Guadiana River on the east (Alveirinho Dias, 1988). The western Algarve is known as the Barlavento (i.e., windward) and the eastern Algarve is known as Sotavento (i.e., leeward). The capital of the Barlavento is Portimão and the capital of the Sotavento is Faro. The eastern coast is occupied mainly by a sandy coast, and the Ria Formosa Barrier Island and coastal lagoon. In contrast, the western coast consists of mainly Mesozoic limestone rocky shores and cliffs (Moura *et al.*, 2006). The continental shelf off the southern Portuguese coast is a dynamic environment, influenced by the Atlantic and Mediterranean currents (Serra and Ambar, 2002). In addition, there are a number of important submarine canyons along the Algarve coast, such as the Lagos canyon, Portimão canyon, Albufeira canyon, Faro canyon and São Vincente canon. These canyons are responsible for the upwelling of nutrient rich water to the surface, thereby facilitating high biodiversity and productivity (Brito *et al.*, 2009).



**Figure 3.2:** Map of the southern Portuguese mainland coast, the Algarve, for objective two of the thesis. Lines represent depth contours (m). Map was created using QGIS (Version 3.10.0).

### 3.2. Data Collection

Cetacean sighting data was obtained from the Portuguese Institute for the Sea and the Atmosphere (IPMA) as part of the PELAGO acoustic surveys. This data was collected from systematic vessel surveys from 2005 to 2020. It is important, however, to note that the data includes some gaps due to the lack of the 2012 survey, or the surveys not occurring during the summer months (i.e., July and August). The survey data was collected by two trained observers from the Portuguese Society for the Study of Birds (SPEA) using the European Seabird at Sea Methodology (ESAS). This methodology involves a strip transect operated on one side of the vessel, where data collected was divided into distance bands and time increments of five minutes. A more detailed description of the sampling methodology can be found in Tasker *et al.* (1984). Environmental data such as Beaufort Sea state and visibility were also recorded.

### 3.3. Objective one: Spatial Distribution

#### 3.3.1. Encounter rate

The encounter rate was obtained in order to standardise the number of common dolphin sightings against the sampling effort.

The sampling effort was obtained by calculating the total distance travelled (km) for each sampling unit. Sampling units were recorded during data collection and are represented by all sightings occurring within a 5-minute interval. Duplicated sampling units were present in cases where more than one sighting was recorded within a sampling unit. The duplicated sampling units were removed from the dataset in order to avoid overestimating the sampling effort. Furthermore, sightings outside the predesignated transect were removed.

Subsequently, the total number of sightings of each cetacean species was found for each sampling unit.

The total encounter rate for each species was obtained by dividing the total number of individuals per species,  $x$ , over the total sampling effort:

$$\text{Total Encounter Rate} = \frac{\text{Total \# of sightings for species } x}{\text{Total Sampling effort}} \quad \text{Equation 3.1.}$$

Next, temporal trends in the encounter rate of the common dolphin were investigated. This involved calculating the total encounter rate for each year and each month. Bar charts were created using Excel (Version 2205) (Microsoft Corporation, 2018) to visualise differences in the encounter rate across the different months and years.

### 3.3.2. Heatmap

In order to visualise hotspots for common dolphin occurrence, a density raster (i.e., Heatmap) was created using the Kernel Density Estimation tool on QGIS (Version 3.10.0) (QGIS Development Team, 2019).

Kernel Density estimation is a non-parametric method to estimate the probability distribution,  $f(x)$ , of a random variable,  $X$ . The Kernel function used was based on the quartic kernel function (as described by Silverman, 1986, pp. 76, equation 4.5), which follows the function (Equation 3.2):

$$\text{Quartic density function: } P(x) = \frac{15}{16}(1 - d^2)^2 \quad \text{Equation 3.2.}$$

The heatmaps were created using common dolphin sightings from all years (i.e., 2005 – 2020). The heatmap was weighed by the common dolphin encounter rate at each sampling unit and adjusted to a radius of 15 km and pixel size of 0.500. Base maps were obtained from <https://www.emodnet-bathymetry.eu/>.

### 3.3.3. Grid maps

Grid maps were used to compare the common dolphin encounter rate between different years and seasons. Grid maps were used instead of heatmaps for the comparison between years and seasons so that the different periods could be analysed on the same scale. The common dolphin encounter rate was quantified in a 10 km<sup>2</sup> orthogonal grid using QGIS, by summing the encounter rate for each sampling unit within each cell.

Grid maps were created using the encounter rate for the following time periods:

- (a) Before and after the Sardine Ban (i.e., 2005 – 2011, 2013 – 2020)
- (b) Every four years (i.e., 2005 – 2008; 2009 – 2012; 2013 – 2016; 2017 – 2020)

Grid maps were also created at a seasonal scale for:

- (c) Seasonal (i.e., “Winter” Cold water season (November – April) vs “Summer” Warm water season (May – October))
- (d) Before and after the Sardine Ban for each season
- (e) Every 4 years for each season.

**Note:** “Winter” represents the season when there is a closure to the fisheries (DGRM, 2018). This was found in order to understand whether there were changes in the distribution of the common dolphin during high fishing seasons vs low fishing seasons.

### 3.3.4. Distance to coast

Changes in the distance to coast for the common dolphin were investigated in order to understand whether the dolphins were moving further offshore during times of low prey availability.

Distance to coast values were obtained by calculating the distance (in metres) from each common dolphin sighting to a shapefile of the European coast (<https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1/gis-data/europe-coastline-shapefile>) (accessed 07/03/2021).

Subsequently, the data was split into different time periods in order to understand temporal changes in the mean distance to coast for the common dolphin. The time intervals were as followed:

- (a) every year (from 2005-2020)
- (b) every four years (2005-2008, 2009-2012, 2013-2016, 2017-2020)
- (c) before (< 2012) and after (> 2012) the sardine ban

The mean distance to coast was also compared at a seasonal level:

- (d) “Winter” Cold water season (November – April) vs “Summer” Warm water season (May – October).

The mean, standard deviation, and Coefficient of Variation (CV) of the distance to coast was obtained for each time period. The Shapiro–Wilk test was used to test for normality. The data was not normally distributed so therefore non-parametric tests were used to test for differences in the distance to coast for the different time periods.

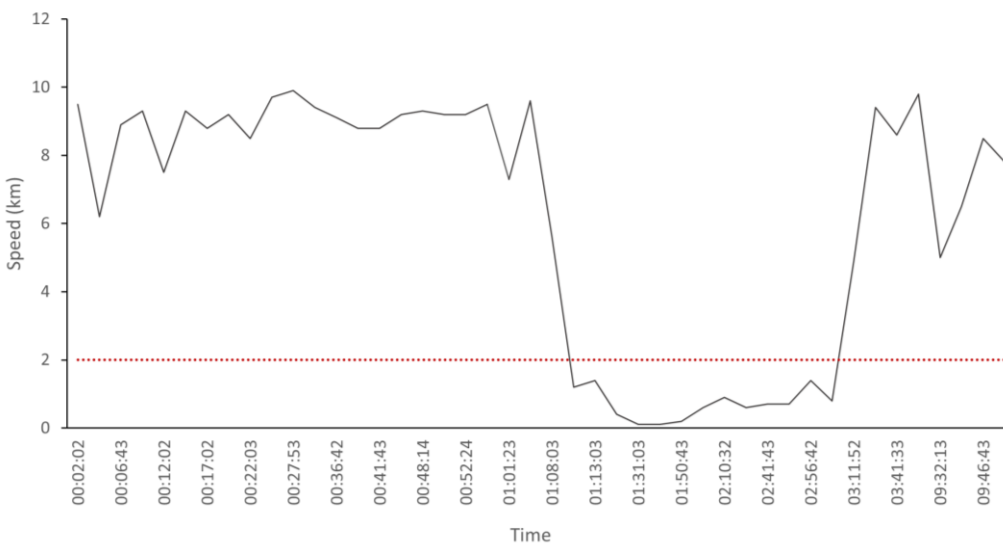
A Wilcoxon test was used to test whether there was a significant difference in the distance to coast before and after the sardine ban. A Kruskal-Wallis test was used to test for a statistical difference in the distance to coast for the different years and seasons. This

was used because more than two groups were compared. Pairwise comparisons were used to understand which time periods were statistically different. Box plots were created to visualise differences in the distance to coast between each time period. R Studio (Version 4.1.2) was used for all analyses (R Studio Team, 2019).

### 3.4. Objective two: By-catch Risk Assessment

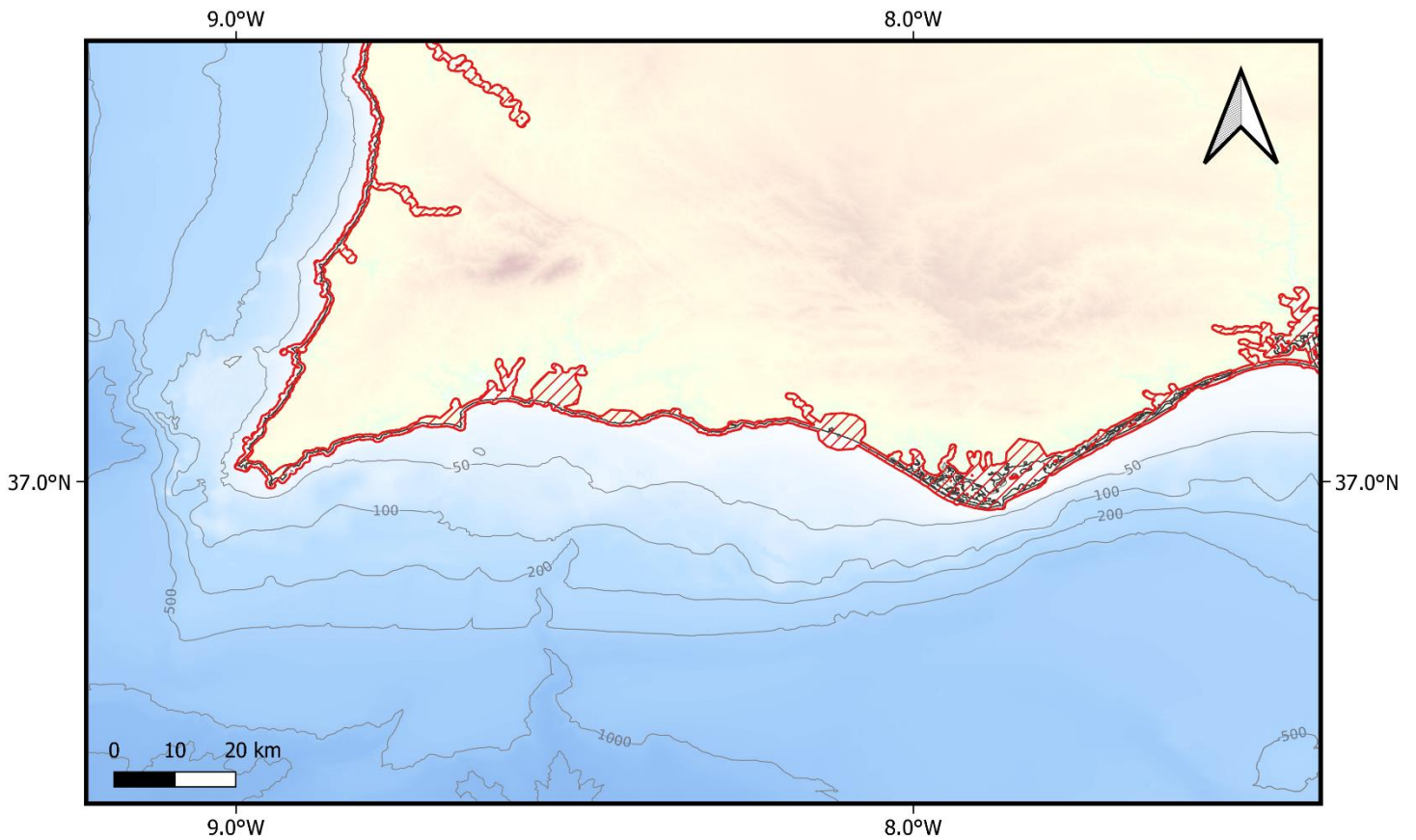
#### 3.4.1. AIS processing

An automatic Identification System (AIS) dataset of purse seine fishing effort for the southern Portuguese mainland coast (Algarve) was obtained for the years 2015 and 2020. The data was filtered to contain only the fishing events and remove points when the boat was in movement or at port. In order to do this, all points where the vessel was at a speed greater than 2 km/hr were removed, as this is the velocity where the vessel is almost stopped and performing the fishing operation. Thus, it was assumed that all speeds less than 2 km/hr represented a fishing event. Speed over ground (sog) per time was plotted in order to choose the minimum speed to define a fishing event (Figure 3.3).



**Figure 3.3:** Graph showing the speed over time for a purse seine vessel for the 28<sup>th</sup> May 2015. The figure shows that 2 km/hr (red dashed line) is a suitable speed to represent a vessel stopped for a fishing event. Graph was created using Excel (Version 2205).

Subsequently, all data points were removed within a buffer zone where purse seine fishing operations are prohibited (Figure 3.4). This buffer zone is defined as areas within a quarter of a mile from the shoreline, as well as at depths of less than 20 m between a quarter and 1 mile away from the shoreline (Diário da República, 2000). Therefore, it can be assumed that all remaining points represent fishing sets.



**Figure 3.4:** Map of the buffer zone (red dashed polygon), where purse seine fishing sets are prohibited, for the southern Portuguese mainland coast (Algarve). Map was created using QGIS (Version 3.10.0).

### 3.4.2. Overlap

A 5 x 5 km grid was created for the Algarve coast. The number of AIS points, representing a fishing event, were calculated for each cell using the “Count points in polygon” tool on QGIS, for the years 2015 and 2020 separately. The grid maps for the AIS data were classified using the Natural Breaks (Jenks) classification on QGIS. All cells within the grid map were scaled from 0-1. Cells with a value of 1 represent areas of high fishing effort and values of 0 represent areas with no fishing effort.

Similarly, the number of common dolphin sightings were pooled together for all years (i.e., 2005-2020) along the Algarve. There was not enough data to include sightings only from 2015 and 2020, as was done for the fishing effort. The “Count points in polygon” tool was used to count the number of common dolphin sightings for each cell. The grid maps for the common dolphin occurrence were classified using the Equal Interval Classification on QGIS and the cells were scaled from 0-1. Cells with a value of 1 represent areas where there was the highest number of sightings, whereas values of 0 represent areas with no sightings.

The scaled values for the fishing effort and common dolphin occurrence were multiplied at each cell to give a risk index. The risk values were re-scaled from 0 – 1. Cells with values of 1 represent the highest relative amount of overlap between the purse seine fishing effort and the dolphins’ distribution, therefore suggesting a high-risk area. Cells with a value of 0.1 represent the lowest relative amount of overlap between the purse seine effort and dolphins’ distribution, therefore suggesting a low-risk area.

## 4. Results

### 4.1. Objective one: Spatial distribution

#### 4.1.1. Encounter rate

A total of 9 cetacean species were recorded over a distance of 27386.76 km and area of 8224.34 km<sup>2</sup> between the years 2005 – 2020 (Table 4.1). The most frequently observed species was the common dolphin, *Delphinus delphis*, followed by the bottlenose dolphin, *Tursiops truncatus*, with 584 and 95 recorded sightings, respectively.

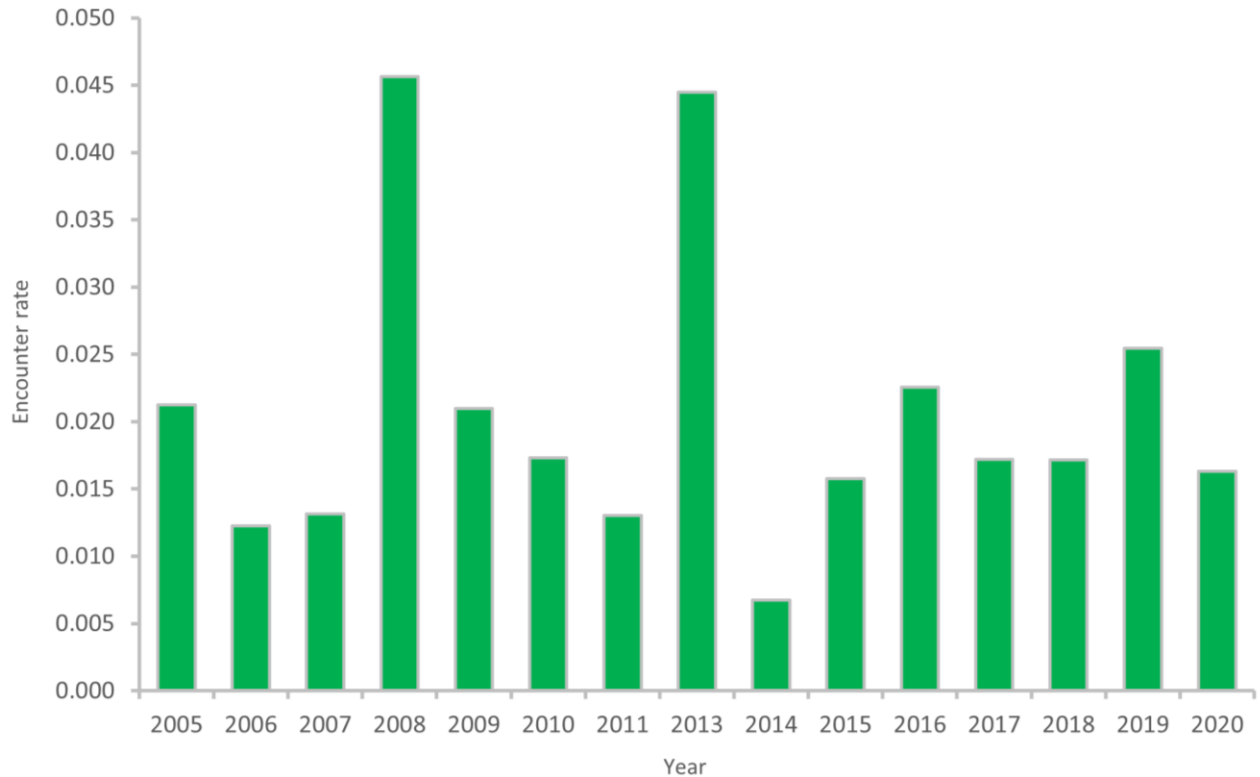
**Table 4.1:** Number of individuals and encounter rate for each species observed during the surveys (2005-2020). The encounter rates were obtained by dividing the number of sightings by the sampling effort (= 27386.76 km).

Species	Count	Encounter rate
Minke whale <i>Balaenoptera acutorostrata</i>	5	0.0002
White-beaked dolphin <i>Lagenorhynchus albirostris</i>	1	< 0.0000
False killer whale <i>Pseudorca crassidens</i>	1	< 0.0000
Long-finned pilot whale <i>Globicephala melas</i>	3	0.0001
Bottlenose dolphin <i>Tursiops truncatus</i>	95	0.0035
Striped dolphin <i>Stenella coeruleoalba</i>	9	0.0003
Common dolphin <i>Delphinus delphis</i>	584	0.0213
Risso's dolphin <i>Grampus griseus</i>	8	0.0003
Harbour porpoise <i>Phocoena phocoena</i>	3	0.0001
<b>Total</b>	<b>711</b>	<b>0.0260</b>

The encounter rates for the common dolphin per year and month are presented in Table 4.2 and 4.3. The encounter rate is highest for 2008, followed by 2013 (Table 4.2, Figure 4.1). The months February, September, and October have the highest encounter rates (Table 4.3, Figure 4.2).

**Table 4.2:** Count, sampling effort (km travelled) and encounter rate for the common dolphin for each year. The encounter rates were obtained by dividing the total common dolphin count for each year by the total sampling effort.

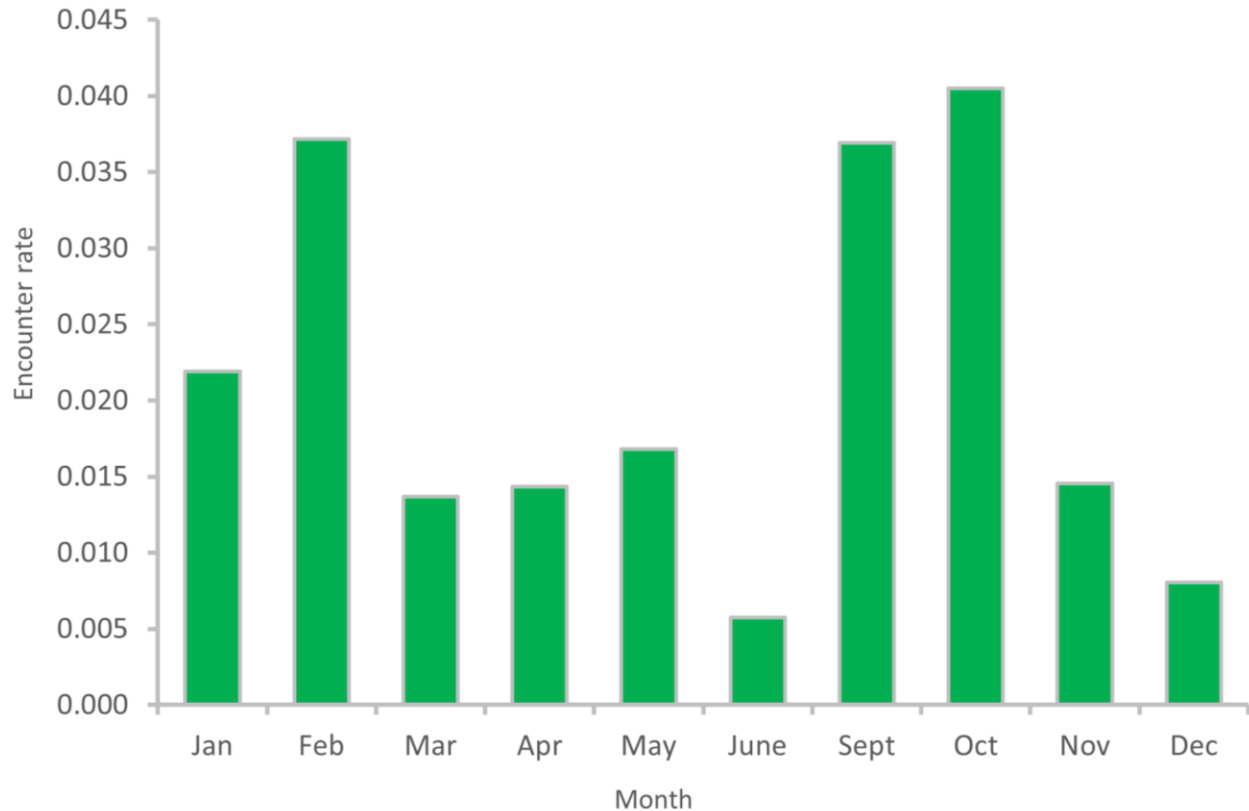
<b>Year</b>	<b>Count</b>	<b>Sampling Effort (km)</b>	<b>Encounter rate</b>
2005	55	2587.55	0.021
2006	43	3505.12	0.012
2007	38	2889.37	0.013
2008	134	2937.02	0.046
2009	28	1335.01	0.021
2010	14	808.95	0.017
2011	18	1383.31	0.013
2013	53	1191.48	0.044
2014	6	889.2	0.007
2015	9	570.66	0.016
2016	19	842.06	0.023
2017	23	1336.98	0.017
2018	22	1282.87	0.017
2019	75	2945.36	0.025
2020	47	2881.82	0.016



**Figure 4.1:** Total Encounter rate of the common dolphin per year. Bar chart was created using Excel (Version 2205).

**Table 4.3:** Count, sampling effort (km travelled) and encounter rate for the common dolphin for each month. The encounter rates were obtained by dividing the total common dolphin count for each month by the total sampling effort.

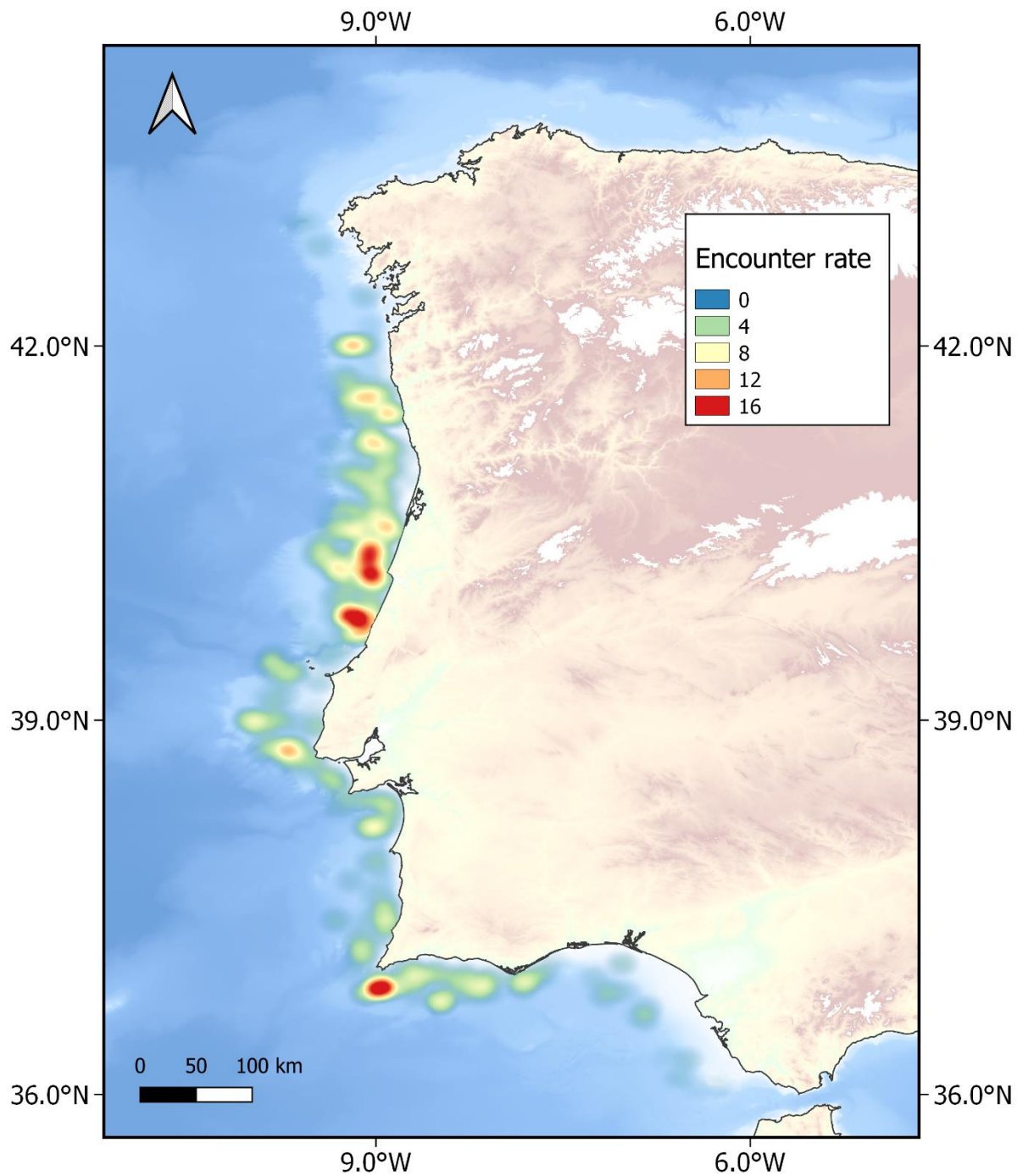
Month	Count	Sampling Effort (km)	Encounter rate
January	19	867.67	0.022
February	169	4546.93	0.037
March	42	3072.09	0.014
April	101	7036.07	0.014
May	71	4223.06	0.017
June	1	174.05	0.006
September	31	839.71	0.037
October	85	2099.26	0.040
November	64	4403.59	0.015
December	1	124.33	0.015



**Figure 4.2:** Total Encounter rate of the common dolphin per month. Bar chart was created using Excel (Version 2205).

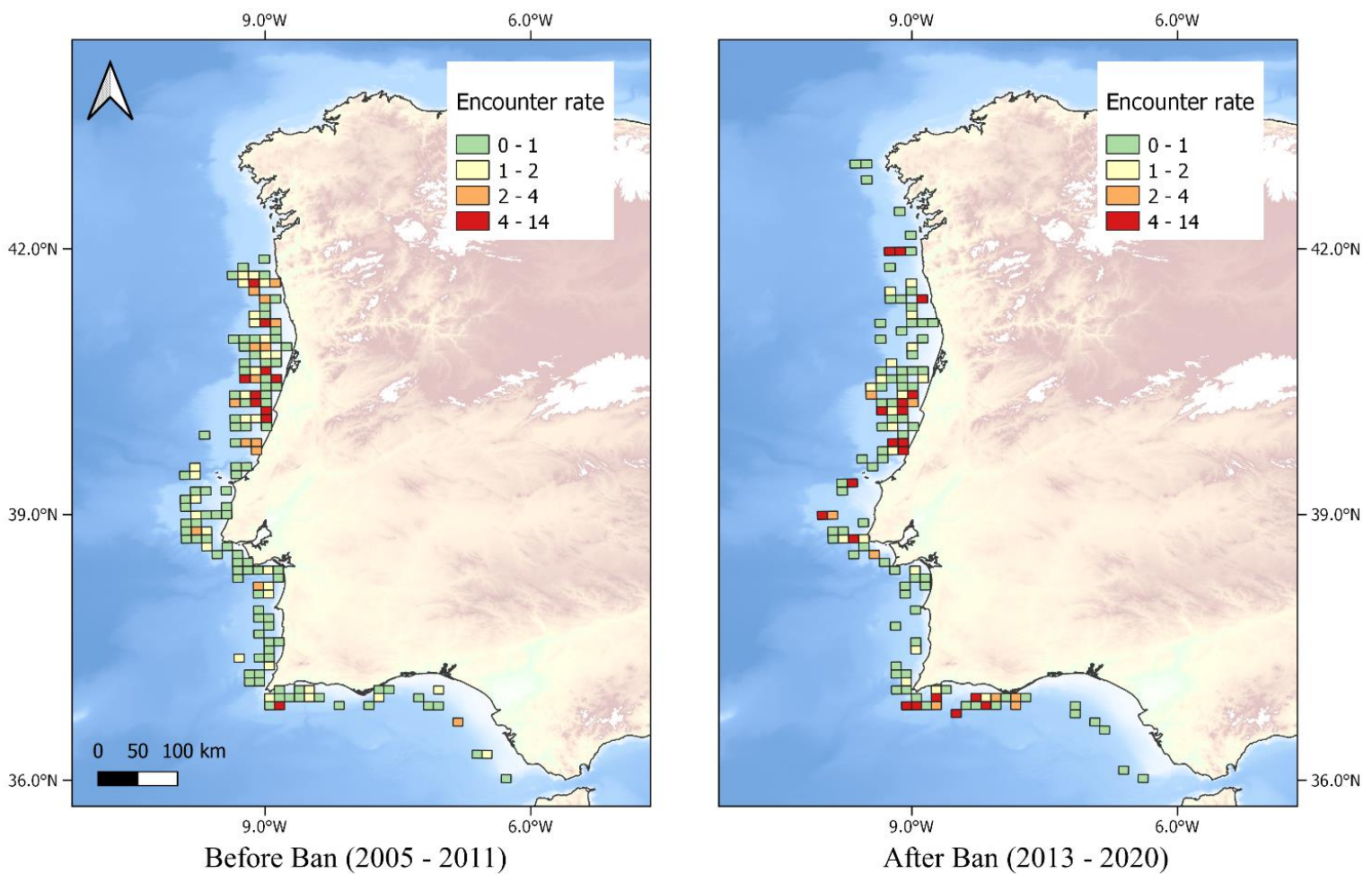
#### 4.1.2. Density and grid maps

A Kernel distribution map based on the encounter rate for the common dolphin from 2005 – 2020 is presented in Figure 4.3. The common dolphin has the highest encounter rate off the central coast of Nazaré ( $39^{\circ}38'N$ ,  $9^{\circ}07'W$ ), Figueira da Foz ( $40^{\circ}10'N$ ,  $9^{\circ}01'W$ ), and Lisboa ( $38^{\circ}41'N$ ,  $9^{\circ}43'W$ ). Off the southern Portuguese coast, there is the highest encounter rate off the coast of Sagres ( $36^{\circ}44'N$ ,  $8^{\circ}58'W$ ). There are also hotspots near Matosinhos ( $41^{\circ}08'N$ ,  $9^{\circ}00'W$ ) and Povia de Varzim ( $41^{\circ}26'N$ ,  $8^{\circ}55'W$ ) in the north. From the heatmap, it is apparent that the majority of hotspots occur off the central coast (from  $41^{\circ}N$  to  $39^{\circ}N$ ).



**Figure 4.3:** Kernel distribution map of the encounter rate for the common dolphin from 2005 – 2020. Map was created using QGIS (Version 3.10.0).

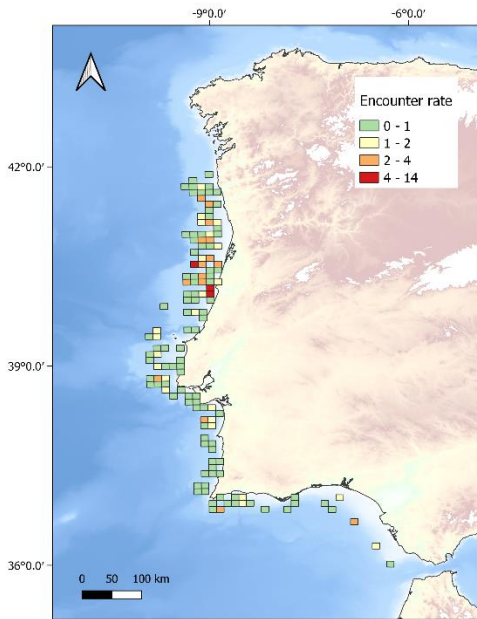
The encounter rate for the common dolphin before (2005 – 2011) and after (2013 – 2020) is compared in Figure 4.4. Before the sardine ban, the main hotspots occur off the central coast between Nazaré and Figueira da Foz (from 39°41'N, 8°57'W to 40°27'N, 8°57'W), the southern coast near Sagres (36°45'N, 8°50'W) and the northern coast near Povoia de Varzim (from 41°05'N, 8°54'W). After the ban, there is an increase in common dolphin occurrence off the coast of Lisboa (38°39'N, 9°35'W) and the western Algarve coast (from 36°46'N, 8°59'W).



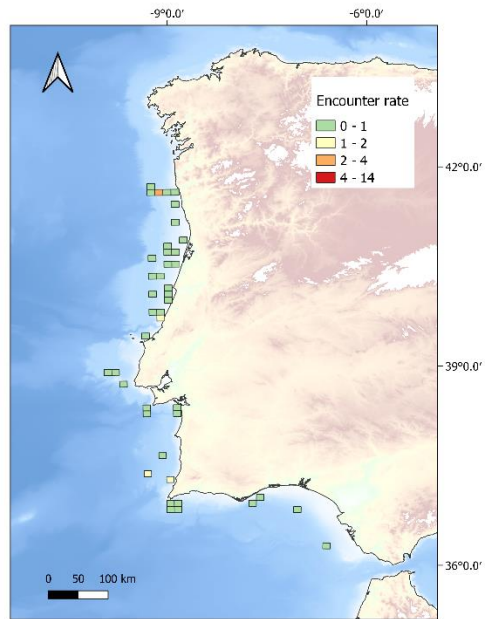
**Figure 4.4:** The encounter rate for the common dolphin before (left) and after (right) the Sardine Ban of 2012. Grid map with a cell resolution of 10 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

The encounter rate for the common dolphin was compared between the time periods 2005 – 2008, 2009 – 2011, 2013 – 2016, and 2017 – 2020 (Figure 4.5). It is evident that the periods 2005 – 2008 and 2017 – 2020 have the highest common dolphin occurrence. From 2005 – 2008, there is a high density along the central and northern coast, particularly around the regions of Coimbra and Aveiro (from 42°N to 40°N). From 2009 – 2016, there is a decline in density of the common dolphin along the mainland coast of Portugal, with most sightings occurring further from the coast. From 2017 – 2020, there is a noticeable increase in the density of the common dolphin. Hotspots are reappearing off the central coast near Nazaré (39°44'N, 9°08'W) and off the southern coast near Sagres (36°54'N, 8°50'W).

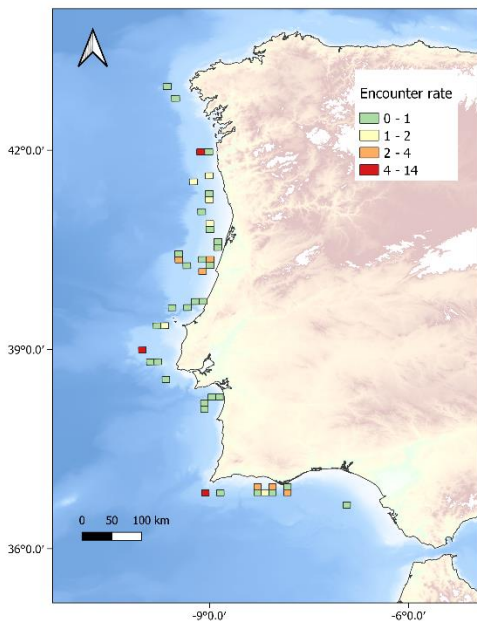
Figure 4.6 shows that during the summer months, the highest density of common dolphins occurs in Central Portugal, around Nazaré and Figueira da Foz (from 40°32'N, 9°02'W to 39°37'N, 9°03'W). There are also hotspots off the coast of Lisboa (38°35'N, 9°33'W) and in the Algarve, particularly around Sagres (36°45'N, 8°35'W). During the winter, the dolphins are concentrated in the same areas as during summer. However, there is a clear increase in the encounter rate during winter. In addition, there is an increase in the encounter rate off the northern Portuguese coast (41°40'N, 9°09'W) and in waters further offshore, particularly near Lisboa (38°47'N, 9°51'W).



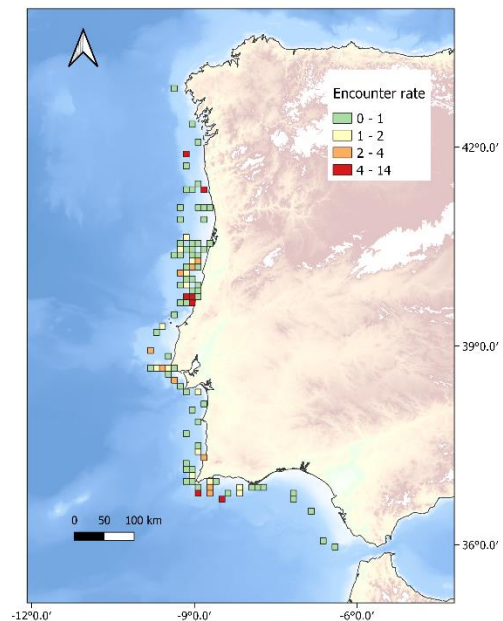
2005 - 2008



2009 - 2012

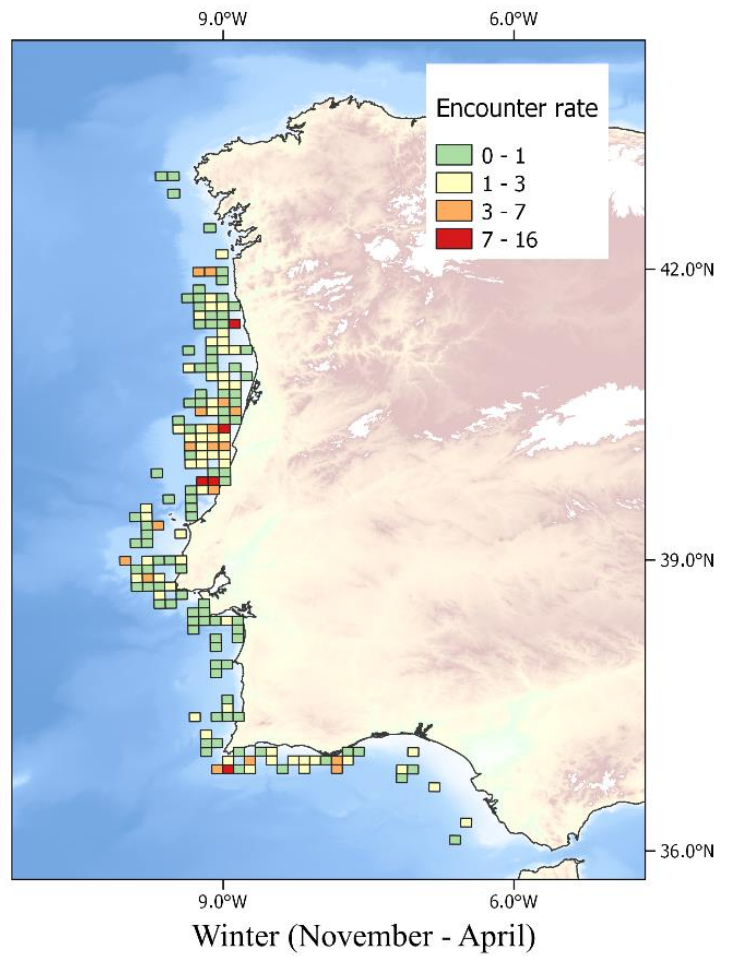
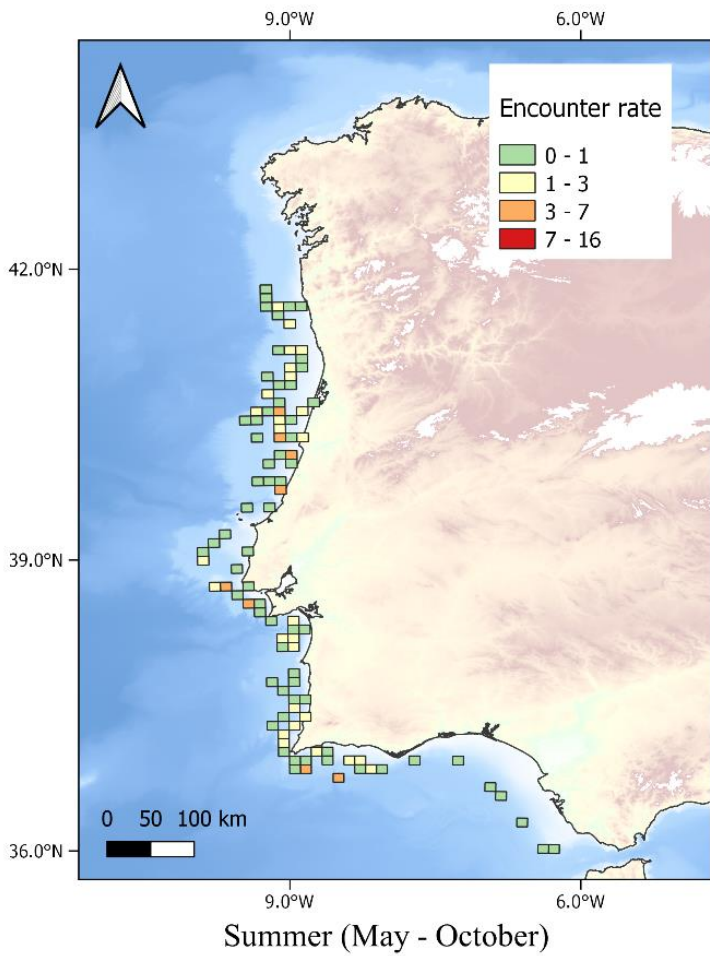


2013 - 2016



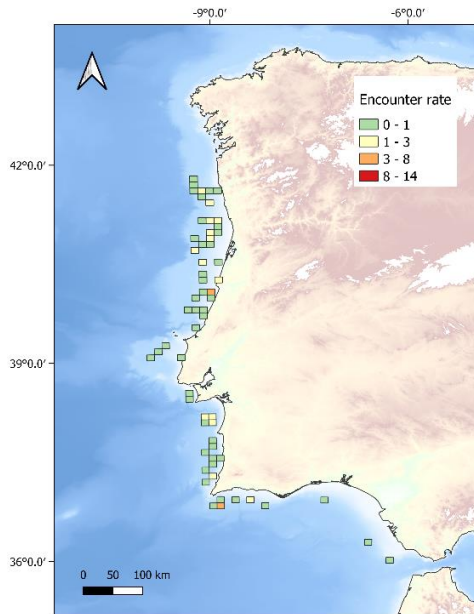
2017 - 2020

**Figure 4.5:** The encounter rate for the common dolphin for every four years. Grid map with a cell resolution of 10 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

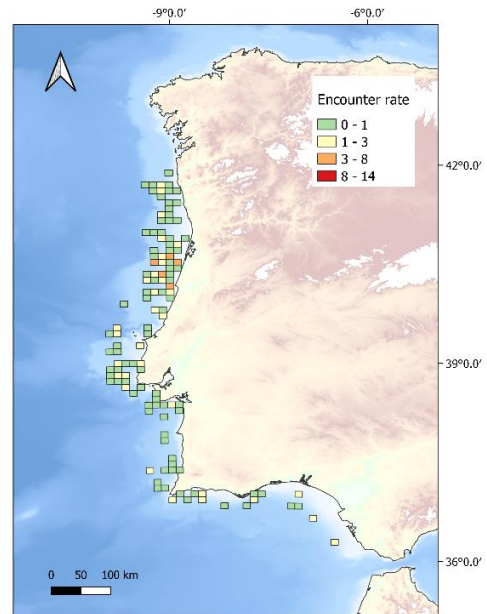


**Figure 4.6:** The encounter rate for the common dolphin during the fishing season (summer) and off season (winter). Grid map with a cell resolution of 10 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

### Before Ban (2005 - 2011)

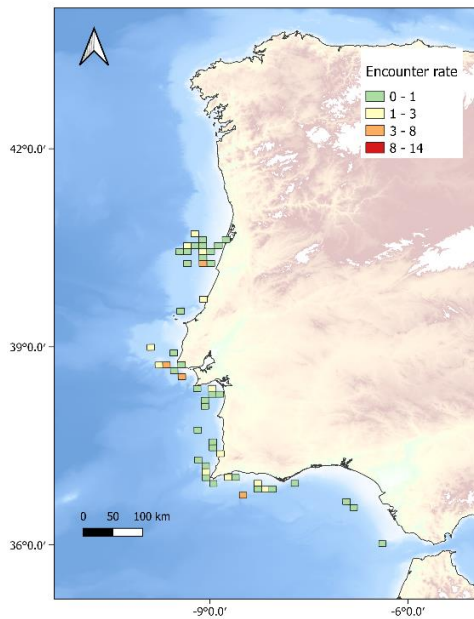


Summer (May - October)

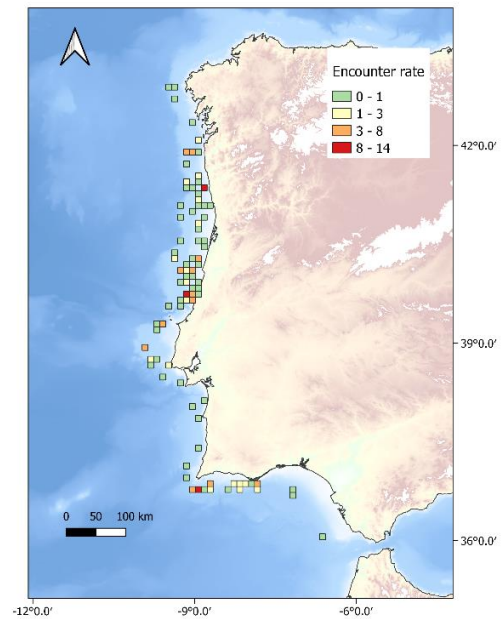


Winter (November - April)

### After Ban (2013 - 2020)



Summer (May - October)



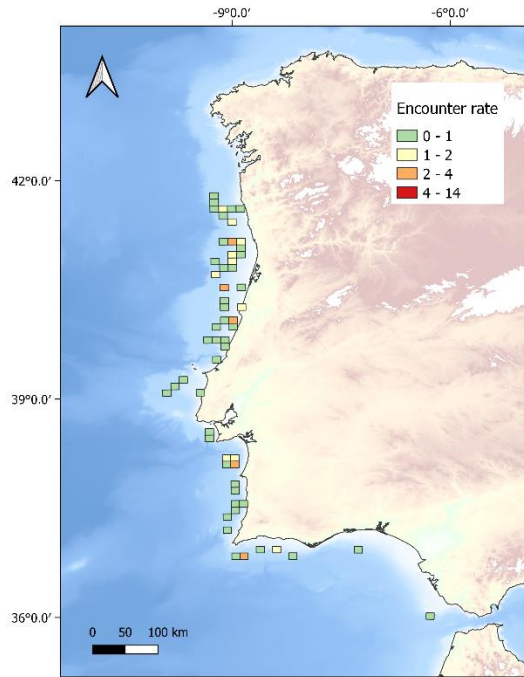
Winter (November - April)

**Figure 4.7:** The encounter rate for the common dolphin during the summer and winter for before and after the sardine ban. Grid map with a cell resolution of 10 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

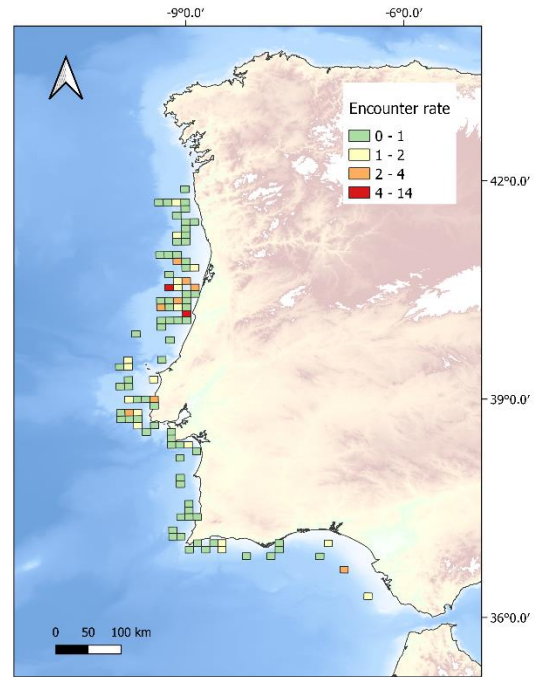
Figure 4.7 compares the distribution of the common dolphin for summer and winter, before and after the sardine ban. In summer before the sardine ban, most of the dolphins were located in low densities throughout the Portuguese mainland coast. During the winter, there was an increase in the dolphin occurrence particularly between Aveiro and Figueira da Foz (from 41°N to 40°N) (Figure 4.7). After the Sardine Ban, the dolphins' distribution appears to be patchier and in lower densities for both summer and winter. During the summer, most of the dolphins are located off the coast of Figueira da Foz (from 41°N to 40°N), Lisboa (from 39°N to 38°N), and the southern coast (from 9°W to 8°W). In winter, most of the dolphins are located along the northern Portuguese coast (from 42°N to 39°N) (Figure 4.7). There appears to be a greater variation in the density of the common dolphin between summer and winter, after the Sardine Ban compared to before the Sardine Ban.

Figure 4.8 compares the distribution of the common dolphin for summer and winter between the four-year periods. In all four-year periods, there appears to be a higher density of common dolphins during the winter months, particularly around Lisboa (from 39°N to 38°N), Figueira do Foz (from 41°N to 40°N) and Sagres (37°N, 9°W) (Figure 4.8). The difference between summer and winter, is particularly noticeable from 2009 to 2016, when the sardine stocks are lowest. During these years, there is a very scarce occurrence of common dolphins, with only a few patches off the coast of the Algarve and Lisboa. There appears to be an increase in the occurrence and density of the common dolphin during the winter, particularly in the northern regions. From 2017-2020, there is an increase in the summer occurrence in the common dolphin throughout the Portuguese coast. The dolphins are reappearing in higher densities near Figueira do Foz (40°N, 9°W), Lisboa (from 39°N to 38°N) and Sagres (36°57'N, 8°50'W). During the winter, there is a movement of the dolphins up the northern coast of Portugal (Figure 4.8).

**2005 - 2008**

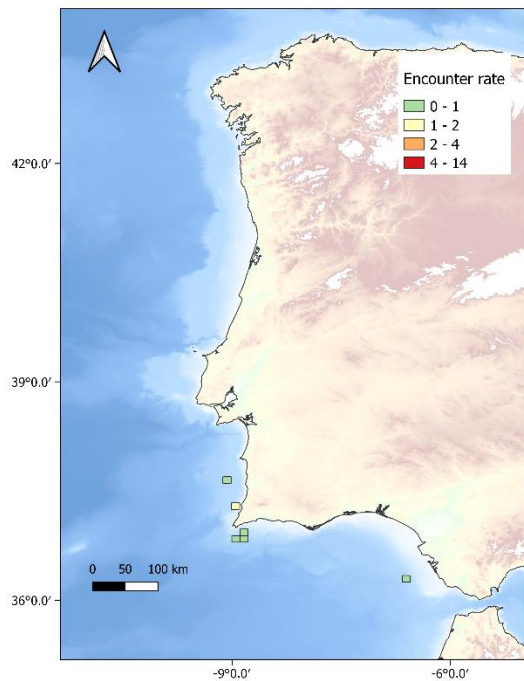


Summer (May - October)

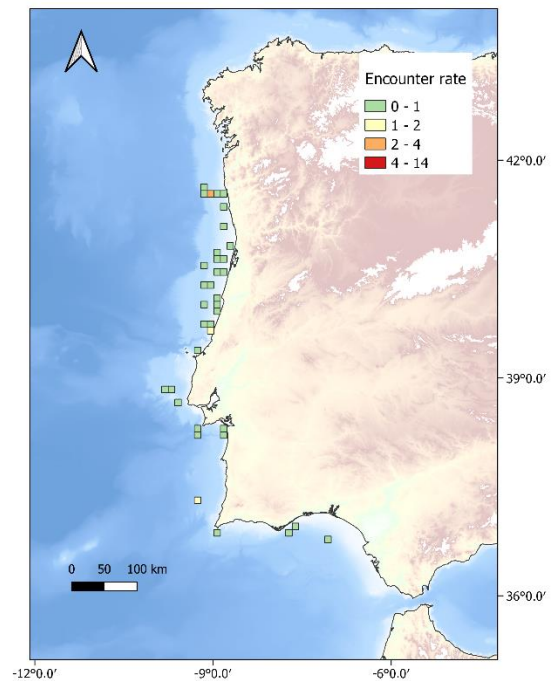


Winter (November - April)

**2009 - 2012**

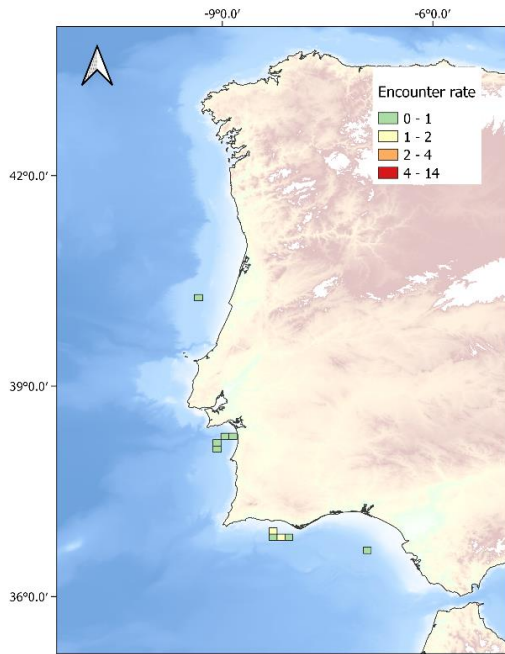


Summer (May - October)

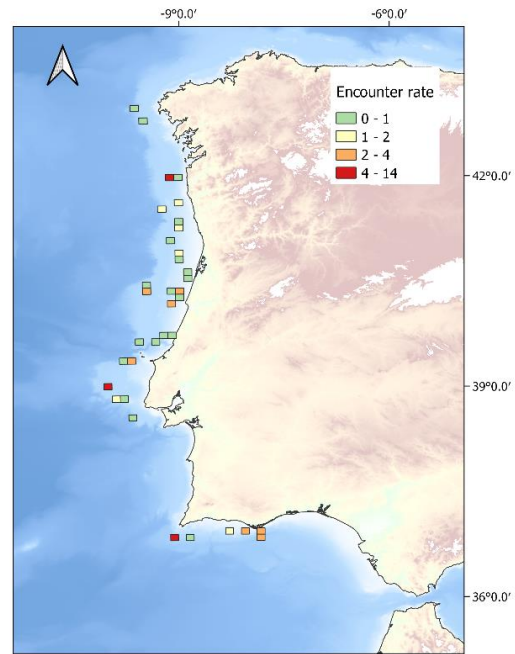


Winter (November - April)

**2013 - 2016**

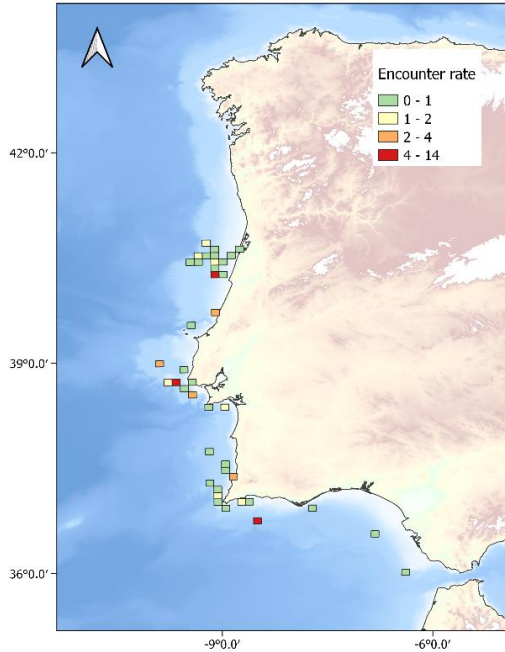


Summer (May - October)

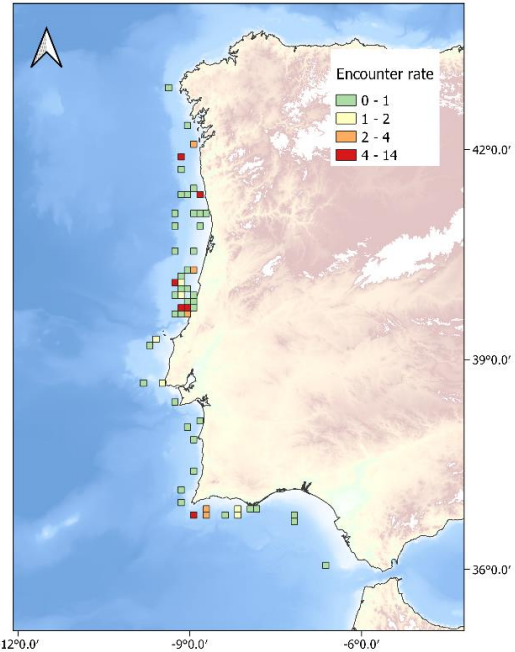


Winter (November - April)

**2017 - 2020**



Summer (May - October)



Winter (November - April)

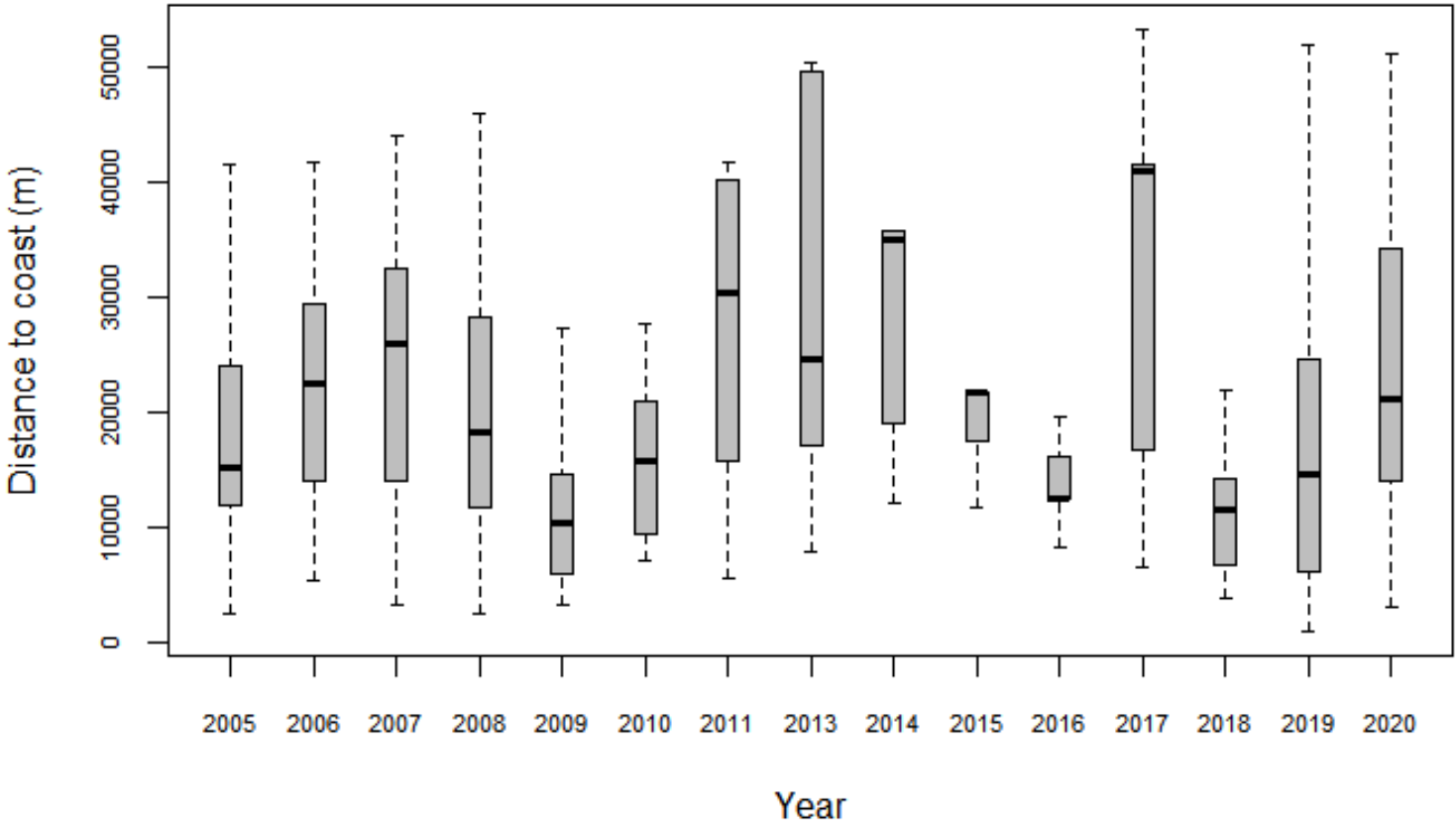
**Figure 4.8:** The encounter rate for the common dolphin during the fishing season (summer) and off season (winter), for every 4 years. Grid map with a cell resolution of 10 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

#### 4.1.3. Distance from coast

The Kruskal Wallis test showed there is a statistically significant difference in the mean distance to coast for the different years ( $p$ -value < 0.05). The mean distance to coast was highest for 2017, followed by 2011 to 2014 (Table 4.4, Figure 4.9).

**Table 4.4:** Mean, standard deviation and Coefficient of Variation (CV) values of the distance to coast of the common dolphin per year.

<b>Year</b>	<b>Mean distance to coast (m)</b>	<b>Standard deviation</b>	<b>CV</b>
2005	18542	10334	55.74
2006	22473	10226	45.50
2007	22905	10861	47.42
2008	20215	11100	54.91
2009	11373	6391	56.20
2010	16607	8502	51.19
2011	28226	12298	43.57
2013	28350	14976	52.83
2014	28408	10028	35.30
2015	19724	6520	33.06
2016	16486	11016	66.82
2017	32933	15221	46.22
2018	14486	11043	76.23
2019	15932	10771	67.60
2020	22679	12270	54.10
<b>Total</b>	<b>18542</b>	<b>10334</b>	<b>55.74</b>



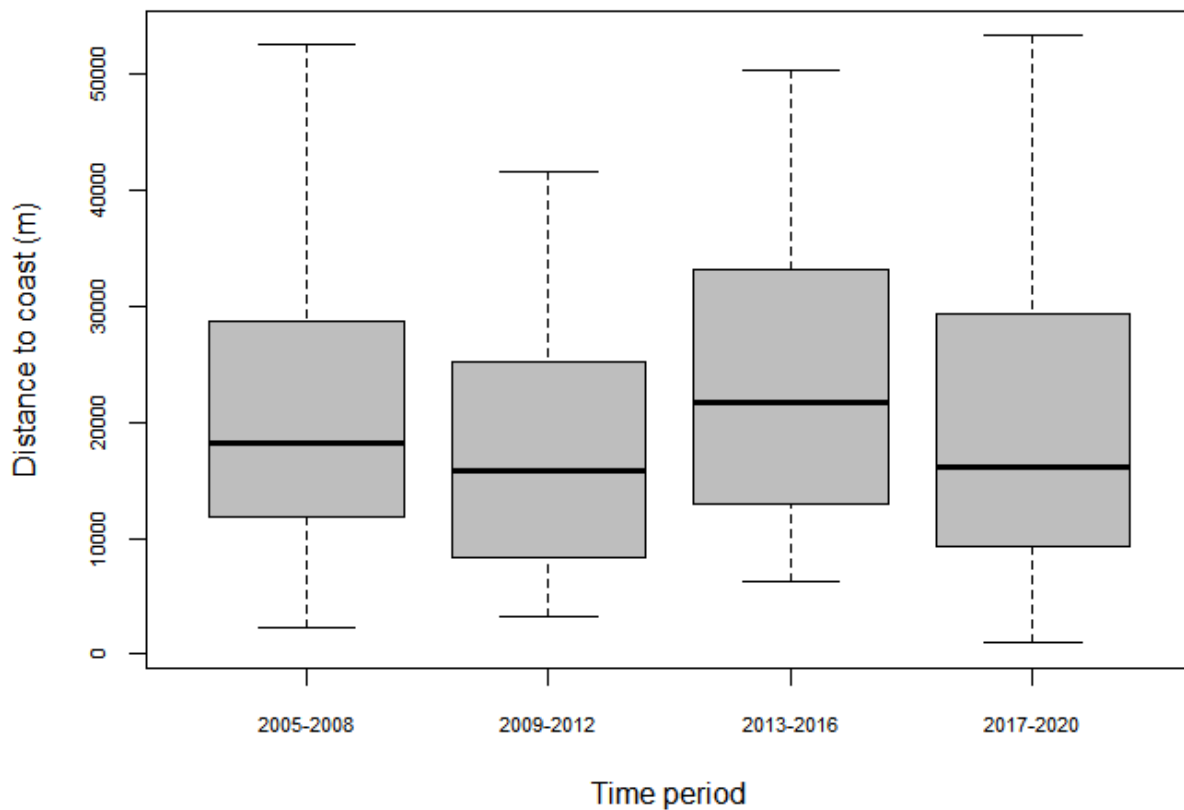
**Figure 4.9:** Median (line), interquartile range (grey box), standard deviation (whiskers) of the distance to coast of the common dolphin for each year. Box plot was created using R Studio (Version 4.1.2).

The Kruskal Wallis and pairwise comparison showed that there was a statistically significant increase in the mean distance to coast between the four-year periods ( $p$ -value  $< 0.0003$ ). The pairwise comparison showed there was a significant difference between: 2005-2008 and 2013-2016; 2009-2012 and 2013-2016; and 2013-2016 and 2017-2020 (Table 4.5, Figure 4.10).

There was no significant difference in the mean distance to coast for common dolphins for (a) before and after the sardine ban ( $p$ -value = 0.50) and (b) between summer and winter ( $p$ -value = 0.19).

**Table 4.5:** Mean, standard deviation and Coefficient of Variation (CV) values of the distance to coast of the common dolphin for every 4 years.

Year	Mean distance to coast (m)	Standard deviation	CV
2005-2008	20684	10879	53
2009-2011	18622	11921	64
2013-2016	25496	14322	56
2017-2020	19856	13269	67



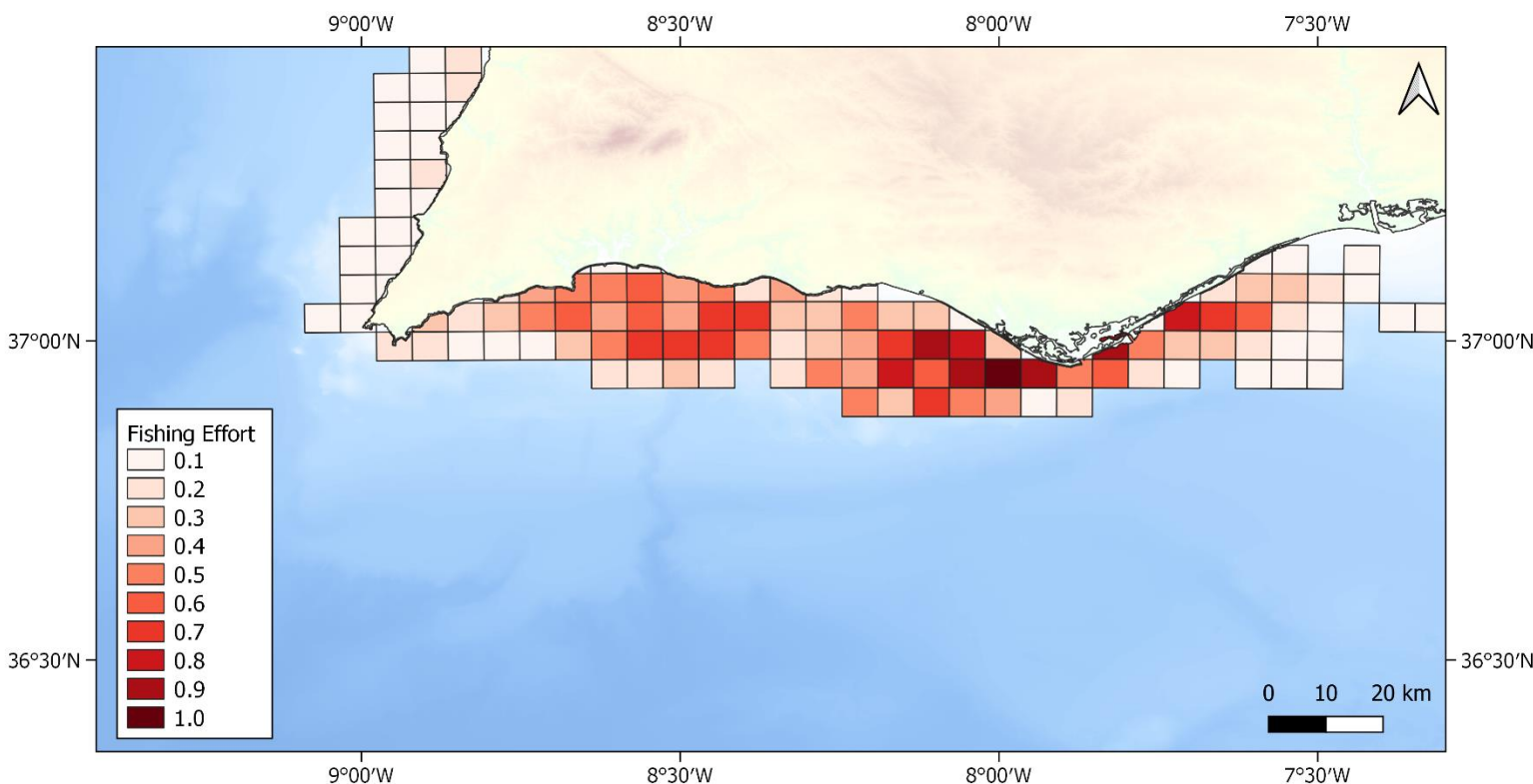
**Figure 4.10:** Median (line), interquartile range (grey box), standard deviation (whiskers) of the distance to coast of the common dolphin for every four years. Significant difference in the distance to coast for 2013-2016. Box plot was created using R Studio (Version 4.1.2).

## 4.2. Objective two: By-catch Risk Assessment

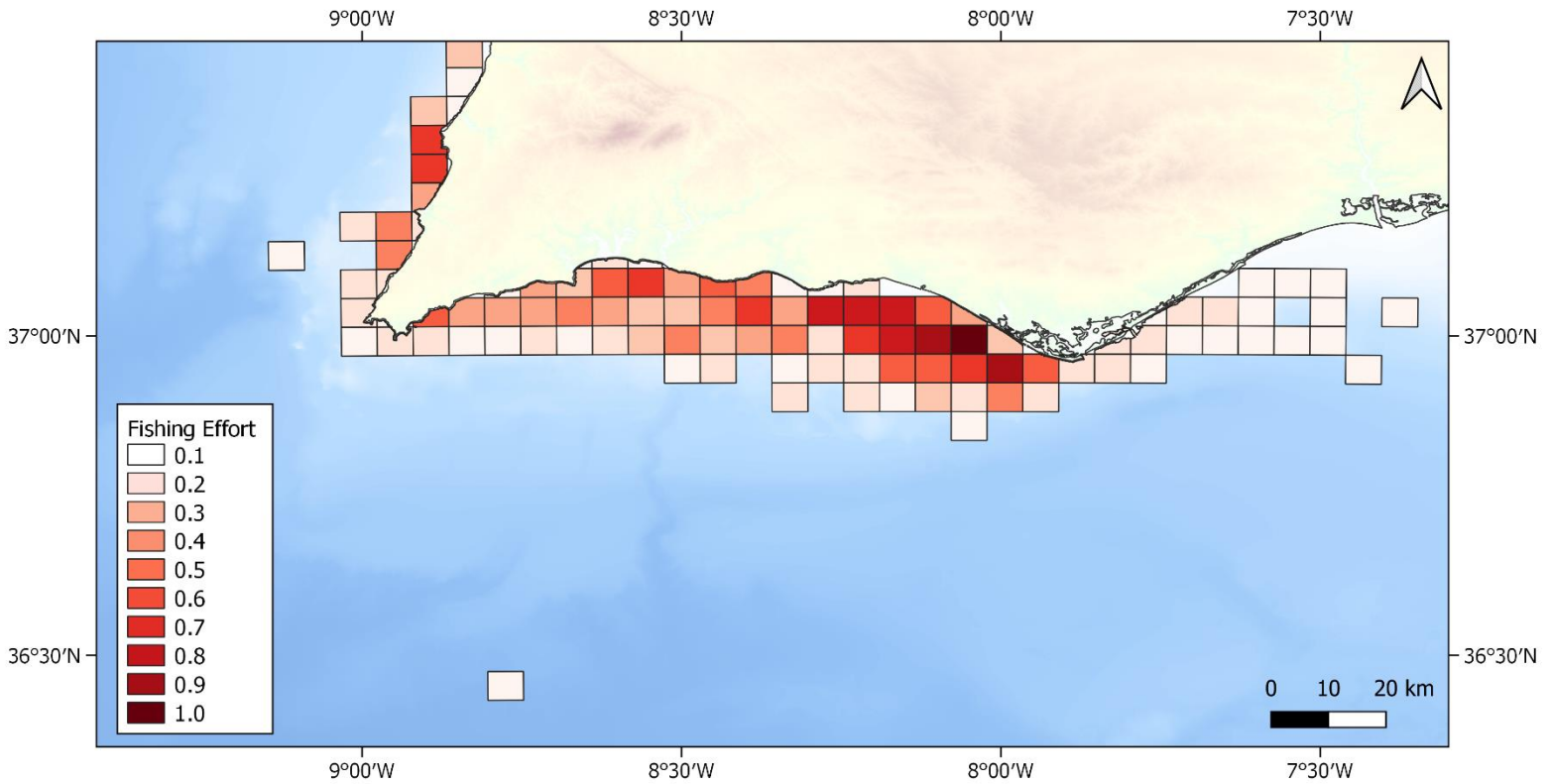
### 4.2.1. Purse seine fishing effort

In 2015, most of the fishing effort was concentrated between Faro and Quarteira (from 37°00'N, 8°10'W to 36°56'N, 7°49'W) and off the coast of Tavira (37°00'N, 7°42'W) and Olhão (36°58'N, 7°49'W). There was also a relatively high fishing effort off the coast of Portimão (from 37°00'N, 8°32'W to 36°59'N, 8°22'W) (Figure 4.11).

In 2020, the highest fishing effort occurred between Faro and Albufeira (from 37°01'N, 8°17'W to 36°56'N, 7°58'W). There was also high fishing effort near Aljezur (37°15'N, 8°53'W) (Figure 4.12).



**Figure 4.11:** Purse seine fishing effort for 2015 along the southern Portuguese mainland coast (Algarve). Grid with a cell resolution of 5 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

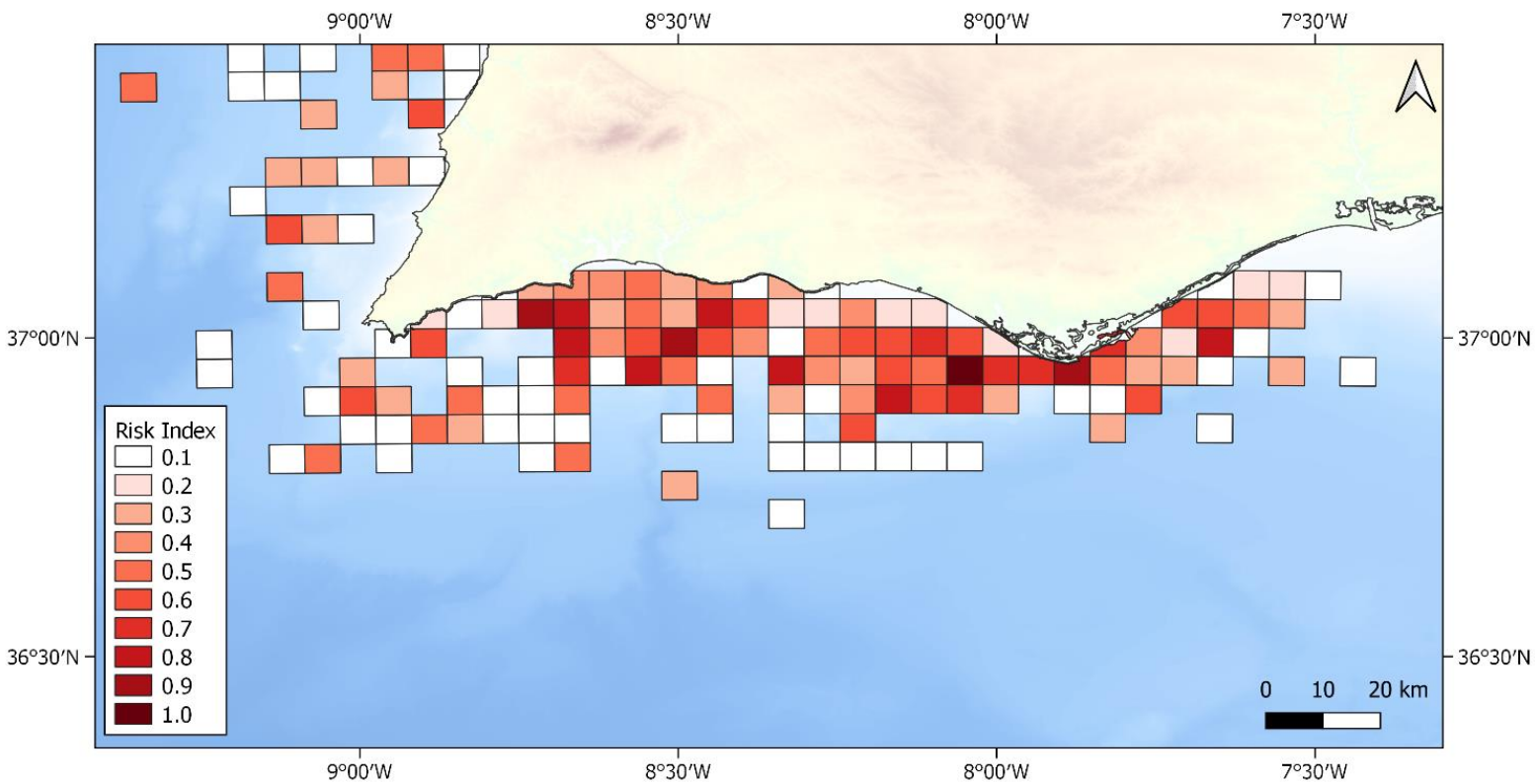


**Figure 4.12:** Purse seine fishing effort for 2020 along the southern Portuguese mainland coast (Algarve). Grid with a cell resolution of 5 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

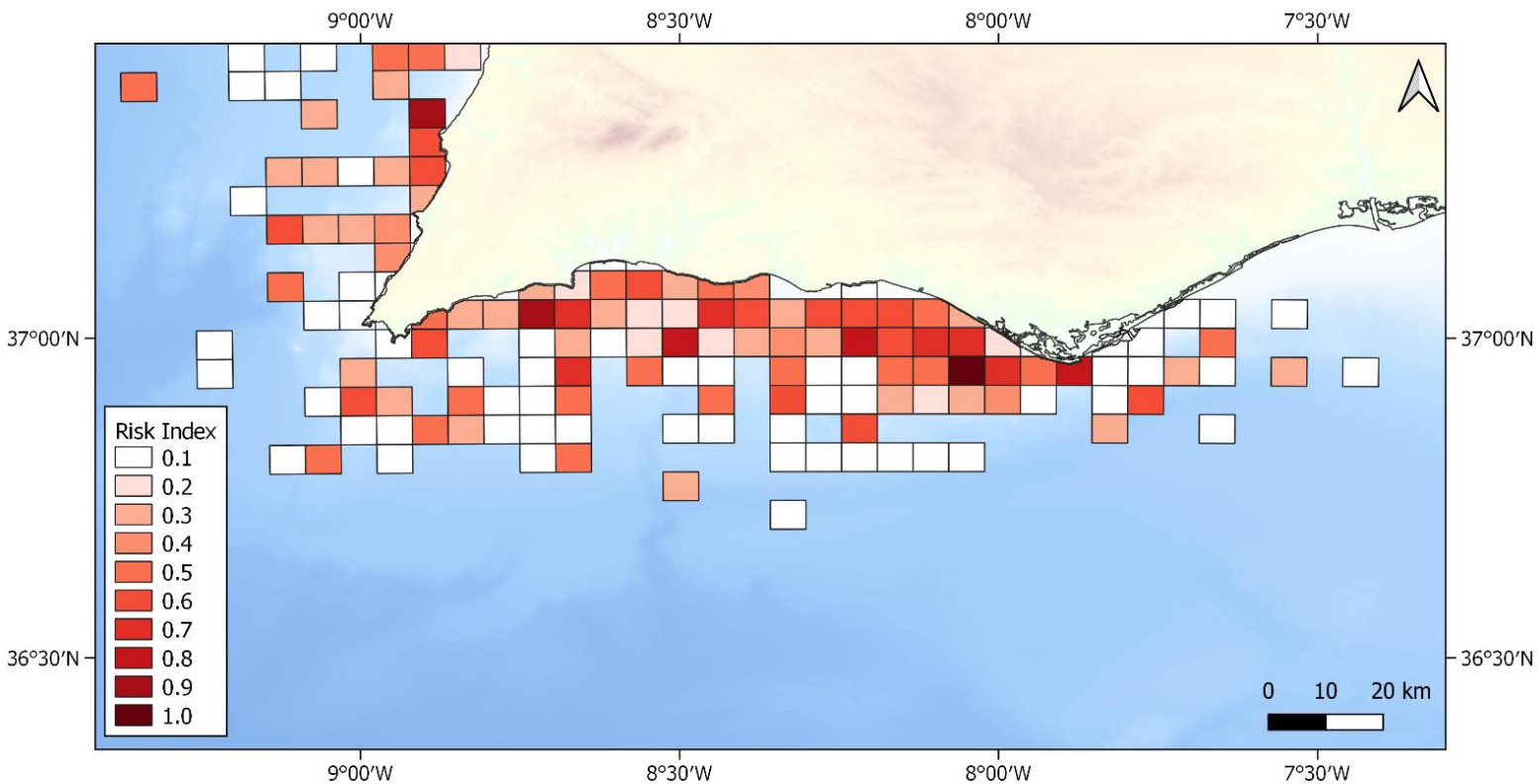
#### 4.2.2. Overlap

For 2015, the highest by-catch risk areas occur near the coast of Faro (36°55'N, 8°04'W), Quarteira (36°54'N, 7°50'W), and between Carvoeiro and Lagos (from 37°00'N, 8°44'W to 36°57'N, 8°18'W) (Figure 4.13).

For 2020, the highest by-catch risk areas occur off the coast of Alijezur (37°18'N, 8°52'W), Lagos (37°01'N, 8°39'W), and between Quarteira and Faro (from 36°57'N, 8°11'W to 36°54'N, 7°52'W). During 2015, there are more high-risk areas than in 2020, particularly in the Western Algarve (Figure 4.14).



**Figure 4.13:** Overlap between purse seine fishing effort and common dolphin distribution for 2015 along the southern Portuguese mainland coast (Algarve). Grid with a cell resolution of 5 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).



**Figure 4.14:** Overlap between purse seine fishing effort and common dolphin distribution for 2020 along the southern Portuguese mainland coast (Algarve). Grid with a cell resolution of 5 km<sup>2</sup>. Map was created using QGIS (Version 3.10.0).

## 5. Discussion

Up until now, there has been limited research on the distribution of the common dolphin along the Portuguese mainland coast, other than the short-term LIFE+ MarPro study. The lack of knowledge about the common dolphins' core habitat is particularly concerning because of the strong fishing activity along the coast. Knowledge about the habitat use of cetaceans is needed for identifying priority conservation areas along with measures to reduce anthropogenic threats (Hammond *et al.*, 2009). This study investigates the habitat use of the common dolphin, *Delphinus delphis*, along the Portuguese mainland coast and provides insight into critical protection sites. The study

uses long-term data collected from the years 2005 – 2020 to identify common dolphin hotspots and to understand how their distribution varies spatially and temporally. In addition, this study represents the first attempt to estimate the overlap between the purse seine fishery and the common dolphin along the southern Portuguese coast (i.e., the Algarve), in order to contribute to by-catch risk assessments.

The study is divided into two objectives: (i) estimating the distribution of the common dolphin along the Portuguese mainland coast at different temporal and spatial scales, and (ii) estimating the overlap between the purse seine fisheries and the common dolphins' distribution in the southern Portuguese mainland coast in order to inform by-catch risk assessments.

## 5.1. Objective one: Spatial Distribution

### 5.1.1. Hotspots for common dolphin occurrence

The study shows that the common dolphin is the most frequently observed species along the Portuguese mainland coast, followed by the bottlenose and striped dolphin. From 2005 – 2020, the common dolphin showed the highest encounter rate off the central and southern mainland coast, particularly from Nazaré to Figueira da Foz, and Sagres. These common dolphin hotspots are likely related to the presence of geographical and oceanographic features that favour high productivity (Rodríguez-Climent *et al.*, 2017; Castro *et al.*, 2020). For instance, there are high densities of common dolphins located near the major Portuguese submarine canyons (i.e., Nazaré, Lisboa and Cape São Vicente). Submarine canyons act as important channels for the upwelling of nutrients to surface water, therefore promoting high biological productivity and abundance of fish and crustacea (Ryan *et al.*, 2005; Salgado Kent *et al.*, 2021). Furthermore, there is a high density of dolphins located near the mouth of the three major estuaries and rivers, the Rio Douro, Ria de Aveiro, Rio Mondego, the Rio/Estuary of Tejo, and the Rio/Estuary of Sado. Studies have shown that the common dolphin tends to aggregate near large river mouths, due to the high nutrient run off (de la Cruz *et al.*, 2021). These river mouths act

as critical fish recruitment sites and spawning grounds, because of their high productivity (Lin *et al.*, 2021). Thus, the high density of common dolphins at these sites suggests that they are specifically aggregating in important fish recruitment grounds due to increased prey availability.

#### 5.1.2. Implications of the Sardine Ban on the common dolphins' distribution

As previously mentioned, the common dolphin tends to aggregate in areas with high prey abundance. Thus, it is expected that changes in prey availability will likely affect the distribution and density of the dolphins. Since 2006, there has been a significant reduction in sardine biomass because of the changes in sardine recruitment caused by intensive fishing practices and environmental factors (Monteiro, 2017; Silva *et al.*, 2018). As a result, a “Sardine Ban” was implemented in 2012, which introduced a set of regulatory and technical fishing measures to prevent the further decline of sardine stocks (DGRM, 2012). One of the objectives of this study was to understand the relationship between changes in sardine stock levels, especially as a consequence of the Sardine Ban, and the common dolphin occurrence.

Indeed, the study showed that the common dolphin encounter rate and distribution followed a similar trend to sardine biomass levels. Based on the grid maps, there was a low density of common dolphins from the years 2009 to 2016 across the Portuguese mainland coast. The low density coincides with the period when sardine biomass was at its lowest levels (Figure 1.1; DGRM, 2018). For instance, in 2009, the sardine landings greatly exceeded ICES scientific advice, with 24% more sardines landed than the advised value (Monteiro, 2017). As a consequence of intense fishing practices, 2011 witnessed a peak mortality for the sardine stocks and their lowest levels of recruitment (Monteiro, 2017; Szalaj *et al.*, 2021). In the current study, there was also a particularly low encounter rate for the common dolphin in 2011. This result suggests that the fishing practices prior to the Sardine Ban were probably reducing prey availability for the common dolphin population in the area.

After the Sardine Ban of 2012, there was a gradual recovery in sardine stock levels along the Portuguese mainland coast (Rosa *et al.*, 2018). For instance, in 2016 and 2017 the stocks recovered 31.6% compared to their levels in 2015 (DGRM, 2018). Furthermore, there appears to be a drop in sardine mortality between 2015 and 2019, compared to earlier years, which could be attributed to a decrease in fishing effort (ICES, 2020). The current study also shows an increase in the common dolphin encounter rate and density from 2016 onwards, which may suggest that the dolphins are benefiting from the sardine stock recovery. Although, it is still too early to accurately assess the complete effectiveness of the Sardine Ban, the study provides some preliminary evidence that the common dolphin is responding positively to the implementation of the Management Plan.

### 5.1.3. Seasonal trends in common dolphin distribution

As part of the Sardine Ban, a fishery closure was introduced during the sardine spawning period from November to April (Feijo *et al.*, 2018). This study sought to investigate changes in the common dolphin distribution in relation to the periods when sardine fishing was prohibited. As evident from the study, there was an increase in dolphin density during the closed fishing season. This trend was particularly evident near the large fishing ports such as Matosinhos, Póvoa de Varzim, Figueira da Foz, Peniche, and Portimão (European Commission, 2020a). It is expected that the dolphins would take advantage of the higher number of sardines during this time when fishing activity is banned. In summer, the fishing effort is higher because of the high demand for sardines, which would lead to a lower prey availability for the common dolphins and thus a lower preference for this region (Almeida *et al.*, 2014). Other studies hypothesised that the higher diversity of cetaceans in regions such as Peniche and Sesimbra is as a consequence of imposed fishery restrictions (Vieira *et al.*, 2009; Moura *et al.*, 2012). This would further support the idea that seasonal fishing restrictions have a positive influence on cetacean diversity and distribution.

The current study also shows that after the implementation of the Sardine Ban there is a greater variation in the density of the common dolphin between summer and winter,

compared to before the Sardine Ban. Before the Sardine Ban, there was no seasonal fishing closure imposed and therefore there was relatively consistent fishing effort throughout the year. It is possible that the lower seasonal variation in common dolphin density before the Sardine Ban could correspond to lower seasonal variation in fishing effort. A study conducted before the 2012 Sardine Ban, showed that there was a significant interaction between the dolphins and the purse seine fishers during the summer months (Marçalo *et al.*, 2015). Perhaps, during this time when there was consistent fishing effort, the dolphins had little option but to compete with the purse seiners for the sardine, thus explaining their interaction during the summer months. With the introduction of the Sardine Ban, the dolphins responded by showing a greater preference for habitats during the winter months when fishing activity was limited.

#### 5.1.4. Distance to coast

As shown from the study, it appears that the common dolphin is occurring in lower densities during the years with low sardine abundance. Previous studies have described the common dolphin as opportunistic feeders and claim that they switch their prey preference at lower sardine abundance (Young and Cockcroft, 1994). However, despite the low sardine recruitment and abundance within the 2013-2016 period, a study showed that the common dolphin still favoured sardine as the leading prey, based on a stomach content analysis (Marçalo *et al.*, 2018). This refutes the claim that common dolphins are purely opportunistic feeders by showing that even during low prey abundance, they still preferentially target the sardine. One possible explanation investigated in this study, is that the dolphins are demonstrating responsive movements to sardine stock levels.

Indeed, the results show that the common dolphin was moving significantly further from the coast between 2013 and 2016. During this period, the sardine stock biomass was at its lowest level, therefore suggesting that the dolphins were moving to locations further offshore in order to compensate for low prey availability closer to the coast (ICES, 2017). Other studies have also documented shifts in the distribution of cetaceans based on changes in prey availability across the Northeast Atlantic (e.g., Hammond *et al.*, 2013).

Although previous studies have shown that sardine was still the most prevalent component in the diet based on stomach content analyses, there is evidence that other small pelagic fish species occupy a greater proportion of the common dolphins' diet than previously (Silva, 1999; Marçalo *et al.*, 2018). It is possible that sardine resources were scarce closer to the coast due to the intensive fishing practices targeting this fish species. As a result, the dolphins were targeting other small pelagic fish closer to the coast and moving further offshore to find sardine where the purse seiners do not operate. This can possibly explain the small changes in the common dolphins' diet as noted by Marçalo *et al.* (2018).

Furthermore, it is possible that the dolphins' distribution is associated with the movements of the purse seiners. In the present study, the common dolphin is occurring further from the coast between 2013 and 2016, which coincides with the period when restrictions were placed on fishing effort due to decreases in sardine stocks (Feijo *et al.*, 2018). Other studies have shown that there is a positive relationship between sardine catches and the number of cetaceans observed (Wise *et al.*, 2007; Marçalo *et al.*, 2015). In areas where there are low sardine catches, there is a lower cetacean abundance (Marçalo *et al.*, 2015). In 2017, there was a gradual recovery in sardine stocks, which led to the lifting of some restrictions and increase in fishing effort, particularly closer to the coast (DGRM, 2018). In the current study, the dolphins are occurring significantly closer to the coast from 2017 onwards. Dias *et al.* (2022) showed that there is a higher probability of occurrence of dolphin-fishery interactions in areas with higher fishing effort. Thus, it can be assumed that the dolphins are probably moving closer to the coast to benefit from the higher availability of sardines inshore, being unable to avoid the usually negative interaction with the fishery (Marçalo *et al.*, 2021). An alternative hypothesis could be that the dolphins are likely associating the purse seiners with sardine availability and are therefore saving energy and time searching for prey by following the vessels. Although it is known from the fishery community's knowledge and from scientific onboard observations that the dolphins are usually the ones that find the sardine schools first (Marçalo *et al.*, 2021).

## 5.2. Objective two: By-catch risk assessment

Worldwide, by-catch is recognised as the primary conservation threat to cetaceans (Read *et al.*, 2006; Rogan *et al.*, 2021). The study identified the major by-catch risk areas of the purse seine fisheries for the years 2015 and 2020 along the southern Portuguese coast (i.e., Algarve). In both years, there is a high risk of by-catch along the western Algarve coast, particularly from Carvoeiro to Lagos, and from Faro to Quarteira. This result agrees with other studies that show that the highest level of cetacean-fishery interaction is along the western Algarve coast (between 8°W and 9°W) (Dias *et al.*, 2022). This strong overlap can be attributed to the high abundance of common dolphins, which is positively related to sardine and chub mackerel (*Scomber colias*) abundance (Marçalo *et al.*, 2015; Dias *et al.*, 2022). For example, the risk area along the Costa Vicentina, near Aljezur, represents an important sardine spawning ground, therefore attracting the common dolphin (Rodríguez-Climent *et al.*, 2017). Therefore, the higher number of dolphins in these important sardine recruitment sites increases the likelihood of negative interaction between the dolphins and fisheries (Dias *et al.*, 2022).

Furthermore, it is possible that the dolphins are attracted to areas with strong fishing activity due to an abundance of sardine. This can explain the high-risk areas near the large fishing ports, such as Quarteira, Olhão and Portimão. Previous studies have shown that common dolphin presence is positively related to fishing effort (Marçalo *et al.*, 2015; Dias *et al.*, 2022). The common dolphin is known to use areas relatively close to the coast, which overlap with the majority of purse seine sets (Feijo *et al.*, 2018). This tendency for the dolphins to concentrate within the operational zone of purse seine fisheries, due to their shared resource, inevitably increases the probability of negative interactions, most noticeably by-catch (Marçalo *et al.*, 2015). Although, in general, there is a lower interaction between the PPSF and cetaceans along the eastern Algarve (Marçalo *et al.*, 2015), in 2015 there are risk areas off the coast of Tavira and Olhão. These risk areas correspond to the location of two important fishing ports along the eastern Algarve. This further suggests that the high by-catch risk areas are related to the presence of fishing grounds, where the dolphins are searching for prey.

It also appears that the high-risk areas are related to the geographic features of the area. It is known that the shallower waters of the continental shelf are an important habitat for small pelagic fish, such as the sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) (Massuti *et al.*, 1996; Lloret *et al.*, 2004; Roque *et al.*, 2010). The high-risk area near Faro could possibly be attributed to the presence of a narrow continental shelf, where the sardines are compressed (Dias *et al.*, 2022). It is likely that the common dolphin and fisheries are taking advantage of the high abundance of resources in these areas, thus increasing the probability of interaction.

### 5.3. Management Implications and Recommendations

In recent decades, there has been an alarming increase in human maritime activity, which has put pressure on the marine and coastal space and resources (Korpinen and Andersen, 2016). This has led to constant conflict between human uses and the marine environment. Marine Spatial Planning (MSP) is one way to address existing or anticipated conflicts and to ensure that the marine environment is managed in a way that allows the maximum compatibility between the different maritime users. Moreover, Article 8(1) of the EU Maritime Spatial Planning Directive specifically addresses that Member states should identify the “spatial and temporal distribution of relevant existing and future activities and uses in their marine waters” (IOC/2009/MG/53). Essentially, MSPs are concerned with investigating the relationship between the distribution of keystone species and human activity, in order to order to achieve ecological, economic, and social objectives.

This present study addresses the requirements of the MSP Directive by providing knowledge about conflict areas between charismatic species and important fisheries along the Portuguese mainland coast. In particular, the research focuses on the distribution of the most abundant cetacean species, the common dolphin, and their overlap with the most important national fishery in the country, the purse seine fishery. The findings from this study can be used as a tool for informing the designation of Marine Protection Areas (MPAs) in MSPs, which encompass temporal and spatial variations in the common dolphin distribution along the Portuguese mainland coast. Furthermore, the

outputs of the study should contribute to the revision and assessment of the Portuguese MPAs. It is clear that the Portuguese mainland coast is well below fulfilling the commitments of the EU's Biodiversity Strategy on protecting 30% of the waters by 2030 (European Commission, 2020b). Currently, there are only 8 MPAs along the mainland coast, which represents only 0.2% of the total territorial area (Timonet and Abecasis, 2020). Even in these protected areas, fishing effort is still taking place, suggesting that the current MPA management is not adequate (Sciaena, 2021). Furthermore, only 0.93% of the current MPAs in Portugal are considered highly protected and 0.11% are fully protected (Roessgar *et al.*, 2022). It has been shown that these highly protected areas exhibit higher biomass and abundance of commercial fish, which confer positive conservation and socio-economic benefits (Zupan *et al.*, 2018). Therefore, the results should be used to improve the current MPA situation in order to increase the resilience to the socio-ecological system (Horta e Coast *et al.*, 2016).

Based on the results of the present study, it is evident that the main common dolphin hotspots are located in the central and southern Portuguese mainland coast, particularly off the coast of Nazaré, Figueira da Foz, Lisboa and Sagres. Previous studies have illustrated that the common dolphin has an affinity for fishing vessels, as the vessels' presence suggest prey availability (Hammond *et al.*, 2017). For this reason, it is not surprising that these major dolphin hotspots coincide with areas of strong fishing activity. This strong association poses a number of different challenges for their conservation such as habitat degradation, by-catch and prey depletion (OceanCare, 2021). Therefore, it is imperative that these areas are treated as critical areas for protection and are prioritised in conservation management plans. Furthermore, the present study brings to light temporal changes in the common dolphin distribution, which is a fundamental consideration in the designation of MPAs. The study shows that the common dolphin is occurring in lower densities during the summer months, when fishing effort is at its peak. It can be assumed that the increased fishing pressure during this season is causing the dolphins to relocate to other regions. Therefore, in order to mitigate seasonal conflict between the common dolphin and purse seining effort, MPAs should be given a higher level of protection during the summer months.

The study also provides information which can be used for the sustainable management of the Portuguese purse seine fishery, by considering the impact that the fishery has on prey availability for the common dolphin. The results show how previous low levels of sardine biomass negatively influenced the distribution of the common dolphin. In years when the sardine stocks were low, the dolphins responded by moving further offshore and occurring in lower densities. Although, since then, there has been a recovery in sardine stock level, they are still below the Maximum Sustainable Yield (Monteiro, 2017). Under the current situation for the purse seine fishery, the Portuguese sardine stocks are at risk of facing irreversible declines. This could lead to long-term consequences for the distribution and abundance of not only the common dolphin, but also the entire food web. In order to mitigate the potential impacts of the purse seine fishery on prey availability for important species, it is essential that a precautionary and adaptive approach to fish stock management is taken. This involves ensuring that the stock levels are assessed on a regular basis and that conservation measures are continuously updated accordingly. Unless resources are effectively managed, it is probable that the Portuguese mainland coast will experience a fate similar to other regions. For example, in the Mediterranean, declines in prey availability due to intensive purse seining activity contributed to the reduction of the common dolphin population from 150 to 15 individuals and a major weakening of the marine food web (Piroddi *et al.*, 2011). In order to prevent a similar situation, it is recommended that additional management restrictions on purse seine fishing activity be implemented throughout the mainland coast.

By-catch in purse seine fisheries is one of the leading causes of human-induced mortality for the common dolphin and other cetacean species along the Portuguese mainland coast (Marçalo *et al.*, 2015; Wade *et al.*, 2021; Dias *et al.*, 2022). The present study addresses the urgent need for by-catch risk assessments by providing knowledge about high-risk areas. More specifically, the study provides preliminary estimates of the overlap of the common dolphin distribution with the purse seining effort along the southern Portuguese mainland coast. From the results, it is evident that the highest degree of overlap occurs along the western Algarve coast, particularly near the important fishing ports. It is recommended that by-catch monitoring and enforcement be strengthened for purse seine vessels operating in these high-risk areas (Sciaena, 2021). Furthermore,

mitigation measures, such as new fishing procedures, fishing operational changes, time-area fishing closures and the use of acoustic devices, should be considered in future management plans. The present study provides a baseline for the development of a holistic impact assessment on ongoing purse seine fishing activities along the southern Algarve coast. Furthermore, the study can contribute to the National Ocean Strategy commitments to “reduce by-catches and discards from fisheries by 2030” and to “develop and implement a certification system for local fisheries that comply with dolphin-friendly practices” (DGPM, 2020).

#### 5.4. Future Directions and Limitations

One suggestion for future studies would be to include abundance estimates. Abundance estimates are essential for assessing the conservation status of a population and impact of anthropogenic threats (EU Habitat Directive 92/43/EEC; Hammond *et al.*, 2013; Hammond *et al.*, 2021). One method for obtaining accurate abundance estimates is through Density Surface Modelling (DSM). DSM is a spatial-explicit model that has been corrected for uncertainty in detection using distance sampling methods (Miller *et al.*, 2013). Such modelling techniques would contribute to a better understanding of temporal and spatial changes in cetacean abundance, thereby allowing managers to make more informed conservation decisions. Furthermore, by-catch mortality rates and biological reference points should be obtained in order to contribute to a more informed by-catch risk assessment for the purse seine fishery (Rogan *et al.*, 2021). The by-catch rates can be compared against reference points in order to understand the likelihood and impact of fisheries on the species' population (Moore *et al.*, 2021).

In addition, it is recommended that predictive models be incorporated as a way to estimate changes in the distribution of the common dolphin under different environmental or fishing scenarios. In the study by Paradell *et al.* (2021), the Ecopath model was used to estimate the effects of various fisheries management strategies on different cetacean species. The results from these models could provide valuable information about the most

sustainable management plan for fisheries stock management and cetacean conservation. Moreover, Generalized Linear Models can be used to extrapolate the distribution of the common dolphin to regions outside of the data sampling range (Bartley *et al.*, 2019). This methodology is particularly useful for predicting the distribution of the common dolphin due to their widespread distribution and small sampling size (Becker *et al.*, 2020). These models can be used to locate hotspots in situations where sampling coverage is limited, therefore providing valuable information for decision makers and managers (Becker *et al.* 2012).

One limitation of the study is that it only considers the interaction between the common dolphin and the purse seine fisheries. It is difficult to accurately assess the total risk of by-catch without considering other fisheries, such as fishing traps, fixed gear and longliners (Fertl and Leatherwood, 1997; Gilman *et al.*, 2006). For instance, gill nets and other entangling nets represent 57% of the total number of fishing vessels in the Portuguese mainland coast and hence are likely to contribute significantly to by-catch mortality and prey depletion (Eurostat and FAO, 2019). Therefore, future studies should consider gear-specific risks in order to contribute to a more comprehensive by-catch risk assessment. In addition, the present study could be improved upon by assessing additional threats to the common dolphin, such as touristic operators, offshore development, and aquaculture. The dolphins are vulnerable to a wide range of stresses and therefore their conservation requires the assessment of cumulative impacts from multiple human sources and activities (Weilgart, 2007).

Another limitation of the by-catch risk assessment is that that it only considers two years of fishing effort, 2015 and 2020. It would have been ideal to have conducted a by-catch risk assessment for before and after the Sardine Ban of 2012, but this was not possible because AIS data was only available from 2015 onwards. In addition, the study only investigates by-catch risk for the Algarve coast. Future studies should expand upon the present research by covering the entire Portuguese mainland coast and over a longer time period. Furthermore, common dolphin sighting data was pooled together for all years (i.e., 2005-2020), rather than using data from only 2015 and 2020. This was because the sampling size for the Algarve coast was too small for these two years. This could present

challenges as the fishing effort and dolphin data are not occurring over a consistent time range, and therefore the level of overlap might not be entirely reliable. Despite this limitation, the research still provides an idea of the main areas of by-catch, and therefore can be treated as a baseline study.

## 5.5. Conclusions

The study investigates the distribution of the most frequently observed species, the common dolphin, along the Portuguese mainland coast and their interaction with the purse seine fishery effort. This study is the first to use heatmaps of the common dolphin along the Portuguese mainland to assess their distribution over a long period of time. The result provides an understanding of the main common dolphin hotspots along the coast, which is an essential tool for informing MSPs and MPA designation. It is evident that the common dolphin has been showing responsive movements that correspond to changes in sardine stock levels. During the years with the lowest sardine levels, the dolphins were occurring in low densities close to the coast. After the implementation of the Sardine Ban of 2012 there was a gradual increase in the sardine stock levels, which resulted in the dolphins moving closer to shore. This suggests that the dolphin's distribution is influenced by prey availability, and thus changes in stock levels could have negative effects on the common dolphins' habitat use. Therefore, preventative measures should be strengthened to prevent future declines in sardine stock levels and to keep them above a Maximum Sustainable Yield.

Furthermore, the study also highlights the potential areas and seasons of conflict between the dolphins and purse seine fishing activity in order to contribute to an urgently needed by-catch risk assessment. The study shows the potential overlap between the dolphins' distribution and the purse seining effort, with a particular focus on the southern Portuguese mainland coast. The results of the study can be used by managers and decision makers to identify the most problematic zones for by-catch. Management plans should be applied to high-risk areas in order to contribute to the sustainable management of the PPSF fleet.

Overall, the results shed light on the importance of adaptive management plans for the conservation of cetaceans. The results of the study address the requirements of the EU Habitats Directive and MSFD to report on the favourable conservation status of cetaceans by using distribution estimates. Conservation management measures should be continuously implemented and enforced to reduce the negative anthropogenic impacts on common dolphin populations, which is essential for ensuring a healthy marine ecosystem.

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