UNIVERSIDADE DO ALGARVE
FACULDADE DE CIÊNCIAS E TECNOLOGIA

Marine Biology Master Program

Academic year 2014 - 2015

Temporal distribution of the short-beaked common dolphin (*Delphinus delphis*) in the south of Madeira Island (Portugal) and relationship with oceanographic variables.

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Faro, 27.09.15 ……………………………..

Acknowledgments

This thesis would never see the light of day without help and hard work of many amazing and entirely selfless people. I want to thank you all for making this idea real.

At the beginning, my supervisor Filipe Alves, initiator of the whole plan, without whom this thesis would not be present. For organizing data, meetings and my incredible field work experience. For all this time spent on the discussions, problems solving and being always “on call” to answer my questions.

My supervisor Ana Barbosa for taking me “under her wings”, giving me all professional advises and critical point of view, which made this thesis better and better, for a huge amount of time spent on the corrections.

Manfred Kaufmann, president of CIIMAR-Madeira for accepting my master thesis project, helping me with settling down in Funchal, and especially for financing my modelling course in Porto and taking care about logistic of this work.

Rui Caldeira from CIIMAR-Madeira for all constructive and long discussions that were leading this thesis to good direction. For helping me in getting and understanding satellite data and giving me some oceanographic background about Madeira Island.

Carlos Lucas from CIIMAR-Madeira for providing me oceanographic data and making some “informatics” magic.

Miguel Fernandes for collecting the most important data of *D. delphis* occurrence that allowed me to do this thesis, as well as for answering all my questions and providing me all important information.

João Manuel Delgado from Direção Regional de Pescas, Madeira. For providing me key fishery data, making this thesis more constructive. For all important comments about them and willing to help me with problems.

Instituto Português do Mar e da Atmosfera (IPMA) for sharing with me meteorological data used for below study.

Company “Sea Born” for allowing me collecting additional information and for giving me opportunity of field work experience.

Company “Ventura-nature emotions” that allowed me to used data from previous sighting to conduct analyses about behaviour and group size of common dolphin, as well as letting me collect additional data during the year 2015. I would like to thank all people that made this experience even more remarkable. Thank you: Gil, Filipe Silva, Filipe Alves, Marco, Geert, Jorge, Luis, Catia and Andreia.

Rita Ferreira for hard and underestimated work of transferring sighting data to digital version.

Ana Dinis, for useful information, good criticism and being always ready to help.

Eliza, for her “Excell magic” and helping me putting me back together during these last days.

Damianowi, for being my “ArcGis call center”. Answering all, even the most stupid, questions and taking me out of my panic zone.

Finally, I would like to thank my family for giving me opportunities and all support that made me be where I am right now. My grandparents, who played important role in making my dreams coming true. I am grateful for all care and faith that you put in me.

And last, but not least, I want to thank Mateusz for all constructive advises, help and seas of support that he gave me when I was going under the waves.

Abstract

Short-beaked common dolphin (*Delphinus delphis*) is a small cetacean species that is among the most common marine mammals in Madeira Island. This thesis represents the first study that describes temporal distribution of *D. delphis* in this region and that relates it with environmental determinants. Results were based on data collected on platform of opportunity on the southern off Madeira Island during the period 2011 – 2014. They revealed that presence of *D. delphis* varied consistently between warm and cold seasons, with higher occurrences between December and May. This temporal distribution pattern reflects a summer migration probably directed northwards. General Additive Models showed that temperature, chlorophyll concentration, wind intensity and direction, as well as landings of sardine, curled picarel and Atlantic chub mackerel were important factors affecting *D. delphis* distribution. This study confirms information from previous studies revealing that common dolphin tents to avoid waters warmer than 18ºC. Moreover modelling results can also reflect a trophic cascade, between phytoplankton, pelagic schooling fish and *D. delphis*. Further studies are needed to evaluate seasonal migration patterns, involving animal telemetry and photo-identification, probably in cooperation with other institutions, as well as exact positioning of dolphin sightings and other potentially relevant environmental variables (e.g., depth, distance from the coast, upwelling intensity).

Keywords: *Delphinus delphis*, Madeira Island, temporal distribution, oceanographic variables, cetacean

Resumo executivo

O golfinho-comum (*Delphinus delphis*) é uma espécie de cetáceo de pequeno porte (cerca de 2 m), que habita as águas tropicais e temperadas do Oceano pacífico e Atlântico, e que é uma das espécies mais abundantes no arquipélago da Madeira. Apresenta um ligeiro dimorfismo sexual e a sua dieta consiste basicamente em peixes pelágicos (tal como sardinhas ou anchovas), mas também pode incluir cefalópodes. O golfinho-comum pode ser observado em grupos numerosos (até à unidade de milhar) mas em que os indivíduos não são parentes. O presente estudo realizou-se na costa Sul da Ilha da Madeira, que é de origem vulcânica e encontra-se localizada entre os arquipélagos dos Açores e das Canárias, a cerca de 1000 km da costa continental europeia. As principais correntes que afetam esta região são as correntes dos Açores, de Portugal, e das Canárias. Alterações na direção do vento nesta região podem causar eventos oceanográficos (downwelling) que afetam a distribuição de larvas de peixe. E entre os canyons submarinos das ilhas da Madeira e das Desertas costumam normalmente registar-se eventos de upwelling. Nesta região a temperatura da água varia entre c.a. 18ºC no Inverno e 24ºC no Verão, e o pico de fitoplâncton observa-se entre o fim do Inverno e o início da Primavera. Durante o resto do ano, as águas são pobres em clorofila e nutrientes. Os estudos focando a utilização do habitat em cetáceos na Madeira são reduzidos, pelo que este é o primeiro estudo dedicado à distribuição temporal do golfinho-comum e sua relação com variáveis ambientais na região.

A ocorrência da espécie foi baseada em dados recolhidos através de uma plataforma de oportunidade, em saídas bi-diárias ao longo de todo o ano entre 2011-2014 na área Sul (até às 6 milhas náuticas) da Ilha da Madeira, em modo presença-ausência. Generalized Additive Models (GAMs) foram usados, numa base semanal, para modelar a distribuição temporal do golfinho-comum em relação com variáveis oceanográficas e biológicas (descarga de presas). Informação adicional sobre o tamanho de grupo e comportamento foi recolhida através de duas plataformas de oportunidade entre 2006-2015. Os resultados mostraram que a presença de golfinho-comum variou significativamente, e consistentemente ao longo dos anos, entre as estações quentes e frias, com ocorrências (e tamanhos de grupo) mais elevados entre dezembro e maio. Estes resultados sugerem que a espécie migra durante os meses mais quentes, provavelmente para águas mais frias. Isto é corroborado por outros estudos que mostraram que pequenos delfinídeos, incluindo o golfinho-comum, são capazes de percorrer longas distâncias durante as migrações, e ainda pela similaridade genética entre indivíduos da Madeira e dos Açores. Baseado no melhor modelo dos GAMs, a temperatura de superfície da

água do mar foi a variável mais importante na previsão da distribuição do golfinho-comum, seguida da concentração de clorofila que é um indicador da biomassa de fitoplâncton. Os resultados obtidos suportam a hipótese de que esta espécie tende a evitar águas com temperaturas superiores a 18ºC, e refletem ainda a existência de uma cadeia trófica entre o fitoplâncton e peixes pelágicos (sardinha, chicharro e cavala). Os dados comportamentais confirmaram que as águas da Madeira constituem uma área importante de alimentação para o golfinho-comum, e que a disponibilidade de presas é um fator importante para a distribuição da espécies. As variáveis direção e intensidade do vento poderão estar ligadas a eventos oceanográficos que afetam a disponibilidade das presas do golfinho-comum, e o modo como afeta a detetabilidade da espécie alvo deverá merecer maior atenção no futuro. Do mesmo modo, outros estudos utilizando telemetria ou foto-identificação, com o envolvimento de várias instituições dos arquipélagos vizinhos, poderão ajudar a compreender melhor os padrões de migração desta espécie na região do Atlântico. Ainda, a utilização da posição dos avistamentos e a inclusão de outras variáveis (e.g., profundidade, distância à costa, intensidade do upwelling) poderão contribuir para explicar os comportamentos e os padrões dos movimentos do golfinho-comum na Madeira.

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1. Introduction and objectives of the work

1.1 History of marine mammalogy in Portugal

Due to the whaling activities, first records of whale and dolphin occurrences in Portuguese waters were made on the 12th century (Brito & Sousa 2011). The same study suggests it was the first time that *Delphinus delphis* was identified as the small cetacean species, and that was probably highly abundant in the Portuguese waters. Since the 12th century, when initial records of dolphins and whales were noted, the number of identified marine mammal species has increased, with the highest number of species being reported during the second part of the 20th century. Yet, on 1981, national legislation prohibited hunting and the use of whales and dolphins for any purpose. Since the 12th century, knowledge and interest on cetacean in Portugal have clearly increased, evolving from species anatomy and taxonomy (Bloodworth & Marshall 2007), to species ecology and behavior (Wursing & Wursing, 1980; Pusineri et al. 2007; Dinis 2014), and more recently to genetics (Quérouil et al. 2007 and 2013), acoustic (Lammers et al. 2002; Benoit-Bird, 2015) and antropogenic impact (Cunha 2013).

1.2 Cetaceans and their role in marine ecosystems

The Order Cetacea represents the largest Order of marine mammals and includes dolphins, whales and porpoises. It is represented by two subOrders: Order Mysticeti (baleen whales), which embraces the biggest whales existing on Earth, and Order Odontoceti (toothed whales), including the Family Delphinidae (Rice 1993). Cetaceans are top predators, thus they play an important role in the oceanic environments (Bowen 1997). First, marine mammals have a direct impact on their prey population, considering fish, zooplankton, as well as other marine mammals (Kenney et al. 1997; Overholtz 2002; Williams et al. 2004). Moreover, due to the fact that marine mammals are the biggest animals on Earth, their carcasses are an important source of detritus for benthic marine communities, supporting dense and diverse communities using whale fall as a source of energy for decades (Smith 2006).

1.3 Factors affecting distribution of marine mammals

Spatio-temporal distribution of marine mammals is influenced by different environmental variables including oceanographic, geographic and topographic factors such as sea temperature, wind intensity and direction, sediment composition, water depth and chlorophyll concentration as the parameter that determine more productive areas (Henderson et al. 2014, Correia et al. 2015). Moreover, migrations of cetaceans were observed on short- (daily, weekly) and long-timescale (monthly, annually) (Gaskin 1968; Cockcroft & Peddemors 1990; Davis et al. 1998; Littaye et al. 2004; de Boer et al. 2014). In Pelagos Sanctuary, Mediterranean Sea, Panigada et al (2008) revealed that sea surface temperature (SST) and chlorophyll concentration affect the occurrence of cetaceans. Depending on the marine ecosystem considered, there are more specific environmental drivers affecting cetaceans' distribution. For example, the use of estuaries in northern New South Wales (Australia) by Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) depends on tidal stage (Fury & Harrison, 2011). During spring season, dolphins prefer to enter the estuary for the duration of high-tide, and throughout summer, dolphins stay in a more restricted region, mostly confined to deeper and cooler estuarine waters. The distribution of bottlenose dolphin (*Tursiops truncatus*) in Scotland waters depends on the topography and hydrography of the area, possibly because these factors control dolphin's prey concentration and the occurrence of predators (Bailey & Thompson 2010). Summer aggregation of fin whales (*Balaenoptera physalus*) in the north western Mediterranean Sea is significantly related to net phytoplankton primary production (Littaye et al. 2004). Effects of tidal and current dynamics and topography on small cetaceans distribution were also referred for Bardsey Island (Whales), where *Phocoena phocoena* was found to prefer highly stratified waters, while *Grampus griseus* tends to aggregate in well mixed waters (de Boer et al. 2014).

In the Bay of Biscay, small delphinid communities (including common dolphin) tend to aggregate near the shelf break (Certain et al. 2008). According to Spyrakos et al. (2011), using opportunistic surveys onboard fishing boats in Galicia coast (Spain), *D. delphis* forages mainly in deeper waters of the Galician continental shelf, while more southern inshore waters may represent a nursery area. Opposite results were obtained by Correia et al. (2015), in a study of cetacean occurrence and spatial distribution in Portuguese waters, revealing that short-beaked common dolphin (*D. delphis*) prefers coastal habitats.

1.4 Habitat preference models and relevance to marine conservation

A limited number of studies tried to define habitats of marine mammals based on complex models that combine different (spatial and temporal) factors underlying cetaceans' distribution. These focused on the areas located in the Mediterranean Sea (Panigada et al. 2008), North-East Atlantic (Cañadas et al. 2005; de Boer et al. 2014; Correia et al. 2015;) and North-West Atlantic (Best et al. 2012). Cetacean habitat preference models allow the identification of potentially critical habitats for these species. As such, these models represent a critical tool for conservation and management of cetacean species, allowing the defining/delineation of most efficient protected areas (Cañadas et al. 2005) or the assessment of the impact of the expansion of marine renewable-energy platforms (de Boer et al. 2014), since they adversely affect cetacean's distribution (Pen et al. 2006; Thompson et al. 2010).

Modelling cetacean habitat choice and movement pattern is a very useful tool to manage endangered cetacean populations, for example killer whales that migrate between Atlantic Ocean and Mediterranean Sea (Esteban et al. 2013). Knowing which environmental variables affect their distribution allows the establishment of temporal protected areas, which may help in species conservation.

1.5 *Delphinus delphis:* biology and distribution

Short-beaked common dolphin (*Delphinus delphis* [Linnaeus 1758]) is a small cetacean species (see Fig. 1.A), which belongs to the Family Delphinidae, that also includes other oceanic dolphins (e.g., stripped dolphin, *Stenella coeruleoalba*; Atlantic spotted dolphin, *Stenella frontalis*; Risso's dolphin, *Grampus griseus*).

Short-beaked common dolphins can be easily distinguished from other delphinid species by their characteristic bright coloration and patterns on the body side. Just below the dorsal fin, this species shows a grey cape creating a V-shaped spot. Ventral patch has bright, white colour and is divided from dark body part by yellow stripe going from the animal's head to the middle of its corpus. Dolphins of this species have also a characteristic dark border around their eyes (http://www.nmfs.noaa.gov) (see Fig. 1.A). Individuals of *D. delphis* are slightly sexual dimorphic. Studies based in individuals stranded on the Irish and French coasts revealed that *D. delphis* reaches sexual maturity at the mean age of 11,9 years (Murphy et al. 2005). In North-East Atlantic region (based on the studies made on individuals stranded on UK, Irish, French, Galician (northwest Spain) and Portuguese coast), females are able to reproduce between 6,5 and 26 years old and become sexually mature at a mean age equal to 8,7 years (Murphy et al. 2009). Males are slightly larger than females, reaching a mean asymptotic size of 2,06 m (Murphy et al. 2005), while females do not reach more than 2,0 m. This species has a relatively short lifespan, around 22 years (Reynolds & Rommel 1999), although individuals with the age 29 years were already reported (Murphy et al. 2009). *Delphinus delphis* is a fast swimmer, reaching a mean speed up to 3 $m*s^{-1}$. Individuals make short dives, typically between 10 seconds and 2 minutes, but dives lasting for as long as 5 minutes have been also recorded (Hoelzel 2009). This species is capable of diving to depths of at least 200 m, in search for prey (http://www.nmfs.noaa.gov). *Delphinus delphis* is acoustically active and able to produce a high variety of sounds including whistles, chirps, barks, and clicks (Reynolds & Rommel 1999). Dolphins of this species tend to aggregate in well-defined fluid pods, composed by ten to up to several thousand individuals (Archer 1996) (Fig. 1.B), not necessary genetically correlated (Viricel et al. 2008). Stomach content analysis of short-beaked common dolphin in Portuguese waters revealed a diet mainly composed by pelagic fish, mostly dominated by the fish families; Clupeidae (e.g., *Sardina pilchardus*) and Gabidae (e.g., *Micromesistius poutassou*), but also cephalopods (Silva 1999). *Delphinus delphis*' diet from the coastal waters of the Bay of Biscay (France) is also dominated by fish, with 73 - 93% of the total prey mass constituted by fat fish (anchovy (*Engraulis encrasicolus*), mackerel (*Trachurus* spp.), sardine (*Sardina pichardus*), sprat (*Sprattus sprattus*)) (Meynier et al. 2008).

Delphinus delphis shows a wide distribution, residing in Pacific and Atlantic temperate (up to 60° to the North and 50° to the South) and tropical waters, as well as in the Mediterranean Sea and Black Sea (Rice 1993). Is also one of the most common cetacean species observed in North Atlantic waters (Correia et al. 2015).

Figure 1: (**A**) Individual of short-beaked common dolphin, *Delphinus delphis,* with its characteristic bright coloration and patterns on the body side; and **(B)** Large group of *Delphinus delphis*. (Source B: *http://us.whales.org*).

1.6 Marine mammals, including *Delphinus delphis*, in Madeira Archipelago

Madeira archipelago is an autonomous region of Portugal, located in the northeast Atlantic Ocean included in the Macaronesia biogeographic region. Studies on marine mammals around Madeira Island focused on several species and subjects. Freitas et al. (2012) recently updated the checklist of cetacean species observed in the region, that currently includes 29 species. This area is also know as a resting habitat of endemic species of monk seal *(Monachus monachus)* (Karamanlidis et al. 2004). Stable associations and dive profiles of Bryde's whale (*Balaenoptera brydei*) in the Madeira archipelago were investigated (Alves et al. 2010), as well as vertical movements of tagged sperm whale (Ph*yseter macrocephalus*) were studied (Freitas et al. 2008). Genetic analyses of bottlenose dolphins' (*T. truncatus*) tissue from Azores, Madeira and mainland Portugal were used to study gene flow between these areas (Quérouil et al. 2007). An extensive investigation of short-finned pilot whales (*Globicephala macrorhynchus*) (Alves 2013), as well as bottlenose dolphins (*T. truncatus*) (Dinis 2014), including information on population dynamics and species-specific habitat was also undertaken. Moreover, potential human impacts on cetaceans near the Madeira Island, including the influence of whale watching boats on the traveling speed of a few Odontoceti and Mysticeti species (Ferreira, 2007) and the effects of traffic near Funchal city on cetaceans (Cunha 2013), were also evaluated.

Delphinus delphis has been suggested as the most common cetacean species around Madeira Island (Freitas et al. 2004). Studies on *D. delphis* in this region are based on genetic and biochemical approaches. Tissue biopsy sampling, coupled to mitochondrial DNA (mtDNA) sequences and microsatellite markers in small cetaceans, including short-baked common dolphins, were used to evaluate genetic differentiation and population genetic structure around this geographic area (Quérouil et al. 2010a).. According to this study, no genetic differences were detected for *D. delphis* in Azores and Madeira archipelagos. These results imply a mixing between populations, maybe due to large migration within and outside the region, and the existence of gene flow over much larger distances than usually documented for small delphinids (Quérouil et al. 2010b). However, fatty acid and stable isotope profiles from skin and blubber of short-beaked dolphins near the Azores and Madeira archipelagos varied between areas, which could indicate the occurrence of two different ecological stocks (Quérouil et al. 2013). Yet, differential seasonal sampling of individuals in both archipelagos could also result from a seasonal variability in feeding habits (Quérouil et al. 2013).

In summary, despite being suggested as the most common cetacean species around Madeira Island and a relevant top predator, studies of the temporal distribution of short-beaked common dolphin *D. delphis* in this area are limited to grey literature (Freitas et al. 2004a). Knowledge of *D. delphis's* habitat preferences and seasonal variability, in combination to underlying environmental drivers, are useful tools for species conservation and design of marine protected areas. Although, *D. delphis* is considered as Least Concern (IUCN regional status) around Madeira Island (Freitas et al. 2004b), in some marine ecosystems its occurrence has dramatically decreased (Piroddi et al. 2011). Moreover, since the evolutionary history and past expansion of short-beaked common dolphin's reveals a close relationship with sea surface temperature (SST) variability, changes in *D. delphis* distribution could be generated as consequence of current global warming trends (Amaral et al. 2012). In this context, knowledge of interaction between *D. delphis* current distribution and oceanographic variables (e.g., SST, phytoplankton biomass) may represent a useful approach for predicting future distribution changes in the area.

1.7 Objectives of the work

This study aims to determine seasonal distribution patterns of *D. delphis* around the south coast of Madeira Island, and contribute to better understand underlying environmental drivers including oceanographic variables (e.g., sea water temperature, chlorophyll concentration, wind direction) and food availability (e.g., fisheries's data). This study is based on a dataset collected in a platform of opportunity, between 2011 and 2014, in the main cetacean-watching area of the archipelago of Madeira.

2. Materials and Methods

2.1 Study area

Madeira archipelago is an autonomous region of Portugal, located in the northeast Atlantic Ocean, and along with Azores (Portugal), Canary Islands (Spain) and Cape Verde, constitute the Macaronesia biogeographic region. It includes four isolated volcanic (groups of) islands: Madeira, Porto Santo, the Deserts, and the Savage Islands (Schmincke 1973). It is located between Azores and Canaries, at around 1000 km from the European coast and around 500 km from Africa (Fig. 2). This study focused on the south coastal area of the main island, Madeira. This island is surrounded by a narrow (< 5 km) continental shelf (Rodrigues et al. 2006), which is followed by deep (ca., 1500 m) oceanic waters (Prada 2000).

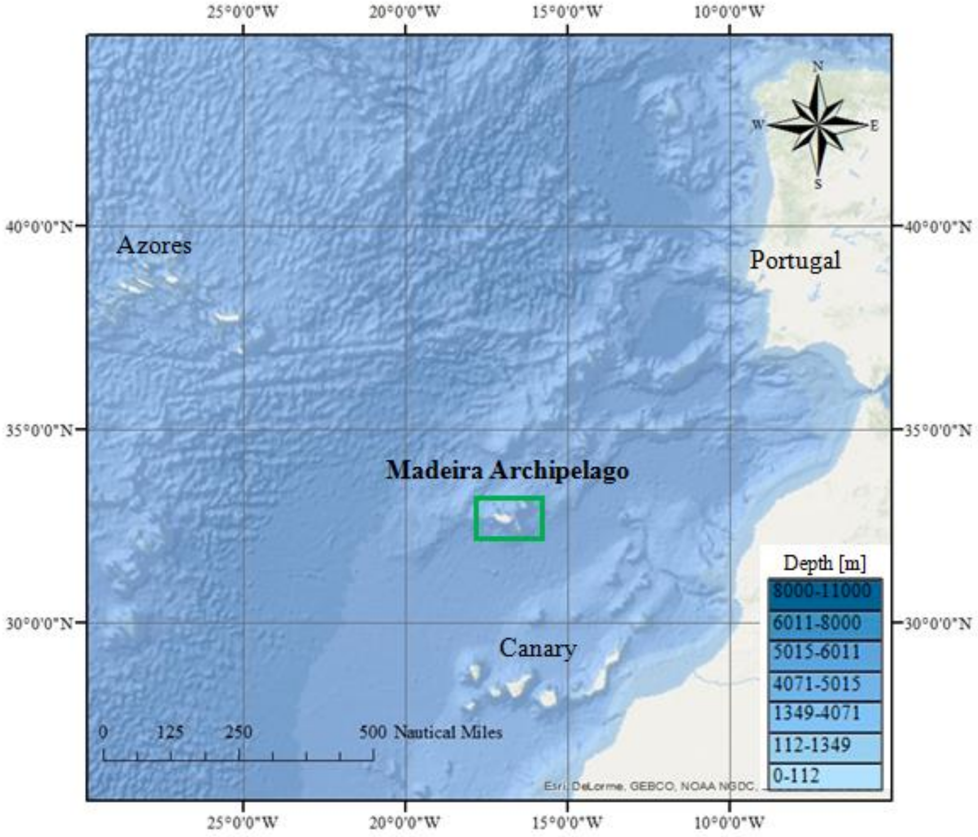

Figure 2 : Location of Madeira Archipelago (green rectangle) in the Atlantic Ocean. Created with *ArcGis for Deskop 10.3.1 (ESRI, 2012).*

Madeira Archipelago is located at the eastern edge of the North Atlantic subtropical gyre. The main large-scale currents affecting the study area include the Azores Current, the Portugal Current and the Canary Current (Sala et al. 2013). Temporal (monthly and annual) changes in the Azores Current bring high salinity and temperature water from the North to the Madeira coast (Johnson & Stevens 2000). North winds dominate and are stronger during the late spring and early summer (Caldeira et al. 2002). The wave climate around the island is in general directionally focused and dominated by 0 to 1 m-height eastern propagation waves, with higher waves, including stormy-waves (3 – 5 m) of northern propagation, during winter. Extreme storms are not expected very often in coastal areas (Rusu & Guedes Soares 2012).

The signatures of island mass effect phenomena (see Doty & Oguri 1956), including warm island wakes, lee anticyclonic eddies, frontal systems and localized upwelling, have been detected around Madeira Island mainly by remote sensing approaches (Caldeira et al. 2002).

Indeed, the topography of the island affects oceanographic variables, usually causing higher sea surface temperatures on the leeward (south coast) of Madeira Island. Moreover, underwater ridges situated between Madeira and Desertas Islands are responsible for local upwelling events, that support primary production, as well as cyclonic gyres in the western part of the Madeira Island, from April until September (Caldeira et al. 2002). Caldeira et al. (2014) revealed that orographically perturbed winds, blowing toward the island, can generate long-lived mesoscale anticyclonic eddies leeward of Madeira (south coast), particularly during summer months. These eddies cause local downwelling events and, after leaving the coastal area around the island, travel northwesterly at a speed of 5 km/day, for at least 2 months. Coastal anticyclonic eddies are associated to reduced concentrations of dissolved inorganic nutrient and transport of fish larvae towards offshore waters (Caldeira et al. 2001).

In respect to physical oceanographic variables, sea surface temperature around Madeira Island ranges between ca. 18°C and 24ºC during winter and summer seasons, respectively (Martins et al. 2007). The concentration of dissolved inorganic macronutrients (e.g., phosphate, nitrate) in surface waters surrounding Madeira Island is usually low, due to vertical stratification, but higher nutrient concentrations are recorded in areas affected by upwelling events, between Madeira and Desertas Islands (Campuzano et al. 2010). Chlorophyll concentration, a proxy for phytoplankton biomass, in the study area shows clear maxima during spring time in the euphotic zone, with values ranging between 0,07 and 0,22 mgL^{-1} (Martins et al. 2007). Phytoplankton communities are composed by at least 200 taxa, dominated by diatoms and dinoflagellates (Kaufmann et al. 2012).

2.2 Assessment of *Delphinus delphis* distribution

Data to determine *D. delphis* occurrences in the south coast of Madeira island (see Fig. 3) were collected onboard a platform of opportunity, the marine mammals watching catamaran “Sea Born”, a 23 m length sailing boat, model Fountaine Pajot Tahiti 75 (Fig. 4). A four year period (from January 2011 to December 2014) of dolphin observations was used for this study.

The exact study area was evaluated by a Global Positioning System (GPS) survey. conducted between January 2015 and May 2015. Since the strategy used by the marine mammal watching vessel “Sea Born” was kept constant since 2011 (e.g., boat, speed, crew, observer, harbor, departure and arrival time), we assumed that the 2015 GPS survey is representative of the area evaluated in the period 2011 - 2014. GPS survey was undertaken using a Garmin eTrex 10 device, which was turned on before catamaran left the harbor and turned off after arrival to harbor. Data were extracted using MapSource software (Garmin 2007). Sampled tracks were used to construct the study area map using ArcGis for Desktop v.10.3.1 program (ESRI 2012). An ocean base map available in the software was applied for visual representation of sampling surveys. For the cartographic image WGS 1984, a geographic coordinate system was used. Most of the sampling surveys onboard observation platform were concentrated around the nearshore area of Funchal city area (where departure and arrival harbor is located), on the southern part of Madeira Island, covering up to 6 nautical miles from the coastline (Fig. 3).

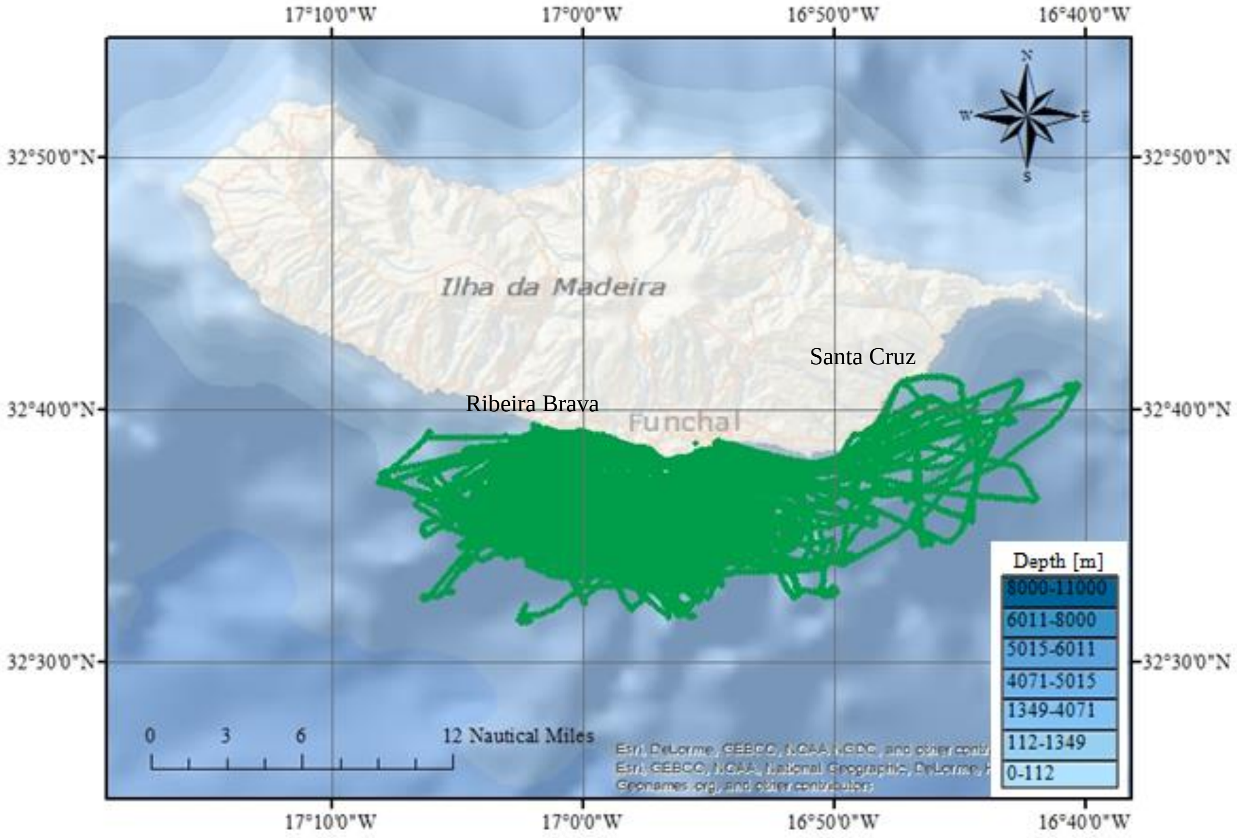

Figure 3 : Location of the study area, off southern Madeira Island (NE Atlantic), based on the GPS tracks. Source: *ArcGis for Deskop 10.3.1 (ESRI, 2012)*.

During the 4-year study period (2011-2014), the sampling surveys (of 3 h each) were regularly conducted on a bi-daily basis, in the morning (10:30 - 13:30) and afternoon (15:00 - 18:00). The few exceptions of days without observations were due to lack of passengers, rough weather or boat's maintenance (see Appendix, Fig. I). Dolphin sightings were conducted using a standardized methodology. Straight after leaving the marina (10 min after departure), one observer (with ca. 1,8 m height), standing on the highest point of the deck (at around 3 m from the sea level), started searching for cetaceans. The period between the initial searching time and *D. delphis* observation varied between 15 min and almost 2 hours. When dolphins were spotted, the boat headed towards the animals, at a speed of approximately 4,5 $m*s^{-1}$. The boat speed was reduced to 1 $m*s^{-1}$ after reaching animals to a distance around 50 m, and stayed in the vicinity for 5 min to 15 min. The skipper then recorded *D. delphis* occurrence and additional information. The probability of species misidentification almost inexist given that *D. delphis* is morphologically conspicuous and that the observer has a large experience (of over 15 years) in cetacean species identification. When dolphins were present in the study/surveyed area and the sea conditions were < Beaufort 5, usually one single group was found, with few exceptions (2 to 3 different groups). In some cases, the crew received information, from local fisherman or other whale watching boats, about areas where cetaceans were being observed, and these areas were actively explored. This external information may have influenced the sampling effort factor (when the crew got information in advance, it was easier to find dolphins in the area), and will be taken into consideration in the discussion.

Figure 4: Whale watching catamaran “Sea Born” used as platform of opportunity for evaluation of *Delphinus delphis* occurrence.

2.3 Information collected on *Delphinus delphis*: group size and behavior patterns

Sampling surveys onboard “Sea Born”, during 2011 - 2014, were used to acquire information about the presence or absence of *D. delphis* in the study area. Moreover, data collected onboard the marine mammal watching vessel “Ventura”, during the period of time 2006 – 2015, and onboard “Sea Born” during January - May 2015, provided additional information on *D. delphis* behaviour group size and behavior. Such data was not collected at a regular basis. Group size was based on information collected from 173 sightings, and derived by visual judgment at sea, based on the estimation of the number individuals occurred in the area limited by the observer’s sight. After the preliminary judgment of the group size data, five classes were distinguished: first class with groups up to 10 individuals; second class from 11 to 20 individuals; third class from 21 to 40 individuals; fourth class from 41 to 70 individuals; and fifth class with more than 70 individuals (Stockin et al. 2008). As the assumption of ANOVA were not met, for the period 2006 - 2015, differences in group size between years and between months were tested using a non-parametric, Kruskall-Wallis one-way analysis of variance by ranks (see Apendix, Table I). Dolphin behavior patterns (of free-ranging) individuals were evaluated by a visual judgment method. Individual behavior patterns were categorized into the following five categories: feeding/foraging, resting, traveling, socializing and other non-defined activities. They were defined according to Shane (1990), a methodology used successfully in previous studies (e.g., Brager 1993; Neumann 2001b;). A total of 153 sightings were used for behavioral analyses.

2.4 Oceanographic variables

2.4.1 Sea surface temperature and chlorophyll concentration

Sea surface temperature (SST) and surface chlorophyll-a concentration (Chla), used as a proxy for phytoplankton biomass, were obtained from the Giovanni platform (www.giovanni.gsfc.nasa.gov) satellite remote sensing and acquired for the study period (2011 - 2014). Both SST (night passes at 4 μm) and Chla data were acquired from Moderate-resolution Imaging Spectroradiometer sensor on NASA’s EOS Aqua satellite (MODIS-Aqua), at a 4 km spatial resolution. Temporal resolution ranged from 8-day composites for Chla to monthly mean composites for SST. Due to the occurrence of mesoscale variability, associated to island mass phenomena (Caldeira et al. 2002), to obtain more representative data, the study area was partitioned into three polygonal regions: western area (area 1; 32.522; 32.643; -

17.104; -16.943), middle area (area 2; 32.529; 32.620; -16.961; -16.774) and eastern area (area 3; 32.529; 32.668; -16.810; -16.666) (see Fig. 5). Since no significant differences in SST and Chla were detected between regions (see Appendix, Fig. II and Fig. III), mean values for all regions were subsequently used.

2.4.2 Current velocity

Sub-surface current velocity (at 15 m) was obtained through Ocean Surface Current Analyses – Real Time (OSCAR) data processing system, accessed at the National Oceanic and Atmospheric Administration (NOAA) website (http://www.oscar.noaa.gov), which combines results from Satellite Altimeter Surface Height Data and Satellite Vector Height Data. Current data were acquired at a five day-temporal resolution and at ca. 36,6 km spatial resolution. Mean current speed [m*s^{-1}] from two sites located in the study area (32.667; -17.00; 32.667; -16.667) were subsequently used (Fig. 5).

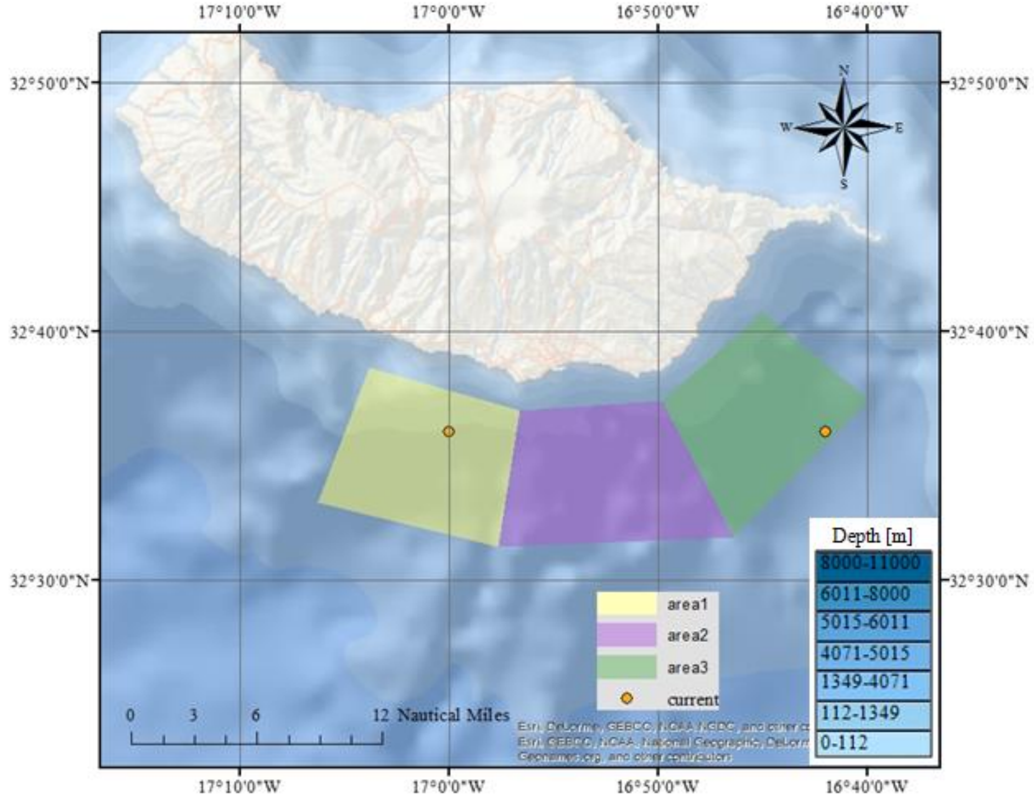

Figure 5: Location of three regions used to obtain satellite data of SST and Chla concentration, and two sites used to extract mean current speed data.

2.4.3 Meteorological data

Wind intensity and directionmeasured at the meteorological station Caniçal (eastern Madeira Island), on a daily basis, were retrieved from Instituto Português do Mar e da Atmosfera (IPMA). Wind intensity was measured in $m*s^{-1}$, and wind direction was described using codes: 0-not defined; 1-north-east (22,5º - 67,5º); 2-east (67,5º - 112,5º); 3-south-east (112,5º - 157,5 º); 4-south (157,5º - 202,5º); 5-south-west (202,5º - 247,5º); 6-west (247,5º - 292,5º); 7-north-west (292,5º - 337,5º); 8-north (337,5º - 22,5º).

2.5 Fishery data

Data on the landings of five main commercial fish species, that are known as a potentially prey species for *D. delphis* (Dinis et al. 2008) were used as proxies for prey availability for dolphins. These were the: bogue (*Boops boops*), the sardine (*Sardina pilchardus*), the Atlantic chub mackerel (*Scomber colias*), the curled picarel (*Centracanthus cirrus*), and the blue jack mackerel (*Trachurus picturatus*). Monthly catches of these five species in the southern part of Madeira Island, during the period 2011 - 2014, were provided by Direção Regional de Pescas, located in Funchal, Madeira. Fish catch [$kg*month^{-1}$] measurements were based on the effort of three fishing boats during 2011 and five fishing boats during 2012 - 2014. The number of fishing trips made each month, within the study period, was used as an effort factor. For future analyses fishery data transform using formula: fish landings = fish catch per month [kg]/ number of fishing trips per month.

2.6 Data analyses

2.6.1 Temporal distribution of *Delphinus delphis*

Data from *D. delphis* observations during 2011 – 2014 were transformed into a binary variable. The presence of individuals during morning, afternoon or both sampling surveys was indexed as 1, while their absence during a whole day was indexed as 0. The same strategy was used for days with and without cruises. Each day of the year was treated separately, meaning that a maximum of 365 observations and sampling surveys per year were possible. The total number of daily sampling surveys (1169) and the total number of surveys with *D. delphis* observations (341) during the period 2011 - 2014 were used for analyses (see Appendix, Fig. IV). Temporal variability was based on weekly-integrated data. Sighting records for each week were calculated as: the number of days with observations per week divided by the number of days with sampling surveys per week. As the assumptions of ANOVA were not met, differences in *D. delphis* sighting record between years were tested using a non-parametric, Kruskall-Wallis one-way analysis of variance by ranks, using “R Software” (R Development Core Team 2012). Based on the SST variability during the study period and previous published information on the study area (see Martins et al. 2007), two seasons were distinguished: a cold season (December - May) and warm season (June - November). Subsequently, differences in weekly mean sighting records for each season and year were tested using Analyses of Variance (ANOVA). Levene test for homogeneity of variances and Shapiro–Wilk test for normality were applied to check the assumptions for the application of ANOVA ($\alpha = 0.05$) , a parametric test. Visualization of the temporal variability of sighting records during the period 2011 - 2014 was based on monthly mean data using Microsoft Office Excel (Microsoft 2007) software.

2.6.2 Modeling *Delphinus delphis* sighting records

Generalized Additive Models (GAM) were used to model the temporal distribution of *D. delphis* in the south Madeira Island, as a function of oceanographic variables and fisheries data. GAM analyses was conducted using “R Software” (R Development Core Team 2012) and the mgcv package. GAM’s were chosen over the Generalized Linear Models (GLM) since preliminary data analyses did not show significant linear relationships between sighting records (the response variable) and available environmental (explanatory) variables. This statistical method was successfully frequently used in studies addressing spatial and temporal distribution of marine cetaceans (e.g., Spyrakos et al. 2011; Esteban et al. 2013; Correia et al. 2015; Best et al. 2012). The following independent environmental variables were used in GAM, as potential predictors/drivers of *D. delphis* sighting records: SST, Chla, current velocity (at sites 1 and 2), wind intensity and direction, and fishery landings of bogue (*Boops boops*), sardine (*Sardina pilchardus*), Atlantic chub mackerel (*Scomber colias*), curled picarel (*Centracanthus cirrus*), and blue jack mackerel (*Trachurus picturatus*). Environmental variables acquired at a monthly temporal resolution (fishery catches, SST) were assumed as representative of the four weeks within each month. Data available on a daily basis were integrated into mean weekly composites (Chla, wind intensity, current velocity). Wind direction was considered the predominant direction within each week; in case a dominant wind direction was not reported, it was indexed as not defined.

First GAM models were run using daily sighting records. Yet, only a minor sighting record deviance was explained by these models (see Appendix, Table II). As a consequence, mean weekly sighting records were used. Gaussian family, function of identity and the cubic regression spline (cr) for smoothing were applied in the model. Resource selection function (rsf) method was used for choosing the best model (Elith & Leathwick 2009). Initially, all environmental variables were integrated into the model. After running a model, variables with the less significant level were excluded from analyses, and the model parameters were re-calculated. Generalized cross-validation (GCV) was used as the main criteria to include or exclude specific variables. When variable elimination from the model lead to smaller GCV, the change was accepted. Yet, if variable elimination did not improve the model, the variable was maintained. The same strategy was applied for all environmental variables starting by the less significant variables.

3. Results

3.1 Oceanographic variables and fishery data

Sea surface temperature (SST) in the study area varied between 17ºC in the colder season and 25ºC in the warmer season during years 2011 - 2014. Temperatures more than 20ºC were observed for ca. 6 months during four years study period. In 2012 the lowest (17ºC) and the highest (25ºC) temperature was observed. Late winter/beginning of spring was the time when phytoplankton bloom was recorded with the highest chlorophyll concentration (Chla) in the water (0,35 – 0,5 $mg*m^{-3}$). Except period of these blooms, during rest of the year Chla concentration was lower than 0,2 $mg*m^{-3}$ (Fig 6). Intensity and direction of the wind did not show any seasonal pattern. Most of the wind during the study period 2011 – 2014 were blowing with the speed from 2 to 8 $m*s^{-1}$ and had north direction (Fig 7). Current velocity detected in two different areas showed similar variability. Velocity more than 0,1 $m*s^{-1}$ was reported sporadically and randomly, as seasonal differences were not easy to distinguished (Fig. 8). The biggest landings of sardine were observed in the end and begging of each year (more than 20 kg per fishing trip), while the biggest one were observed in December of 2011 and 2014. Landings of bogue varied between years, with the smaller quantities during 2011 and the biggest in 2013 (Fig. 9). Culred pickerel was observed only in the begging of the year 2012 and 2014. The biggest landings of Atlantic chub mackerel and blue jack mackerel were observed in 2011 and they were followed by very low landings rated of both species in 2012 (Fig. 10).

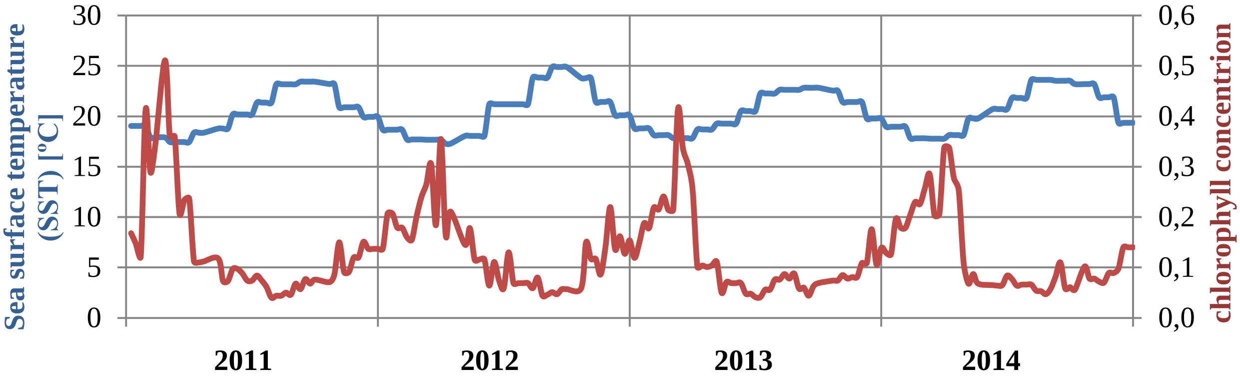

Figure 6: Sea surface temperature (SST) and chlorophyll concentration (Chla) represented by weekly means during the study period 2011 – 2014.

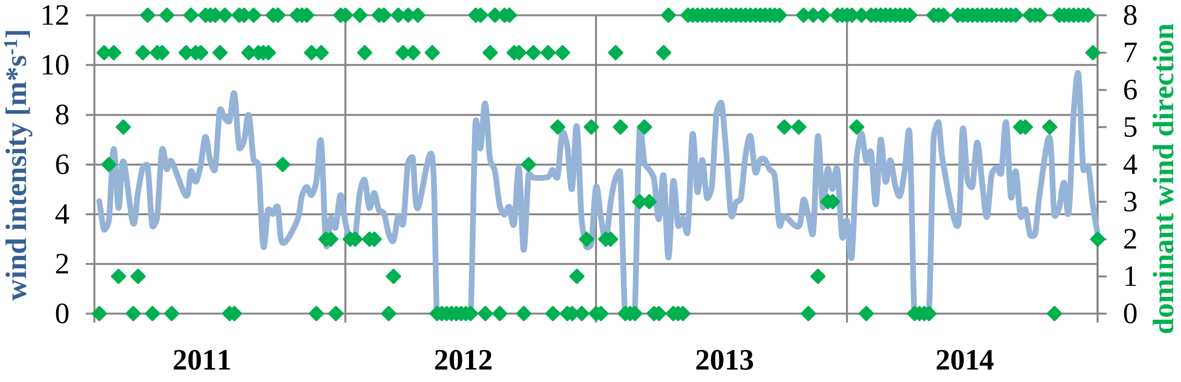

Figure 7: Wind intensity (weekly mean) and wind direction (dominant per week) the study period 2011 – 2014. Dominant wind direction was determine as followed; 0-not defined; 1-north-east; 2-east; 3-south-east; 4-south; 5-south-west; 6-west; 7-north-west; 8-north.

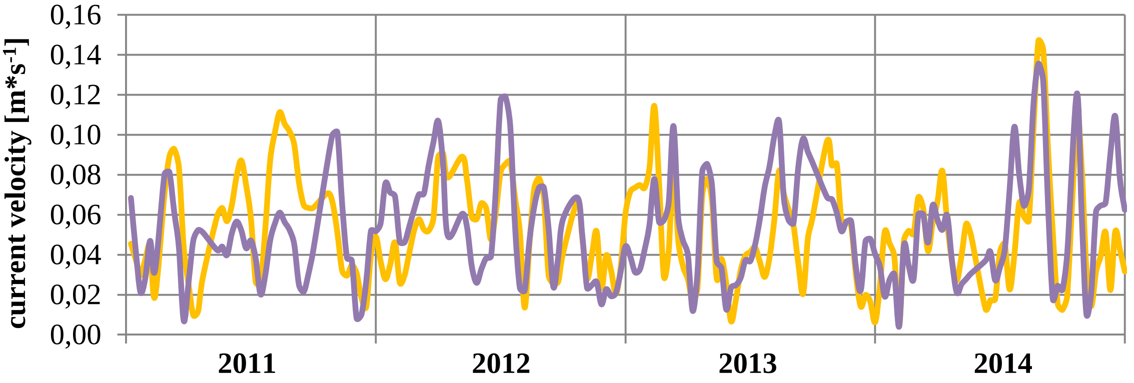

Figure 8: Mean current velocity detected from two points located within study area represented by weekly means during the study period 2011 – 2014.

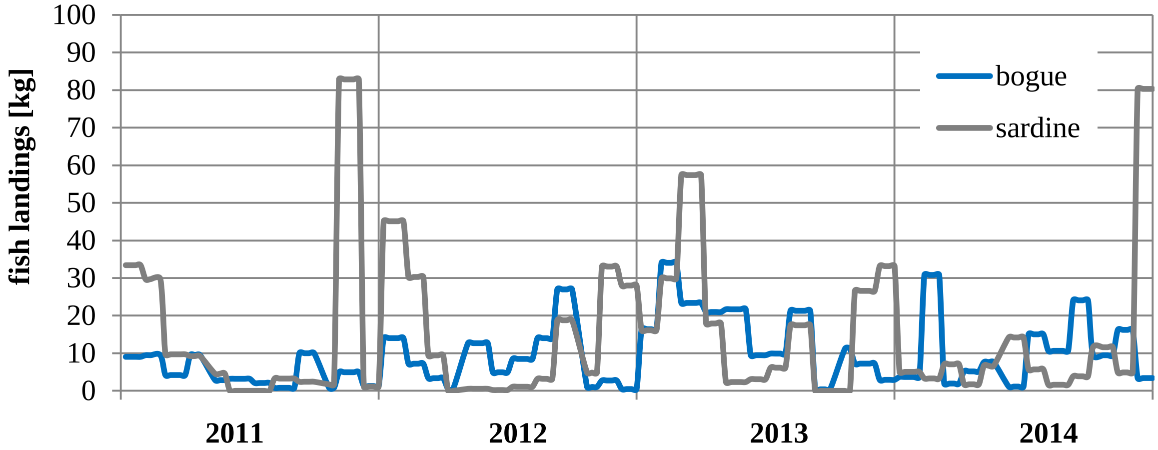

Figure 9: Landings of sardine and bogue represented by weekly means during the study period 2011 – 2014.

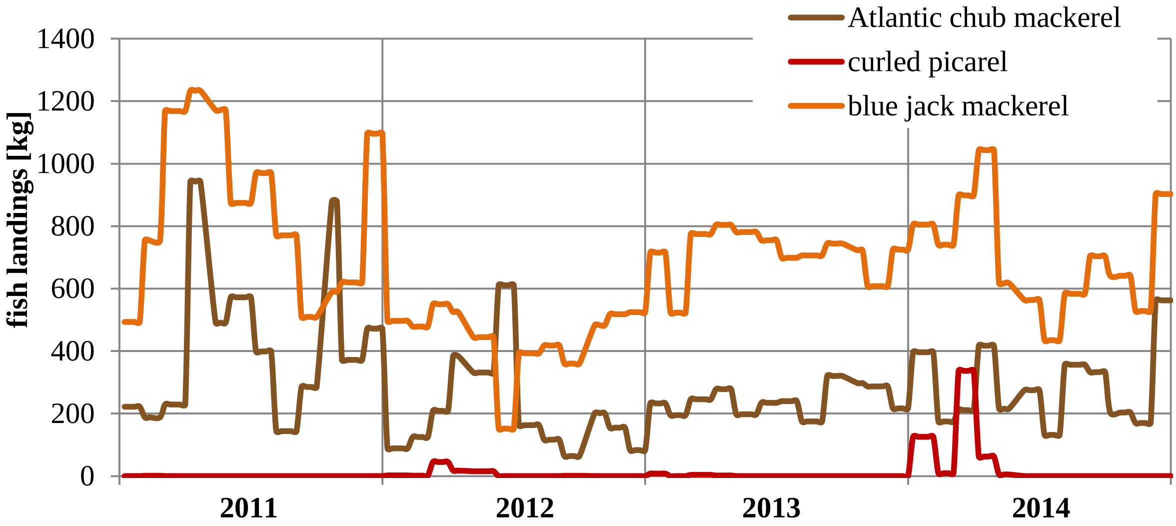

Figure 10: Landings of Atlantic chub mackerel, curled pickerel and blue jack mackerel represented by weekly means during the study period 2011 – 2014.

3.2 Temporal variability of *Delphinus delphis* sighting records

During the period 2011 - 2014, a total of 2189 sampling surveys were undertaken. They were conducted all year round, with the highest frequency during the summer period and the lowest during October (Fig. 11). Although some inter-annual variability in the *D. delphis* sighting records was observed (Fig. 12), this was not significant (Kruskal – Wallis test, p-value = 0.822) (see appendix, Table III). Yet, significant differences in *D. delphis* sighting records were detected between warm and cold seasons (ANOVA, $p < 0.001$; see Appendix, Table IV), with higher picks during winter-spring period (December – May), and lower picks during late spring-autumn (June – November, see Fig. 11). The largest amplitude in sighting records was observed between May and June. In March and April *D. delphis* was spotted during more than 70% of the surveys, while in September and October less than 5% (Fig. 11).

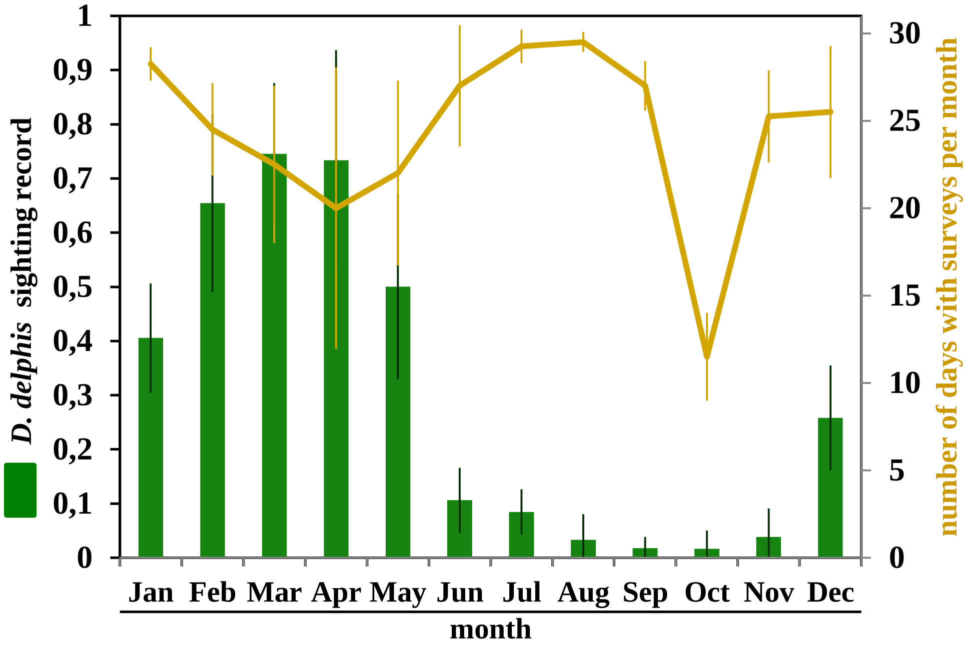

Figure 11: Monthly mean variability in *Delphinus delphis* sighting records [number of days with observations/number of days surveyed per month] in south Madeira Island and total number of days surveyed during each month (sampling effort) during the period 2011-2014 (total of 1462 surveys). Vertical bars represent standard deviation of sighting records.

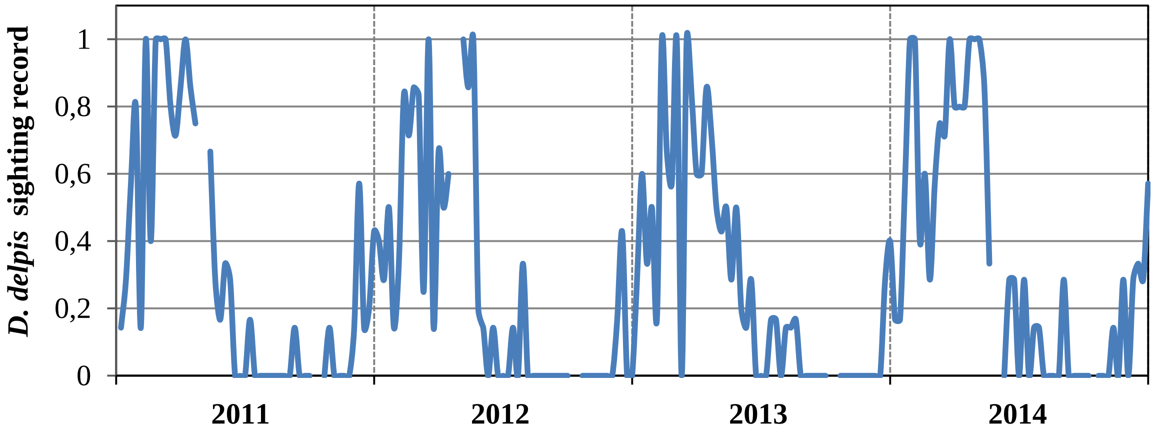

Figure 12: Inter-annual variability in *Delphinus delphis* sighting records [number of days with observations/number of days surveyed per week] in south Madeira Island during the period 2011-2014.

3.3 Modeling *Delphinus delphis* sighting records

Apart from one environmental variable (monthly landings of *T. picturatus*) that was eliminated, all the remaining variables were kept in the best model. This model used ten environmental variables and explained 79.4% of the deviance in *D. delphis* sighting records, with a GCV value of 0.0341 and an adjusted R^2 equal to 0.747 (see Table 4). The model showed a highly significant correlation ($p< 0.001$) between *D. delphis* sighting records and SST, Chla and sardine catches. It revealed a negative correlation between SST and presence of *D. delphis* and positive with Chla concentration. Landings of curled picarel (*C. cirrus*, $p< 0.01$) and Atlantic chub mackerel (*S. colias*, $p< 0.05$), as well as wind intensity and direction ($p< 0.01$), were also significant predictors of *D. delphis* sighting records. It was showed that occurrence of curled picarel and Atlantic chub mackerel have a positive impact on common dolphins presence. Combining direction and intensity of the wind revealed that *D. delphis* was observed more often when intensity of the wind did not reach 7 $m*s^{-1}$ and when its direction was restricted to southern, eastern or south-eastern propagation. The remaining three variables kept in the model (bogue discharges and current velocity at sites 1 and 2) were not individually important predictors of the present or absence of *D. delphis*. The effect of bogue landing was slightly above the defined significance level ($p= 0.051$; see Table 1, Fig. 13).

Table 1: Results of Generalized Additive Model (GAM) analyses of *Delphinus delphis* sighting records in south Madeira Island (2011 – 2014), predictor environmental variables and associated statistical parameters (bs = cr - cubic regression splines smoothing, edf - effective degrees of freedom, F - test value, GCV - generalized cross validation**,** k - basis dimension, n - number of samples, Pr(>|t|) – p value of t-test, R-sq.(adj)- Adjusted R squared; Scale est – scale parameter; significance: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’; s - smoothing, t - test value).

<table>
<tr><td colspan="5">Best final model: sighting rate ~ s(SST, k = 8, bs = “cr”) + s(chlorophyll, k = 8, bs = “cr”) + s(bogue, k = 8, bs = “cr”) + s(Atlantic chub mackerel, k = 8, bs = “cr”) + s(sardine, k = 8, bs = “cr”) + s(curled picarel, k = 8, bs = “cr”) + s(current2, k = 8, bs = “cr”) + s(current1, k = 8, bs = “cr”) + s(intensity of the wind, k = 8, bs = “cr” + s(wind direction, k = 8, bs = “cr”)</td></tr>
<tr><td colspan="5">Parametric coefficients</td></tr>
<tr><td rowspan="2">Intercept</td><td>Estimate</td><td>Standard Error</td><td>t value</td><td>Pr(>|t|)</td></tr>
<tr><td>0.2798</td><td>0.0124</td><td>22.56</td><td><2e-16 (***)</td></tr>
<tr><td colspan="5">Statistical parameters</td></tr>
<tr><td>n</td><td>R-sq.(adj)</td><td>Deviance explained</td><td>GCV</td><td>Scale est</td></tr>
<tr><td>179</td><td>0.747</td><td>79.4%</td><td>0.034052</td><td>0.027532</td></tr>
<tr><td colspan="5">Approximate significance of smooth terms</td></tr>
<tr><td>Variables</td><td>edf</td><td>F</td><td colspan="2">p-value</td></tr>
<tr><td>s(SST)</td><td>2.701</td><td>22.670</td><td colspan="2">3.42e-13 (***)</td></tr>
<tr><td>s(chlorophyll)</td><td>1.000</td><td>14.503</td><td colspan="2">0.000204 (***)</td></tr>
<tr><td>s(sardine)</td><td>4.821</td><td>5.633</td><td colspan="2">6.73e-05 (***)</td></tr>
<tr><td>s(curled picarel)</td><td>5.140</td><td>3.821</td><td colspan="2">0.002088 (**)</td></tr>
<tr><td>s(wind direction)</td><td>6.125</td><td>2.427</td><td colspan="2">0.024473 (*)</td></tr>
<tr><td>s(intensity of the wind)</td><td>4.076</td><td>2.344</td><td colspan="2">0.045578 (*)</td></tr>
<tr><td>s(Atlantic chub mackerel)</td><td>1.000</td><td>3.962</td><td colspan="2">0.048389 (*)</td></tr>
<tr><td>s(bogue)</td><td>2.226</td><td>2.752</td><td colspan="2">0.051081 (.)</td></tr>
<tr><td>s(current1)</td><td>2.573</td><td>2.293</td><td colspan="2">0.076571 (.)</td></tr>
<tr><td>s(current2)</td><td>3.610</td><td>1.709</td><td colspan="2">0.144862</td></tr>
</table>

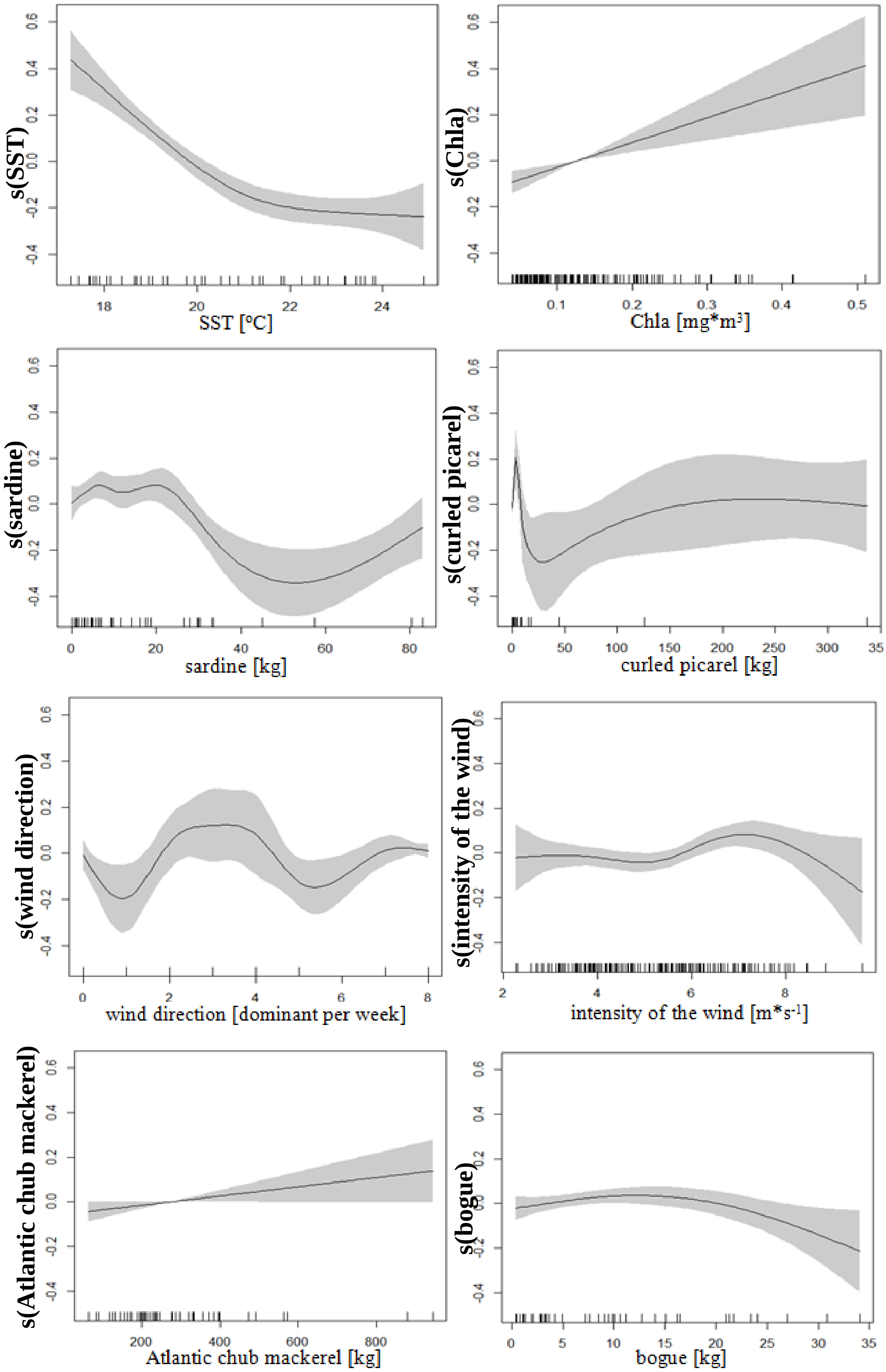

Figure 13: Visualization of General Additive Model (GAM). Y- axis represents predictable variable of *Delphinus delphis* occurrence in relation to explanatory variable (x-axis) . The shaded areas represents a 95% confident interval of the model predictability. Black ticks above the x-axis mark *Delphinus delphis* presence.

3.4 *Delphinus delphis* group size and behavior patterns

Delphinus delphis group size, measured as the number of individuals per group, did not show significant differences between years (Kruskall – Wallis test, p= 0.05264) and months (Kruskall – Wallis test, p= 0.1455), during the period 2006 – 2015 (see Appendix, Table I)**.** Due to significant sesaonal differences in sighting records (see Fig. 11), most information on *D. delphis* pod size was obtained between December and May.

This 10-year timeseries revealed that from August to October only the three smallest size classes were observed, while larger groups were observed with higher frequency only during the period January-May and occasionally in December and July. During the cold season (December -May), all pod size categories were present whereas during the warm season (June – November) pod sizes were dominated by small-size categories (Fig. 14).

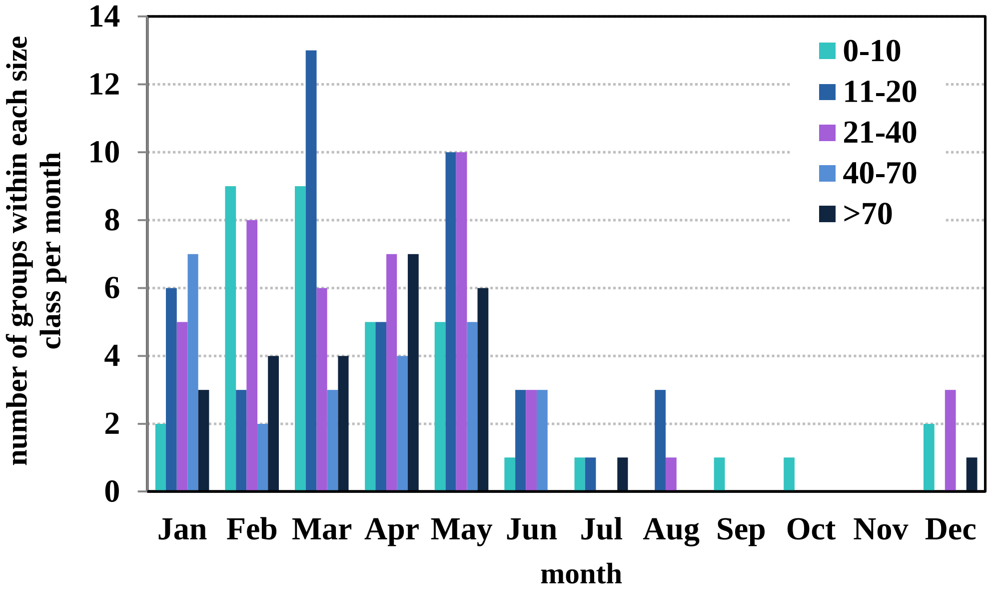

Figure 14: Monthly distribution of *Delphinus delphis* group sizes off southern Madeira Island coastline by bins, organized into five size classes, during the period 2006 – 2015 (total 173 sampling surveys).

During the period 2006 – 2015, the two most common behavior patterns exhibited by free-ranging *D. delphis* off southern Madeira Island were traveling (58,8%) and feeding (19,6%). Socializing and resting behavior patterns represented around 4% and 6% of total patterns observed, respectively, and non-identified behavior patterns accounted for ca. of 12% (Fig.15).

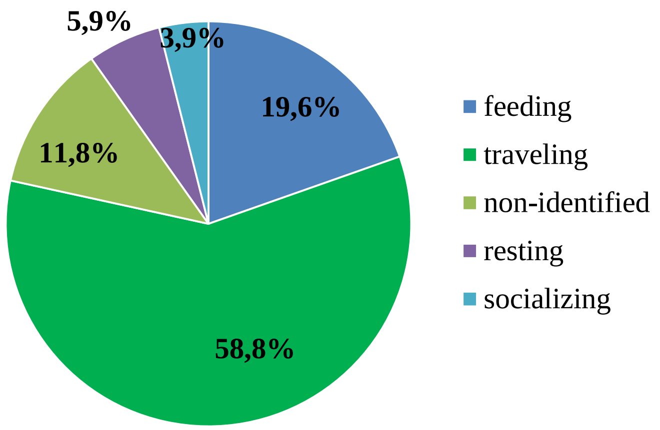

Figure 15: Behaviour patterns of free-ranging individuals of *Delphinus delphis* off southern Madeira Island coastline, observed onboard platforms of opportunity, during the period 2006 – 2015 (total 153 sampling surveys).

4. Discussion

4.1 Critical evaluation of data acquision strategy

This study was conducted using a marine mammal watching boat, as a sampling platform of opportunity. Applied strategy involves several limitations and it has its followers and opponents. Firstly, touristic operators represents an important industry, that provides a significant income for different regions and countries (Cisneros-Montemayor et al. 2010), as for the Madeira Island (Ferreira 2007). This is the reason why getting scientific information from these boats is now easier and more effective than in the past. A clear advantage is the fact that researchers are able to collect data, with high frequency (e.g., twice a day), with minimal financial load. However, it is important to note that the main purpose of touristic boats is tourists' satisfaction and they search for all cetacean species and not one in particular (Alves et al. 2015). This is the reason why data collected using this strategy have many limitations and errors. For example, the same group of marine mammals can be observed more than once during a specific observation period. Also, observers usually do not have a scientific background so identifications errors can occur during data collection. Moreover, the largest disadvantage of collecting cetacean data using platforms of opportunity is the season-dependent sampling effort over the year. In fact, in respect to the winter, during the high touristic season, trips (sampling surveys) are more frequent due to higher touristic demand and better sea and weather conditions. Besides, ethic doubts should be also taken into consideration, since some scientists suspect that whale watching business may adversely impact the ecology of marine mammals. Studies evaluation the potential effects of boats on cetaceans are limited but s report changes in cetacean swimming speed (Ferreira 2007) and individuals' behavior patterns in presence of whale watching boats (Parsons 2012). Despite all mentioned disadvantages, due to low cost and high-frequency data collection, platforms of opportunities are successfully used in many scientific activities, including marine mammal ecology (Leaper 1997; Holt 2003; Alves 2013). This strategy was succeffuly used to establish robust ecolological models of *D. delphis* habitat preferences in the portuguese mainland coast (Moura et al. 2010).

4.2 Temporal variability of *Delphinus delphis* off south Madeira Island

Temporal variability of *D. delphis* occurrence off south Madeira Island, during 2011 - 2014, revealed no significant differences between years but significant and consistent differences between warm and cold seasons, with significantly higher occurrences during the later ($p< 0.001$). It is important to mention that lower *D. delphis* occurrences observed during summer were coincident with a significantly higher sampling effort (see Fig. 11), which was also associated to greater collaboration between different whale watching boats, that could globally increase the probability of *D. delphis* spotting in the area. Then, the observed seasonal pattern, with minima values during summer, is very reliable. Moreover, differences in *D. delphis* sightings between seasons cannot be attributed to seasonal differences in dolphin aggregation. Indeed, larger dolphin aggregations were observed more frequently during the colder season (December - May), during summer, dolphin groups were smaller, usually composed by less than forty individuals, theoretically increasing the probability of dolphin spotting.

The seasonal pattern observed supports available *grey literature* information (Freitas et al. 2004), that reports more frequent occurrences of this species off Madeira Island during the period from autumn to early-spring. This seasonal pattern, with significantly lower occurrences during the warm season suggests that *D. delphis* migrates to other northern (based on its cold SST preferences) during this period from south Madeira Island to other area. Coastal dolphin species may exhibit a wide range of movement patterns, including seasonal migration, stable residency and temporary residence with seasonal or yearly fidelity (Bearzi et al. 2008, Genov et al. 2012, Dinis, 2014*)*. However, intra-annual movements associated to seasonal migrations were already documented for the short beaked common dolphin; according to Archer (1996), seasonal migration from temporal to tropical areas could be used to obtain warm feeding grounds. In temperate western Atlantic, near Georges Bank, *D. delphis* movements from open ocean towards the continental slope were observed during the colder seasons (Selzer & Payne 1988). However, an opposite pattern was reported for north-western Bay of Plenty (New Zealand), where it moves towards open ocean during autumn (Neumann 2001a). Similar behaviour was also observed in south-east coast of South Africa, where *D. delphis* was more abundant during winter (Cockcroft & Peddemors 1990).

Differences in annual distribution of cetaceans in the coastal areas were also reported for other marine mammals species. In north-eastern Scotland, bottlenose dolphin (*T. truncatus*) was more common during summer and autumn (Wilson et al. 1997). Seasonal movements were also documented for smaller cetaceans, like spotted (*Stenella 1ongirostris*) and stripped dolphin (*Stenella coeruleoalba*), in eastern tropical Pacific, where an offshore expansion was observed during summer (Reilly 1990). O'Brien et al (2009), using photo-identification, demonstrated the existence of wide, long-distance movements of bottlenose dolphin around the Irish coast, ranging between 130 km up to 650 km. Moreover, studies of tagged pelagic dolphins (*Stenella spp.*), during the period 1969 – 1976, revealed long-distance migrations, covering distances between 900 and 1080 km (Perrin et al. 1979). Genov et al. 2012 reported the longest documented movement (1000 km) of *D. delphis* based on the naturally marked individual in the basin of Mediterranean Sea. To resume, dolphins display the capability to travel for long time, and up to hundreds of kilometers, to areas of more appropriate environmental conditions.

The frequent reports of long-distance seasonal dolphins migrations (see above), and the absence of genetic differentiation in *D. delphis* from Azores and Madeira archipelagos (Quérouil et al. 2010b), meaning these two groups of common dolphins meet during the reproduction seasons, possibly imply *D. delphis* migration from coastal regions around south Madeira Island to offshore waters, during the warmer season. This hypothetical summer migration may include two non-mutually exclusive scenarios: dolphins observed around south Madeira migrate to Azores, where the "two populations" interact; and/or individuals from both Madeira and Azores archipelagos meet in oceanic waters, somewhere between these two regions. The evaluation of these scenarios requires further studies, involving photo-identification or invasive satellite tagging strategies.

4.3 Environmental drivers underlying temporal variability of *Delphinus delphis*

In order to comprehensively understand the environmental determinants of *D. delphis* distribution, a set of oceanographic, meteorologic and fisheries-related variables, used as direct or indirect proxies of habitat hydrodynamics and food availability, were tested as predictors of *D. delphis* occurrences off south Madeira, during 2011-2014. Sea surface temperature (SST) was the environmental variable with a higher predictive power to model the presence or absence of common dolphin off south Madeira Island. *D. delphis* is usually considered a temperate rather than a tropical species (Selzer & Payne 1988, Neumann 2001a), and environmental models revealed that common dolphins in Southern California coast are strongly associated with SST, for a temperature range of 14°C to 18°C (Henderson et al. 2014). This temperature range is similar to that observed off south Madeira, during this study. During the colder season, the period when the presence of *D. delphis* was detected, SST varied between 17°C and 21° C (see Fig. 6; see also Martins et al. 2007). During the warmer season (June - November), SST reached values higher than 20°C and common dolphin was absent or observed occasionally.

Significant relationships between SST and temporal distribution of cetaceans were previously reported, and are usually interpreted as the result of indirect effects of sea surface temperature on cetaceans' prey availability (Neumann 2001; Henderson et al. 2014).

Furthermore, other environmental variables are also correlated to the distribution of marine cetaceans, namely chlorophyll-a concentration, a proxy for phytoplankton biomass (Ware & Thomson 2005). As in the case of other marine vertebrates, distribution of dolphins is correlated with the availability of their prey (Reynolds & Rommel 1999), and cetaceans presence is often connected with more productive waters (Selzer & Payne 1988; Moura et al. 2012). This fact may explain why chlorophyll concentration was the second most significant variable in the GAM model. Phytoplankton in the study area exhibit a unimodal annual cycle, with blooms consistently occurring during late-winter to early-spring up to 0,5 [mg Chla*m^{-3}] (see Fig. 6; see also Martins et al. 2007), period of maximum sighting rates of common dolphin in the area (see Fig. 7). However, as previously suggested, is rather unlikely that phytoplankton blooms, *per se,* are directly controling the absence or presence of *D. delphis* (Moura et al. 2012). Alternatively, phytoplankton concentration is probably a proxy for other relevant biological variables, namely the occurrence of pelagic schooling fishes (Solanki et al. 2005; Ware & Thomson 2005; Pusineri et al. 2007), that are attractive prey for *D. delphis.* Indeed, the diet of *D. delphis* in Portuguese waters, is dominated by small pelagic schooling fishes, mostly sardines (Silva 1999), that are known to feed mainly on planktonic prey (see Garrido et al. 2007).

Based on studies upon *Stenella frontalis* (Freitas, et al. 2004), *B. bryde* (Alves et al. 2010*),* *G. macrorhynchus* (Alves 2013) confirm the occurrence of other cetacean species around the south coast of Madeira Island during period of minimum chlorophyll a concentration (summer) and on the fact that common dolphin was rarely recorded in that period, it is probably that *D. delphis* and these species feed on different fish species.

In respect to fisheries catches, potential prey items, GAM analyses showed the most important prey affecting temporal distribution of *D. delphis* was sardine, but curled pickerel and Atlantic chub mackerel catches were also significant predictors (see Table 1). All of three species are small sized and pelagic schooling fishes and plankton feeders (http://www.fishbase.org; Hernandes & Ortega, 2000; Garrido et al. 2007). As previously referred, the diet of *D. delphis* in Portuguese waters, based on the analyses of stomach contents of stranded or caught individuals, is dominated by small pelagic schooling fishes, mostly sardines (Silva 1999), that are known to feed mainly on planktonic prey (see Garrido et al. 2007). Similar dietary composition, including sardine, anchovies, sprat and mackerel, was reported for *D. delphis* in the Bay of Biscay (Meynier et al. 2008). Small pelagic fish were also reported as the dominant prey for dolphins using both oceanic and neritic regions of Northeast Atlantic (Pusineri et al. 2007). In this context, Moura et al. (2012) suggested that, although common dolphin can be a generalist and able to feed on a large variety of prey, its strong correlations with chlorophyll concentration (Spyrakos et al. 2011; Correia et al. 2015) probably reflects an ecological specialization on pelagic schooling fish. Behavior analyses revealed traveling and feeding were the most common behavior patterns/activities of *D. delphis*. These results are very similar to one revealed in Bay of Plenty (New Zealand) where traveling was the main behavior of common dolphin (54,8%) and feeding behavioral was seen during 17% of the sighting (Neumann, 2001b). These results show that *D. delphis* is an active hunter in both regions, including the study area, and then, prey distribution probably represents a relevant determinant of *D. delphis* temporal-spatial variability.

It was already suggested that annual winter migration of pilchard (*Sardinops ocellatus*) toward the south African (known as “sardine run”) may be related with seasonal movements of *D. delphis* in this area. Baleen whales, like humpback whale (*Megaptera novaeangliae*), blue whale (*Balenoptera musculus*) and bowhead whale (*Balaena mysticetus*), are well known for their long- distance migrations towards breeding or feeding grounds (Braham et al. 1980; Baker & Herman 1981; Mate et al. 1999). Although seasonal movements of smaller cetaceans are not so well described, some studies revealed that their movements are driven by prey availability. Temporal variability in the distribution of dusky dolphin (*Lagenorhynchus obscures*) in the coast of Argentina is correlated with anchovy occurrence (Würsig & Würsig 1980). Also, differences in the seasonal occurrence of harbour porpoise (*Phocoena phocoena*) and white-beaked dolphin (*Lagenorhynchus albirostris*) in the north-western North Sea were associated to prey availability (Weir et al. 2007). Thus, we hypothesize that *D. delphis* temporal distribution off south Madeira Island is directly affected by the abundance of sardine, curled pickerel and Atlantic chub mackerel, statistically predictors in the model ($p< 0.05$).

Other significant predictors of *D. delphis* occurrence were wind intensity and direction. These variables directly control relevant oceanic processes, including water column stratification and upper layer circulation and upwelling events (Schumann et al. 1982; Campos et al. 2000; Capet et al. 2004). Thus, they directly affect nutrient and phytoplankton concentration in surface waters (Hutchins & Bruland 1998; Laanement et al. 2006), indirectly influencing the distribution of small pelagic planktivorous fish (Cury & Roy 1989; Rodrmh et al. 1999; Cury et al. 2000) and the occurrence of dolphins (Papastavrou & Waerebeek 1997; Tynan et al. 2005). It is important to mention that southern and eastern winds were positively correlated with *D. delphis* occurrence (Fig. 13). As dominant wind direction in the study area is north (see Fig. 7), these results suggest that occasional changes in wind direction may cause movements of water mass and thus affect dolphins' prey distribution. However, due to lack of spatial distribution data of *D. delphis* occurrence, there is no direct evidence that these effects were relevant in the study area. The effects of wind intensity and direction can be also connected with the sea state and its impacts on observer's capability to spot dolphins from the boat. Clearly, it is much easier when the sea/wind is more calm, when the wind speed is lower. This hypothesis is support by the model results, which suggest that occurrence of *D. delphis* rapidly decreases with the wind speed 7 $m*s^{-1}$ and more (Fig. 13).

This study, as the first one, revealed information about *D. delphis* temporal distribution off south Madeira and tried to relate it with oceanographic and biological factors. However, knowledge of dolphin sightings coordinates and other potentially relevant environmental variables, including depth, distance from the coast, or upwelling intensity, are required for a more detailed analyses of drivers underlying *D. delphis* distribution.

5. Conclusions

This study revealed that distribution of *D. delphis* in south Madeira Island varied consistently between warm and cold seasons, with higher occurrences between December and May. This seasonal pattern reflects a summer seasonal migration probably directed northwards. According to GAMs best model, SST was the most important predictor of *D. delphis* presence and absence, followed by chlorophyll concentration, a proxy for phytoplankton biomass. These results may support information from previous studies revealing that *D. delphis* is rather temperate than tropical species and tends to avoid waters warmer than 18ºC. However, they can also show indirect effects, reflecting a trophic cascade, between phytoplankton, pelagic schooling fish (sardine, curled pickerel, Atlantic chub mackerel) and *D. delphis*. Significant effects of wind direction and intensity on *D. delphis* occurrence may be connected with upwelling events and changes in upper layer mixing, that affect the availability of the common dolphin's prey. However, the effects of strong wind on sea state and the observer's capability to spot dolphins cannot be ignore.

This was the first study aiming to describe temporal distribution of *D. delphis,* the most often sighted cetacean in the North Atlantic waters, in south Madeira Island and to understand related environmental determinants. It revealed important information on its seasonal distribution during a 4-year period (2011-2014), and relevant oceanographic and biological predictive variables. However, further studies are clearly needed to evaluate seasonal migration patterns, involving animal telemetry (tagging) and photo-identification, probably in cooperation with other institutions located in this biogeographic region (ex.: Azores and Canaries archipelagos). Studies including exact positioning of dolphin sightings and other potentially relevant environmental variables (e.g., depth, distance from the coast, upwelling intensity), are required to increase our comprehensive understanding of *D. delphis* behaviour and movement patterns off south Madeira.

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7. Appendix

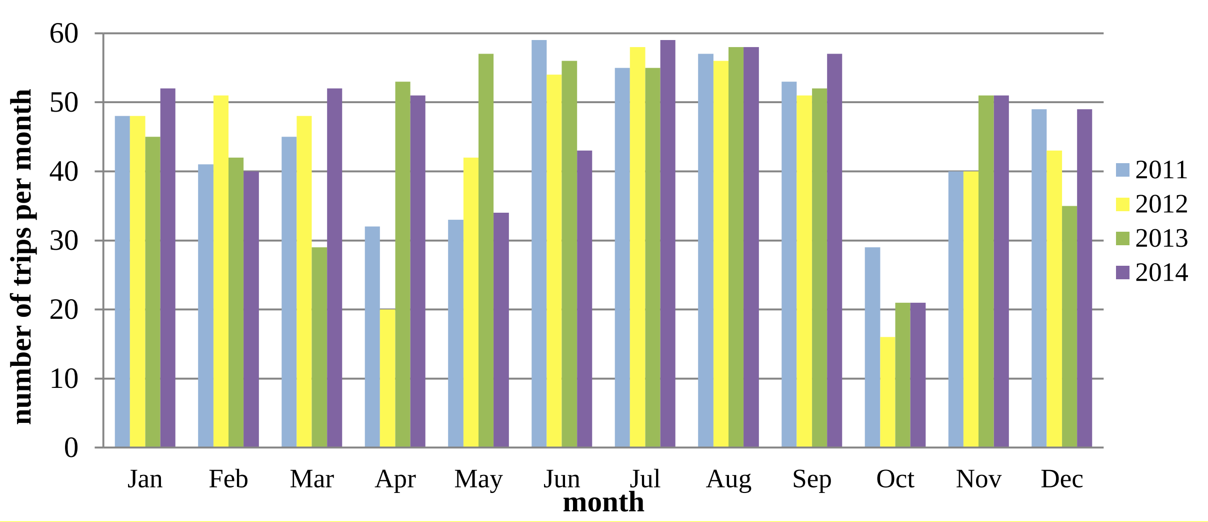

Figure I: Distribution of sampling trip within a month along the year season during four years period 2011-2014.

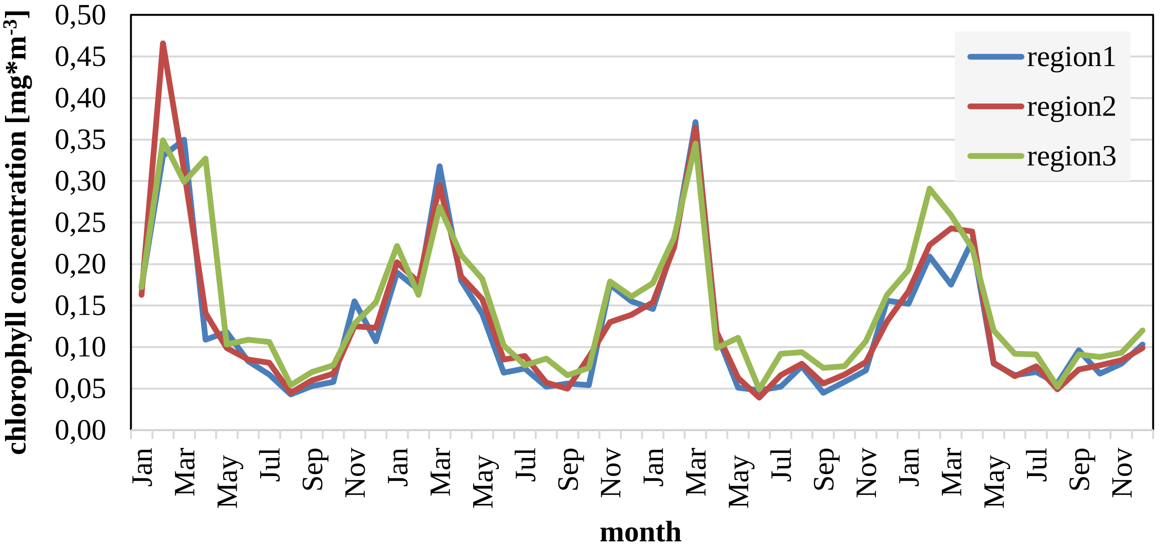

Figure II: Mean chlorophyll concentration [mg*m^{-3}] within three deferent regions obtained by satellite images.

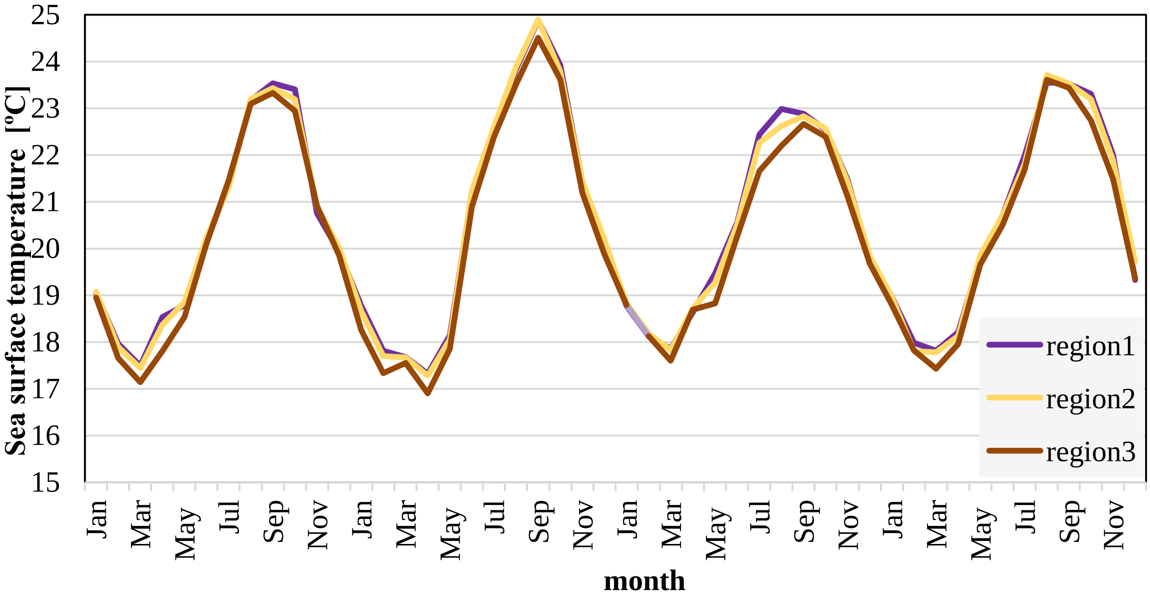

Figure III: Mean sea surface temperature (SST) [ºC] within three deferent regions obtained by satellite images.

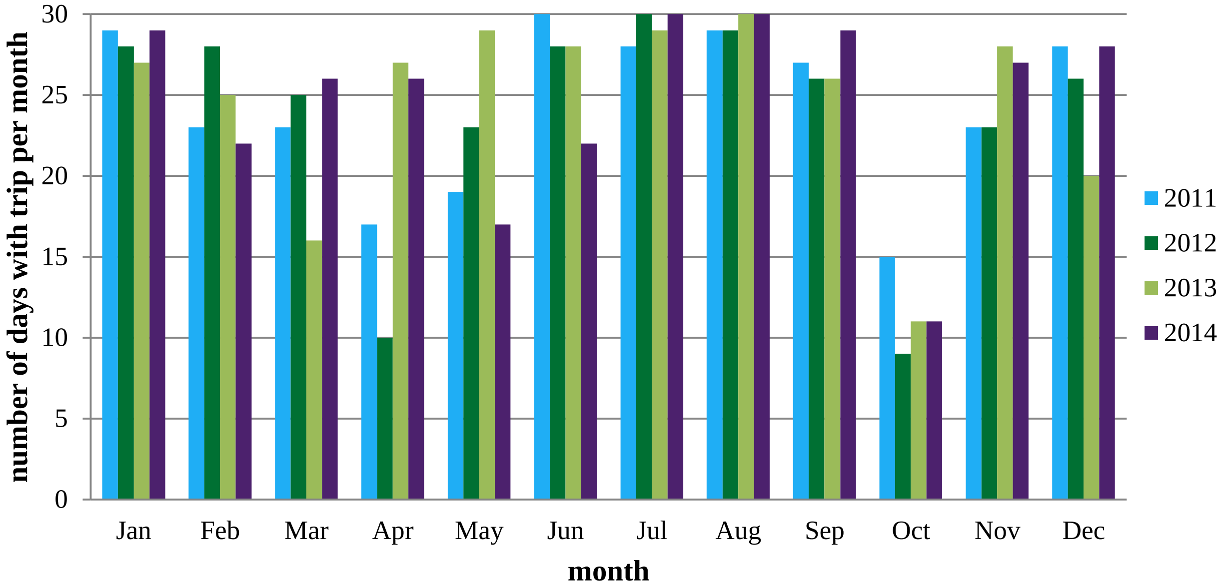

Figure IV: Number of days with sampling trips per month during the study period 2011 - 2014 after transforming the data to the binary character.

Table I: Results of Kruskall – Wallis test used to checked differences in group size between years (2006 – 2015) and months within these years.

	Statistical parameters		
Differences between	chi-squared	df	p-value
Years (2006-2015)	16.758	9	0.05264
Months	13.3954	9	0.1455

Table II: The best final model made on the daily basis with its variables and (bs = cr - cubic regression splines smoothing, edf - effective degrees of freedom, F - test value, GCV - generalized cross validation**,** k - basis dimension, n - number of samples, Pr(>|t|) – p value of t-test, R-sq.(adj)- Adjusted R squared; Scale est – scale parameter; significance: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’; s - smoothing, t - test value).

<table>
<tr><td colspan="5">Best final model: sighting rate ~ s(SST, k = 8, bs = “cr”) + s(chlorophyll, k = 8, bs = “cr”) + s(Bogue, k = 8, bs = “cr”) + s(Atlantic chub mackerel, k = 8, bs = “cr”) + s(Sardine, k = 8, bs = “cr”) + s(Blue jack mackerel, k=8, bs=”cr”) + s(wind direction, k = 8, bs = “cr”) + + s(current2, k = 8, bs = “cr”) + s(current1, k = 8, bs = “cr”)</td></tr>
<tr><td colspan="5">Parametric coefficients</td></tr>
<tr><td rowspan="2">Intercept</td><td>Estimate</td><td>Standard Error</td><td>t value</td><td>Pr(>|t|)</td></tr>
<tr><td>0.26960</td><td>0.01094</td><td>24.65</td><td><2e-16 (***)</td></tr>
<tr><td colspan="5">Statistical parameters</td></tr>
<tr><td>n</td><td>R-sq.(adj)</td><td>Deviance explained</td><td>GCV</td><td>Scale est</td></tr>
<tr><td>1046</td><td>0.365</td><td>38.5%</td><td>0.12929</td><td>0.12517</td></tr>
<tr><td colspan="5">Approximate significance of smooth terms</td></tr>
<tr><td>Variables</td><td>edf</td><td>F</td><td colspan="2">p-value</td></tr>
<tr><td>s(SST)</td><td>6.707</td><td>16.875</td><td colspan="2">< 2e-16 (***)</td></tr>
<tr><td>s(wind direction)</td><td>2.060</td><td>4.713</td><td colspan="2">0.00543 (**)</td></tr>
<tr><td>s(Atlantic chub mackerel)</td><td>5.536</td><td>2.732</td><td colspan="2">0.01184 (*)</td></tr>
<tr><td>s(bogue)</td><td>5.624</td><td>2.677</td><td colspan="2">0.01358 (*)</td></tr>
<tr><td>s(sardine)</td><td>4.658</td><td>1.740</td><td colspan="2">0.13235</td></tr>
<tr><td>s(blue jack mackerel)</td><td>3.795</td><td>1.736</td><td colspan="2">0.002088</td></tr>
<tr><td>s(current2)</td><td>1.975</td><td>1.650</td><td colspan="2">0.18144</td></tr>
<tr><td>s(chlorophyll)</td><td>1.000</td><td>0.801</td><td colspan="2">0.37104</td></tr>
<tr><td>s(current1)</td><td>1.000</td><td>0.630</td><td colspan="2">0.42750</td></tr>
</table>

Table III: Results of Kruskal – Wallis test used for testing differences in *D. delphis* sighting records between years, during 2011 - 2014.

chi-squared	df	p-value
0.9133	3	0.8222

Table IV: Results of ANOVA used for testing differences in *D. delphis* sighting records between warm (June-November) and cold (December-May) seasons, during the period years 2011 – 2014.

df	sum sq	mean Sq	F-value	p-value
1	1.830	1.8302	31.61	< 0.001

Table V Results of statistical tests used to verify the assumptions associated to parametric ANOVA.

	Statistical parameters	
Parameters tested	Test statistic	p-value
Homogeneity of variance (Levene test)	9.9252	0.002752 (**)
Normal distribution of the data (Shapiro- Wilk test)	0.9387	0.1132

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1