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Spatial and temporal distribution and potential residency patterns of bottlenose dolphins (*Tursiops truncatus*) off São Miguel Island, Azores.

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Faculdade de Ciências e Tecnologia

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<u>Declaração de autoria de trabalho</u>

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

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Abstract

The common bottlenose dolphin (*Tursiops truncatus*) is a cosmopolitan cetacean species distributed all over the world, except in the poles. This species is also one of the most sighted in the island of São Miguel, Azores, however it is still poorly studied. This thesis describes the spatial and temporal distribution of bottlenose dolphins sighted off São Miguel and presents a catalogue with the individuals identified between 2014 and 2019. Furthermore, their degree of residency around the island of São Miguel is also assessed. Data was collected using as opportunistic platforms of observation the whale watching boats of Futurismo Azores Adventures, a company with main base port in Ponta Delgada, on the south of the island. Two datasets were used: the first includes the information from the bottlenose dolphin sightings registered between 2010 and 2019, and it was used to analyse spatial and temporal distribution of bottlenose dolphins around the island; the second dataset includes pictures taken during the whale watching trips from 2014 until 2019, and it was used to build a catalogue with the individuals identified during that period, look for residency patterns and associations among the residents. The results revealed a preference for shallower waters indicating a higher number of sightings in depths lower than 500m. The presence of bottlenose dolphins varied between seasons and inter-annually, with higher occurrences during the warmer months. This pattern has been seen in other studies and it could be related to higher concentration of prey after a peak in phytoplankton in the previous months. From the 505 individuals identified only 52 dolphins were considered residents. Within these dolphins there were four possible associations between several individuals based on the dates they were encountered on. This study is the first to present a catalogue with individuals from São Miguel and one of the first to analyse the spatial and temporal distribution of bottlenose dolphins in the island. Further research would be needed to contribute to the overall knowledge of this species in São Miguel and support proper management and conservation plans for the species in this area.

Keywords: Bottlenose dolphin, cetacean, Azores, São Miguel, distribution, photo-identification

Resumo

O golfinho roaz (*Tursiops truncatus*) é uma espécie cosmopolita, com uma ampla distribuição por todos os oceanos, exceto nas altas latitudes, podendo habitar em águas ao longo dos continentes, em lagos e mares fechados, águas oceânicas e em redor de ilhas. Por preferirem diferentes habitats, os golfinhos roazes foram divididos em dois ecótipos- costeiro e oceânico- que divergem em características como a genética, morfologia, fisiologia e tipo de alimentação. Os indivíduos que habitam em áreas mais abertas, como em redor de ilhas oceânicas, tendem a formar grandes populações, com vastas deslocações e baixa fidelidade à área, enquanto populações que habitam em zonas costeiras ou fechadas como estuários são normalmente mais pequenas e com maior fidelidade. A Ilha de São Miguel, uma das nove ilhas do arquipélago dos Açores, encontra-se no meio do oceano Atlântico numa localização privilegiada para vários mamíferos marinhos, tanto os que residem ao seu redor como aqueles que simplesmente passam durante a sua rota migratória. A ocorrência de correntes juntamente com a complexa batimetria favorece a produção primária, permitindo que o alimento de vários predadores de topo cresça. Atualmente por razões logísticas e monetárias, muitos estudos de mamíferos marinhos são feitos com recurso a dados oportunistas, recorrendo muitas vezes a empresas de observação de cetáceos. Estas empresas estão presentes em várias ilhas do arquipélago dos Açores, algo que antes da década de 90 era impensável devido à caça da baleia, que, entretanto, foi abolida na década de 80. Embora esta forma de recolher dados apresente algumas limitações é sem dúvida uma mais-valia em estudos de curto e longo prazo, para o conhecimento destes animais e também por serem indispensáveis para o desenvolvimento de medidas de proteção das espécies. Em São Miguel, o golfinho roaz é uma das espécies mais avistadas, sendo observada durante todo o ano em viagens de observação de cetáceos. No entanto, a informação disponível sobre estes golfinhos é limitada. No arquipélago dos Açores, vários estudos foram feitos em tópicos como estrutura da população, padrões de residência e movimentos, ocorrência e distribuição e também abundância. No entanto, embora tenham sido recolhidos bastantes dados ao longo dos anos, a maior parte do esforço utilizado para estes estudos foi feito no grupo central, dividido entre as ilhas do Pico e do Faial. Em São Miguel muito pouco se sabe sobre a distribuição, variação sazonal e padrões de residência desta espécie. Este estudo é o primeiro a avaliar a distribuição temporal e espacial de golfinhos roazes e possíveis

graus de residência na costa Sul de São Miguel. Entender a dinâmica e a distribuição espacial e temporal desta população local é necessário para o reconhecimento de áreas importantes para estes indivíduos, entender o estado da população e para a implementação de medidas de conservação efetivas. Neste estudo foram utilizadas duas bases de dados, sendo uma delas com informação sobre a ocorrência dos avistamentos de golfinhos roazes durante 10 anos (2010-2019) e outra com fotos desta espécie tiradas num período de seis anos (2014-2019). Estes dados foram recolhidos de forma oportunista em viagens de observação de cetáceos da empresa Futurismo Azores Adventuures com base em Ponta Delgada. As bases de dados foram usadas para analisar a distribuição espacial e temporal e criar um catálogo de foto-identificação, respetivamente. Este estudo pretende entender o espaço utilizado pelos golfinhos e a existência de diferenças anuais e sazonais no número de encontros e identificar possíveis residentes através da utilização do catálogo. Como objetivo secundário será necessário comparar as variações de temperatura superficial da água e concentração de clorofila-a com os dados de avistamentos e taxa de encontros, de modo a verificar se estes se relacionam. Para além disso será necessário verificar a ocorrência e identificar associações (grupos) utilizando o catálogo. Para o catálogo foram usadas apenas fotos de golfinhos que pudessem ser identificáveis, com marcas proeminentes na barbatana dorsal como cortes e/ou pigmentação. Os resultados relacionados com a distribuição espacial revelaram dois locais de concentração de avistamentos, um localizado a sul de Ponta Delgada e outro entre Lagoa e Caloura. A distância dos encontros à costa deu-se, maioritariamente, abaixo dos 4 km, embora seja visível um aumento da mesma durante o verão e o outono. As profundidades a que foram encontrados revelam preferência por águas pouco profundas, abaixo dos 400 m. A preferência por estas áreas costeiras parece estar relacionada com vários fatores, como a possível maior produção primária verificada nestas zonas e a proteção à predação e competição. Em relação à distribuição temporal verificou-se que existem variações notáveis no número de avistamentos nos distintos anos. Similarmente, embora os roazes possam ser avistados durante todo o ano, houve uma grande variação no número de ocorrências entre meses frios e quentes. Como esperado, tendo em conta os resultados de outros estudos, a época em que mais vezes foram avistados golfinhos roazes foi nos meses mais quentes entre junho e agosto. Esta maior concentração nos meses quentes parece estar relacionada com o aumento de presas na área, resultado de um máximo de clorofila que ocorreu nos meses anteriores, desencadeando uma cadeia trófica que aumenta a abundância de pequenos peixes de cardume, um tipo de presa que faz parte da dieta

habitual destes golfinhos. Por outro lado, a temperatura da superfície do mar atinge no verão os seus valores máximos o que também parece agradar aos golfinhos, especialmente às fêmeas, originando boas condições para que estas tenham as suas crias. Estes resultados sugerem que a disponibilidade de presas é um fator importante para a distribuição espacial e temporal da espécie. Em relação aos resultados obtidos através da foto-identificação, estes mostram que apenas 52 golfinhos dos 505 identificados foram avistados frequentemente em diferentes estações e em diferentes anos mostrando assim grande fidelidade à área, podendo ser considerados residentes. A maioria dos golfinhos foi avistada apenas uma ou duas vezes durante o período estudado e provavelmente estavam apenas de passagem pela ilha. Através da análise das datas dentro do grupo dos residentes verificou-se a existência de quatro possíveis associações diferentes de golfinhos, o que leva a crer que dentro da mesma população existem golfinhos com mais afinidade e por isso encontram-se juntos durante vários anos. Como a informação sobre os golfinhos roazes em São Miguel é limitada e sendo esta uma espécie bastante móvel num ambiente dinâmico, é extremamente necessário a contribuição de mais estudos, de forma a aumentar o conhecimento geral, mas também para fornecer informação realista ajudando a implementar planos de gestão e conservação eficazes, ao redor da ilha.

Palavras-chave: golfinho-roaz, cetáceos, Açores, São Miguel, distribuição, foto-identificação

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1.1 Marine mammals' history in Portugal

The relationship between humans and marine mammals has always been somehow driven by the need of survival, and since whales are a natural resource, activities like sealing and whaling and the trade of their goods has been recorded and belongs now to an important part of marine environmental history (Romero & Keith, 2002; Hughes, 2006).
The curiosity and fascination hovering over these large whales and dolphins contributed to the origin of myths and legends and later on to the documentation of their sightings and strandings, creating and historical database that can now be used for biological information such as the species occurrence and distribution (Figure 1.1 and 1.2) (Romero & Keith, 2002; Perrin & Geraci, 2009).

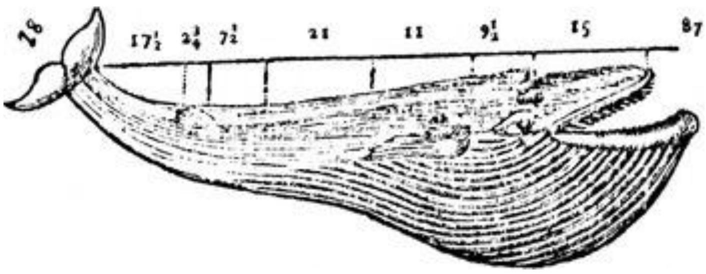

Figure 1.1.: Representation of a Fin whale (*Balaenoptera physalus*) that stranded in Cacilhas in January 1723. The image was published along with an article in a newspaper. Source: Brito & Sousa, 2011.

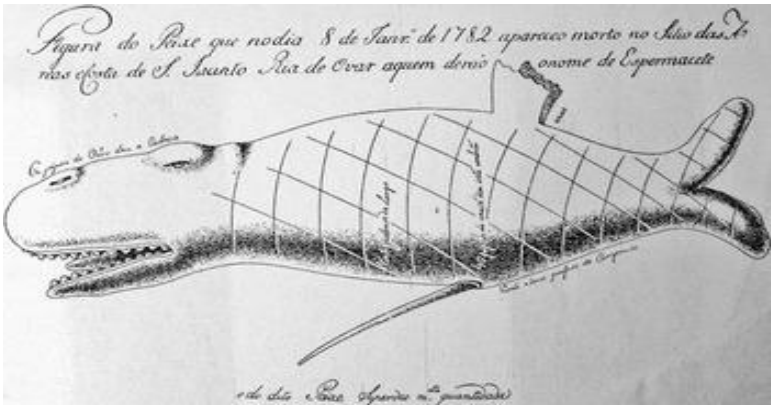

Figure 1.2.: Representation of a sperm whale (*Physeter macrocephalus*) that stranded in Aveiro on 8 January 1782. Source: Brito & Sousa, 2011.

Since the medieval period that whales and dolphins were exploited, exported and traded in Portugal, however there is no reference until the 12th century, when the first cetacean related word emerged in Portugal: "whaling" was present in monastery books and taxes applied on the hunting of whales and dolphins (Castro, 1964). The capture of these animals continued over the centuries (for consumption or due to its competition with fisheries) along the coastline but also in Azores (Figure 1.3) and Madeira Island and had an historical importance in the Portuguese maritime history since it not only brought profit to the kingdom but also led to the implementation of laws and taxes (Brito, 2011).

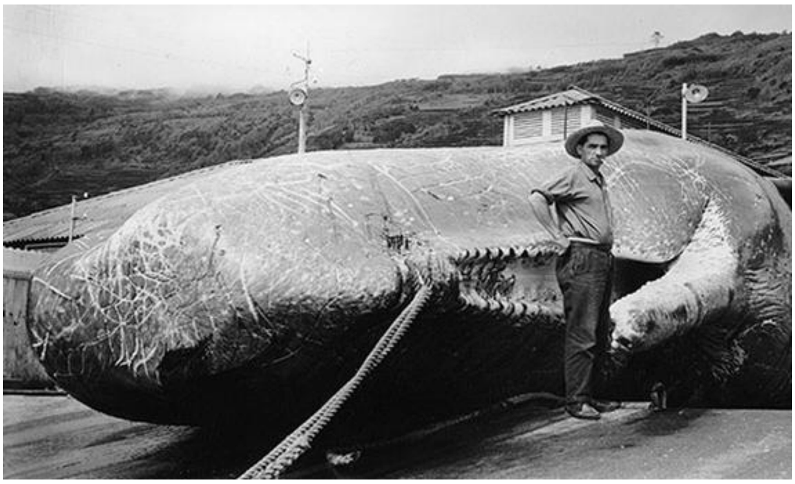

Figure 1.3.: Sperm whale recently caught ready to be cut. Source: Futurismo Azores Adventures.

After a decline of the activity during the 15th and 16th centuries in Portugal whaling re-started at the end of the 19th century with more developed techniques, but it would not last long, as a wave of ideas regarding cetacean's conservation rouse (Brito, 2009). Whales and dolphins stopped being viewed only as a source of food and profit, but also as a study subject which increased the knowledge on these animals, the number of species identified and the number of aspects included in their descriptions, such as distribution, ecology, and behaviour (Brito & Sousa, 2011). Whaling officially ended in 1986 with the International Moratorium of the International Whaling Commission and the implementation of national protection legislation and was replaced by whale-watching an activity with less impact on the animals that was also regulated in order to defend the animal's welfare (Brito & Vieira, 2010).

Whale watching was established in the central group of the Azores archipelago in 1989 and later in 1994 in São Miguel (Oliveira *et al.*, 2007; González García, 2019). Interestingly, the lookout's method ("vigias" in Portuguese) used to find the animals during the whale hunting years, is also the method used in whale watching until this day (González García, 2019).

With a rapid growth, whale watching in the Azores has more than 100000 whale-watchers a year (data provided by the Direção Regional de Turismo, on 12/07/2018). For that reason, São Miguel went from being operated during the summer months to all year around, from using small rigid-hulled inflatable boats (Figure 1.4) to larger in capacity and size catamarans (Figure 1.5). The qualifications of the employees have also improved. Nowadays boat skippers, lookouts and biologists or guides are people with interest in marine mammals and preservation of the ecosystem and try to communicate these principles to the tourists during the trips. Also, data collection is now a main goal for the companies and its quality has increased. Companies like Futurismo are now able to create long-term databases of occurrence and photo-identification that can be used to do research on whales and dolphins in the Azores.

Figure 1.4.: Futurismo's Whale Watching company rigid-hulled inflatable boat during a trip. Source: Futurismo Azores Adventures (by Mariana Silva).

Figure 1.5.: Futurismo Whale Watching company catamaran during a trip. Source: Futurismo Azores Adventures (by David Rodrigues).

Nonetheless, this growth had to be accompanied by management regulations that assured the welfare and conservation of cetacean populations, but also, the economic development of the region (Oliveira, 2005). The creation of legislation started in 1996 and the first law was implemented three years later (DLR 9/99/A), however it was altered in 2003 and complemented in 2004 (DLR 10/2003/A) (Oliveira *et al.*, 2007; González García, 2019). One of the main issues presented on this law was the way boats should approach the animals and that it should be done towards the rear of the animal, up to 50 m of distance, within slow speeds (<2kn) and maximum duration of 30 minutes (Oliveira *et al.*, 2007; González García, 2019). In 2013 a project called World Cetacean Alliance (WCA) was created by scientists, non-profit organisations, whale watching tour operators and the public from all around the world with the purpose of working together to protect whales, dolphins and porpoises (Mifsud *et al.*, 2015). In order to achieve these objectives, the WCA works with several partners in different countries from the fields of science and research, education and conservation and also responsible wild whale and dolphin watching ecotourism (Mifsud *et al.*, 2015; Bay *et al.*, 2019). The WCA awards responsible whale watching companies that prioritize the care for local wildlife, sustainability, and customer experience, and nowadays more companies are improving their activity according to the WCA guidelines to get their certification (Figure 1.6) and be recognised as a responsible company (Mifsud et al., 2015; Bay et al., 2019).

Figure 1.6.: World Cetacean Alliance certification for responsible whale watching. Source: https://worldcetaceanalliance.org/certification/whalewatchcertification/.

By agreeing with the guidelines and becoming more responsible, whale watching companies are setting an example to the public and bringing awareness on marine conservation besides that there are advantages in the educational and scientific field as these companies are also known for being an important platform on data collection (Hoyt, 2000, 2005; González García, 2019).

1.2 The importance of studying cetaceans

As a great number of the world's cetaceans are confirmed to be threatened and the situation of many others remains data deficient, it is crucial that studies are performed in order to understand the potential effect of different threats on these animals (Simmonds & Isaac, 2007; Simmonds & Eliott, 2009). Cetaceans play an important role in the marine ecosystem (Briand, 2004). Since these animals live for a long time, they accumulate contaminants in their tissues, which in turn makes them great bio-indicators for the ocean's status (Moore, 2008). As top predators they can control lower trophic levels and provide ecological and environmental information on other links of their food chain (Roman & McCarthy, 2010; Fossi *et al.*, 2018).

Marine mammals face a variety of threats such as prey depletion, entanglement in fishing gear, marine litter, collision with boats, noise pollution, whale hunting, climate change and many others (Parsons *et al.,* 2010; Hunt *et al.,* 2013; Fossi *et al.,* 2018). Their consequences on marine mammals are still under discussion adding to the limited information on distribution, abundance and movements patterns the situation only gets worse (Parsons *et al.,* 2010). If the way these changes affect cetacean's distribution are not understood, it will be hard to take action to minimize the impact, and the consequences for marine mammals' populations worldwide could be irreversible leading them to leave their habitats, decrease their ranging pattern and worst-case scenario extinguish populations (Parsons *et al.,* 2010; Fossi *et al.,* 2018). Having in mind the well-being of cetaceans is the well-being of an entire ecosystem. It is therefore essential to understand abundance, distribution, site fidelity, ranging patterns and other aspects of the biology and ecology of cetaceans (Hoyt, 2005; Silva, 2007; Nowacek *et al.,* 2016). Only in this way it will be possible to understand what threats they are facing, how are these populations responding to them, how to act and what measures can be implemented to preserve these animals (Evans & Hammond, 2004; Silva, 2007).

1.3 Bottlenose dolphins

The bottlenose dolphins (genus *Tursiops*) are currently divided into three species: the common bottlenose dolphin (*T. truncatus*), the Indo Pacific bottlenose dolphin (*T. aduncus*) and the recently discovered Burrunan dolphin (*T. australis*) (Wang *et al.,*1999; Shirakihara 2003; Kurihara & Oda 2007, Charlton-Robb *et al.,* 2011). Although, in the past their large distribution globally and their capacity to adapt to the different conditions of each habitat led to the wrongful identification of around 20 species, those were later considered geographic variants (Silva *et al.,* 2007; Kingston *et al.,* 2009). The species studied here is the common bottlenose dolphin (Figure 1.7), a cosmopolitan species with a very widespread distribution, except for the very high latitudes (Figure 1.8) (Leatherwood & Reeves 1983). This animal occurs in offshore but also coastal waters, along the continents or around islands (Leatherwood & Reeves 1983; Forcada *et al.,* 2004; Silva *et al.,* 2007). Due to their presence in nearshore waters, but also the exposure in aquariums all around the world and tv-shows, they became the most studied cetacean species in the world (Bearzi *et al.,* 2009; Mann *et al.,* 2000; Leatherwood & Reeves, 2012). Populations of coastal and offshore bottlenose dolphins are considered to differ ecologically, and so, two ecotypes - inshore (coastal) and offshore - have been recognized based on differences in morphology and morphometry (Hersh & Duffield, 1990; Van Waerebeek *et al.,* 1990), hematology (Duffield *et al.,* 1983), cranial morphology (Hersh & Duffield, 1990) and parasite faunas (Mead & Potter, 1990).

Bottlenose dolphins are long-lived animals with females and males living in the wild more than 50 and 40 years, respectively (Silva, 2007). Several studies suggest that the peak of births usually happens right before the water reaches the higher temperatures, however females can give birth all year around (Wells *et al.,* 1987; Urian *et al.,* 1996; Mann *et al.,* 2000; Henderson *et al.,* 2014). The calf depends on the mother for about three years, not only energetically, but also to increase the chances of survival, to learn cultural knowledge and for social development. As the calves age, they grow apart from their mothers (Grellier *et al.,* 2003; Silva. 2007).
The species is a top predator and is known to feed opportunistically on whatever prey is available (Barros & Odell, 1990; Walker *et al.,* 1999; Santos *et al.,* 2007). However, diet differences have been described for coastal and offshore dolphins. In the case of bottlenose dolphins inhabiting areas close to the shore, they feed mainly on smaller benthic and coastal fish species (Barros & Odell, 1990; Cockroft & Ross, 1990; Gannon & Waples 2004); while in open waters dolphins have more variety of prey and feed mainly on small schooling fish and cephalopods (Barros *et al.,* 2000; González *et al.,* 1994; Mead & Potter, 1990).

Coastal communities of bottlenose dolphins are usually seen in small but highly fluid groups, with restricted movement patterns and high site-fidelity (De Waal & Tyack, 2009; Wiszniewski *et al.,* 2010), contrary to offshore populations, that occur in large groups, with low site-fidelity and wide ranging patterns (Bearzi, 2004; Silva *et al.,* 2008). In terms of social structure, bottlenose dolphin individuals associate in small groups that change in size and composition very often (hourly or daily basis), presenting a fission-fusion society (Connor *et al.,* 2000). According to Connor *et al.,* (2000), the fission-fusion grouping pattern reflects a requirement to spread out to reduce feeding competition. Dolphins live in open environments with few boundaries, feed on mobile prey, and when resources are not available, they move between areas to find them (Williams, 1999). As a result, they are highly mobile and show a wide variety of site fidelity and ranging patterns (Tucker *et al.*, 2014). Understand how bottlenose dolphins use their environment and the relationship between individuals, groups or even populations, helps to create adequate conservation and management strategies (Cañadas *et al.*, 2005; Passadore *et al.*, 2018)

Figure 1.7.: Image of a bottlenose dolphin (*Tursiops truncatus*). Source: Futurismo Azores Adventures (by Ida Eriksson).

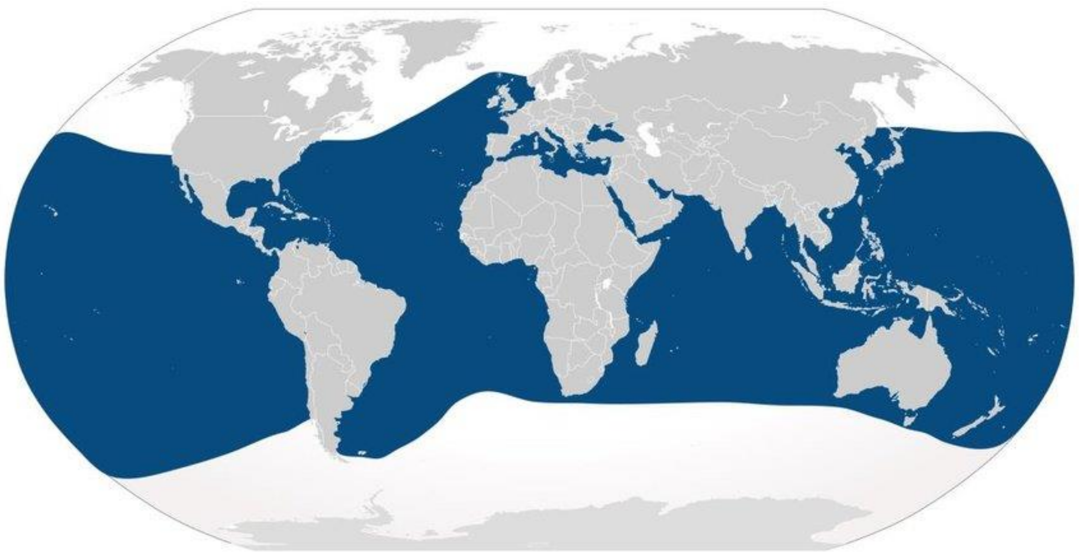

Figure 1.8.: Bottlenose dolphin (*Tursiops truncatus*) range distribution. Source: iucnredlist.org.

1.4 Previous studies on bottlenose dolphin ranging patterns and residency

Previous studies show that populations of dolphins reflect specific ecological and behavioural adaptations to local habitats, and striking differences in ranging and movement patterns among populations of bottlenose dolphins occuring in different areas (Silva, 2007; Oudejans *et al.,* 2015). For example, in Sarasota Bay, Florida, bottlenose dolphins are year-round residents, and show strong site fidelity to the area (reviewed in Scott *et al.,* 1990); while, in Bahia Kino (Gulf of California, Mexico) and in Shannon Estuary (Ireland) the dolphins identified are not year-round residents and appear to have extensive ranging patterns (Ballance, 1992; Ingram & Rogan, 2002). This difference may be related to the availability of food resources (Bowen *et al.,* 2002). In areas where the availability is lower, the home ranges are more extensive because the animals have to move further to find food (Harestad & Bunnel, 1979).

Closer to the Azores, in Madeira Island, the population of bottlenose dolphins is open with few individuals showing fidelity to the area, however just like in the Azores the high productivity around the island attracts dolphins living in the surrounding area, mixing residents with temporary migrants and transients (Dinis *et al.,* 2016; Dinis *et al.,* 2021). The same occurs in the Canary Islands with a low percentage of the individuals identified being residents (Tobeña *et al.*, 2014). Similarly, to what happens in the Azorean archipelago, the residents travel between the different islands searching for food (Silva, 2007; Tobeña *et al.*, 2014).

In the Azores, bottlenose dolphins (*Tursiops truncatus*) are one of the most sighted cetacean species. They are observed all year-round. Although they can be found close to the islands and offshore waters, they are usually found in areas with shallow waters between 100m and 600m (Silva *et al.*, 2014; Fernández *et al.*, 2017; González García, 2019). The first photo-identification study of bottlenose dolphins in the Azores started in 1997 in the central group of islands (Pico, São Jorge and Faial) with the intention to understand distributional ecology, behaviour and interspecific associations (Mendes *et al.,* 1999). The results showed that there is a resident population around the islands of Faial and Pico, however the residence pattern remains unknown (Mendes *et al.,* 1999).

Other studies in the Azores have been conducted on bottlenose dolphins, about population structure describing that no structure was found within the archipelago or between the former and Madeira (Quérouil *et al.,* 2007). Studies on ranging and residence patterns suggesting bottlenose dolphins in the Azores are a single and open population, consisting of different geographic communities interacting with each other and with groups from outside the archipelago (Silva *et al.,* 2008). Occurrence and distribution studies showing year-round sightings, the majority occurring close to the coast (Silva *et al.,* 2014). Survival studies resulting in higher survival for adults than for subadults (Silva *et al.,* 2009). A PhD thesis published in 2007 on the population biology of bottlenose dolphins in the Azores archipelago (Silva, 2007), addressed issues like the ranging patterns, population genetic structure, capture-recapture estimates of survival, temporary emigration and population size, creating the first vast resource of information on this species in the Azores, focusing mostly on the central group of islands, especially Faial and Pico. The study performed by Monica Silva suggested that bottlenose dolphins occurring in the Azores constitute a single and open population with high mobility between islands.

1.5 The Azores

The Archipelago of the Azores is located in the mid North Atlantic Ocean, between 36°55′ and 39°43′N and 25°01′and 31°07′W, about 1300 km from west of Lisbon and 1900 km from North America. This archipelago is composed of nine islands, forming three groups: the eastern group that consists of São Miguel and Santa Maria Island; the central group composed of the islands of Graciosa, Terceira, São Jorge, Pico and Faial; and the western group composed of the islands of Flores and Corvo (Figure 1.9).

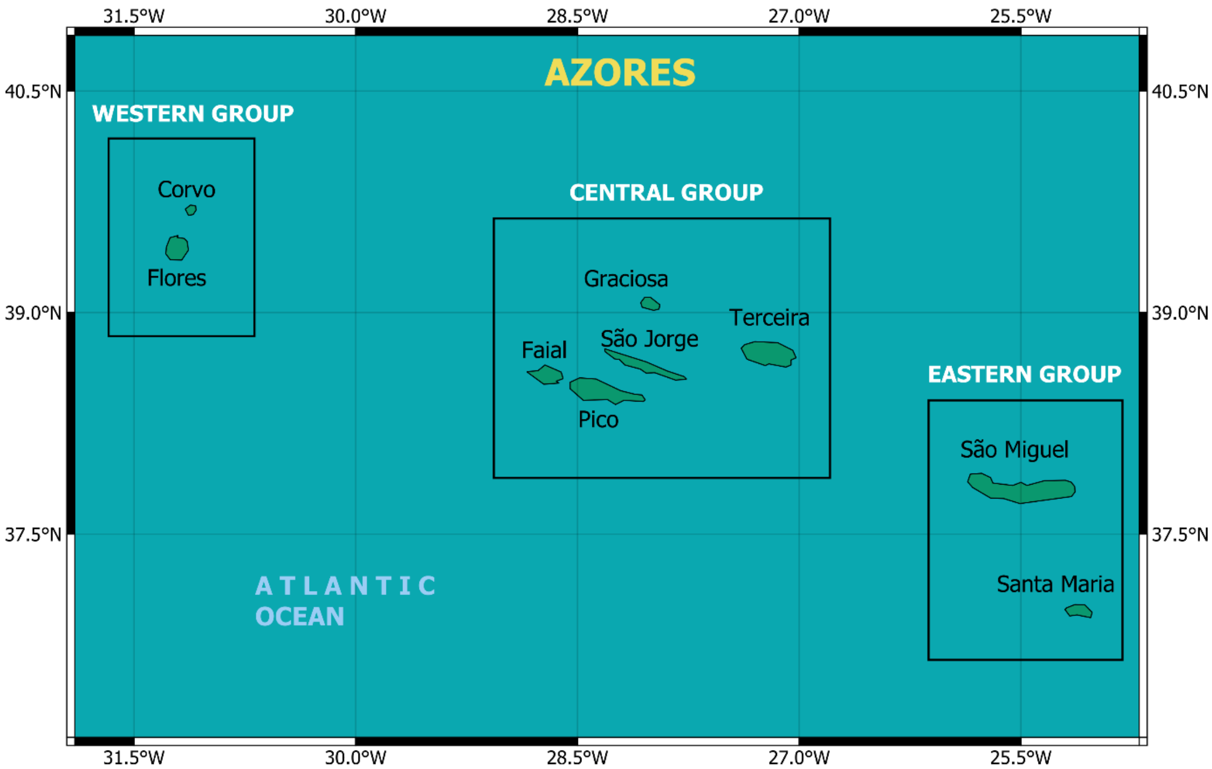

Figure 1.9.: Map of the Azores archipelago with the nine islands divided into the respective groups.

The marine topography of the region is highly variable and complex, characterized by numerous shallow-water and emergent features like seamounts, islets and islands, that rise from abyssal depths (>4000m), as well as deep-water ridges and submarine canyons (Martins, 1986; Silva, 2007; Morato *et al.*, 2008). The Azores have been classified as temperate warm or subtropical region (Gorshkov, 1979). The diversity of topographic features and the complex oceanography around the islands promote primary productivity through bottom-up processes making the Azores a good spot for foraging (Ballance *et al.*, 2006; González García, 2019).

Data for this study were collected in the south coast of São Miguel (Figure 1.10), which is the largest island with an area of 759 km^2, and also the most populous (approximately 140,000 inhabitants) (Moore, 1990; Silva, 2007). In the last 20 years, the number of people living and working around the coast of the island has increased, increasing the pressure created on the environment (Rodrigues *et al.*, 2012). The truth is that Azoreans are highly dependent on the sea, not only for economic income but also for communication and trade, which explains why the major commercial facilities, employment opportunities, economic activities and population are concentrated in the coastal area (Andrade *et al.*, 2006; Rodrigues *et al.*, 2012).

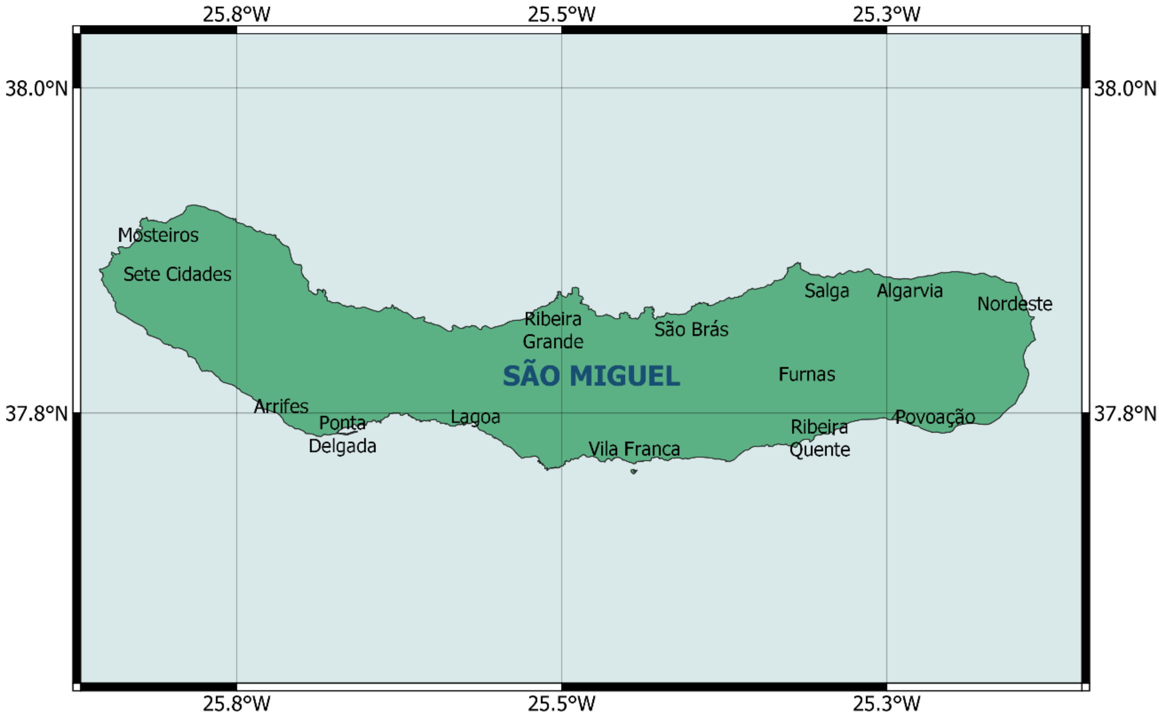

Figure 1.10.: Map of the island of São Miguel.

The Azores Current highly influences the island of São Miguel, increasing primary production and attracting marine life (González García *et al.*, 2018). The bathymetry around the island is very diverse, influences oceanic conditions and creates different habitats that will allure a great spectrum of marine life, making the island an oasis for residents but also migratory species (González García *et al.*, 2018).

1.6 Thesis objectives

The main objectives of this study are:

1) To analyse temporal and spatial distribution of bottlenose dolphins sighted in the south coast of São Miguel, using data collected during Futurismo's whale watching tours over the course of 10 years (2010-2019).
2) To create a photo-identification catalogue of bottlenose, identify individuals and their residency patterns dolphins in the south coast of São Miguel, using photos taken opportunistically during Futurismo's whale watching tours in São Miguel (Azores) over the course of 6 years (2014-2019).

Secondary objectives are:

1) To identify potential long-term/stable associations between individuals identified as residents.
2) To compare how temporal variations of sea surface temperature and concentration of chlorophyll-a are related with the temporal distribution of bottlenose dolphins.

The hypothesis to be tested are:

- Bottlenose dolphins have a year-around distribution in the island but most of the sightings occur during warmer seasons.
- Bottlenose dolphins present very stable social links and form groups of dolphins that can be re-sighted year-round and in different years.
- The bottlenose population around the island of São Miguel is composed of individuals with different levels of site fidelity.

This study will provide useful information to minimize the existent data gap for this species around São Miguel. We will demonstrate the viability of opportunistic data to assess cetacean distribution and ecology. We will provide a complete photo-identification catalogue of bottlenose dolphins in São Miguel. With this catalogue, future researchers might be able to conduct long-term tracking revealing information about long-range movements, side fidelity, calculate home range areas and even longevity of bottlenose dolphins in the wild. Furthermore, we hope to encourage more studies about this species in this region.

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MANUSCRIPT

Spatial and temporal distribution and potential residency patterns of bottlenose dolphins (*Tursiops truncatus*) off São Miguel Island, Azores

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ABSTRACT

Bottlenose dolphins (*Tursiops truncatus*) are one of the most sighted species in the island of São Miguel, Azores, observed year-round during whale watching trips. Although a few studies have been conducted on their distribution and residency patterns around the archipelago, the main effort occurred in the central group of islands leaving São Miguel with little results obtained from the available information. This study aims to understand spatial and temporal distribution of bottlenose dolphins around the south coast of São Miguel and to create a photo-identification catalogue and identify residents. It also aims to evaluate the relationship between temporal variations in SST and chl-a with the temporal distribution and verify for possible associations between dolphins identified as residents. Data was collected opportunistically during whale watching trips on the south coast of São Miguel. The two sets of data used consisted of a 10-year (2010-2019) occurrence data and photographs taken during a period of six years (2014-2019). These data were used to build maps on QGIS to analyse the species distribution regarding topographic variables and to create time series revealing temporal distribution. Furthermore, to use photo-identification methods to build a catalogue of the individuals found, understand their potential level of fidelity to the area and the existence of associations between residents based on capture-recapture. The results obtained suggest that bottlenose dolphins in São Miguel prefer coastal and shallow waters and are mainly sighted during late spring and summer. That time of the year corresponds to low levels of chl-a (a proxy for phytoplankton) and an increase in SST. The photo-identification catalogue consists of 505 individuals, however, only 52 were considered residents. From these 52 individuals, four possible associations were discovered. This study will set a sound baseline about bottlenose dolphins in São Miguel and will constitute a good support for further studies in the area, as well as for future conservation and/or management measures.

Keywords: Bottlenose dolphin, Azores, São Miguel, photo-identification, distribution

1. INTRODUCTION

In biology, the definition of population describes a group of organisms of the same species occupying a particular space at a particular time (Krebs, 1994). Nonetheless, individuals from the same population can have different ranging patterns and move differently, which can highly impact population distribution and abundance, habitat selection, interactions with other species, and social and population structure (Defran *et al.,* 1999; Nathan *et al.,* 2008; Börger, 2016). Whether they stay in the same area or leave, their movements are usually driven by the discontinuities in the distribution of limiting resources like food, mates, nursery, resting and predator avoidance areas (Silva, 2007; Nathan *et al.,* 2008).

Site fidelity and ranging patterns can influence the conservation of cetaceans by affecting their distribution and abundance, leading species with high site fidelity and restricted ranging patterns to be more vulnerable to population declines due to local threats (Warkentin & Hernández, 1996; Atkins *et al.,* 2016). Bottlenose dolphin's movement patterns differ among populations worldwide, some are year-round residents and show strong site fidelity (e.g Gaspar, 2003; Rako-Gospić *et al.,* 2017). Some exhibit seasonal fidelity (e.g Balance 1992; Ingram & Rogan, 2002) and might stay around while resources are still available before travelling long distances looking for it in different areas. While in other areas dolphins simply pass by, not showing any type of fidelity (Barco et al., 1999; Defran & Weller, 1999). And then there are areas like the Azores and Madeira with a mixed population composed of individuals with different degrees of site fidelity (Silva, 2007; Dinis et al., 2016).

Bottlenose dolphins are known to live in fission–fusion societies in which associations between individuals are very dynamic and fluid and can change within hours or days (Connor *et al.,* 2000). Nevertheless, they can also form long term associations between individuals (Connor *et al.,* 2000). These bonds might bring some advantages to the individuals, such as, low predation risk, cooperation during foraging, care for each other and higher calf survival (Louis *et al.,* 2017).

The study of marine mammals such as bottlenose dolphins is difficult and demanding, since they do not spend a great amount of time at the surface, are highly mobile, sometimes present elusive behaviour and the conditions of their habitat can be unfavourable and hinder data collection (Dinis *et al.,* 2016; Nowacek *et al.,* 2016; González García, 2019). Starting a study with lack of background knowledge and limitations in the field is extremely difficult, therefore working with platforms of opportunity such as whale watching boats to obtain occurrence data is now widely used for cetacean research, considering advantages such as easier logistics, cheaper and with observations of a vast number of different species usually on a long-term regular basis (Redfern *et al.,* 2006; González García, 2019). During those opportunistic surveys, it is possible to take information on time and location of the sighting, group composition, behaviour, site fidelity and ranging patterns (Würsig & Jefferson, 1990). Opportunistic platforms of observation (OPOs), provide also excellent opportunities to get photography data on bottlenose dolphins, useful to identify individuals based on their natural marks like nicks and notches on the dorsal fin, pigmentation patterns, and scars (e.g Pleslić et al 2019; Baker et al., 2018; Louis et al., 2017; Baird et al., 2009). This technique proves to be more effective and non-invasive than physically capture the animals (Hammond *et al.,* 1990; Neumann *et al.,* 2002; Evans & Hammond, 2004).

The Azores archipelago, in the middle of the North Atlantic, is an oasis for megafauna due to the dynamic oceanography around the islands and the association between the different currents with the local bathymetry, which results in mesoscale oceanographic events that enhance primary production and aggregation of trophic levels in the area (Ballance *et al.,* 2006; Tobeña *et al.,* 2016; Caldeira & Reis, 2017; González García *et al.,* 2018). However, when it comes to the study of bottlenose dolphins, there is a record of studies aimed at understanding their behaviour, habitat preferences, genetic structure, demographic parameters (Quérouil *et al.,* 2007; Silva, 2007; Silva, 2009), but most of the effort occurred in the central islands of the Azores. Bottlenose dolphins are one of the most sighted species in the archipelago and they are considered one of the resident species because they are observed year-round (Silva, 2007; González García, 2019). However, residency patterns are hard to evaluate and require long term studies to verify if they have been maintained through time (Scott *et al.,* 1990; Dinis *et al.,* 2016). The present study aims to: (1) understand bottlenose dolphins spatial and temporal distribution on the south of São Miguel, using occurrence data taken over the course of 10 years (2010-2019) on board whale watching boats in São Miguel island, combined with oceanic and environmental variables and (2) to create a photo-identification catalogue using the photographs taken during the whale watching trips over the course of 6 years (2014-2019) to identify residents and possible associations between them.

Bottlenose dolphins at a global level are listed as "least concern" in the IUCN Red List, however, local populations such as the Mediterranean and Fiordland are labelled "vulnerable" and "critically endangered", respectively (IUCN, 2009, 2010, 2018). Populations from all around the world do not show the same residency patterns, distribution, and social structure and therefore it is not possible to generalize nor apply the same conservation measures (Martinho *et al.,* 2015; Dinis *et al.,* 2016). Each site has their own characteristics and their own population which makes local studies like this important (Dinis *et al.*, 2016, Martinho *et al.*, 2015). This thesis will not only contribute to fill in the gap of information regarding bottlenose dolphins in São Miguel but also to understand if individuals identified show any kind of residency around this island, where touristic operation runs on a daily basis year-round. Those findings will set the baseline for further and deeper studies about residency of this species in São Miguel, and could give support to build new appropriate management plans for the area.

2. MATERIALS AND METHODS

2.1 Study area

The archipelago of the Azores consists of nine volcanic islands located between 37º and 40ºN latitude, 25º and 32ºW longitude, in the middle of the warm-temperate waters of the North-East Atlantic Ocean. Located 1400 km from Europe and 2000 km from North America (Figure 2.1), the archipelago is divided into three groups Occidental Group (Flores and Corvo), Central Group (Graciosa, São Jorge, Faial, Pico and Terceira) and the Oriental Group (São Miguel and Santa Maria). The islands are separated by waters deeper than 2000 m, while shallow waters occur only near the coast, except for emergent features like seamounts and islets (Silva, 2007; Morato *et al.*, 2008; Silva *et al.*, 2014). The conservation of the archipelago is controlled by the "Parque Marinho do Arquipélago dos Açores" (Azores Marine Park) (DLR 28/2011/A later altered to DLR 13/2016/A).

Nevertheless, each island constitutes a natural park ("Parque Natural de Ilha") and is responsible for their own conservation (DLR 15/2007/A; DLR 19/2008/A).

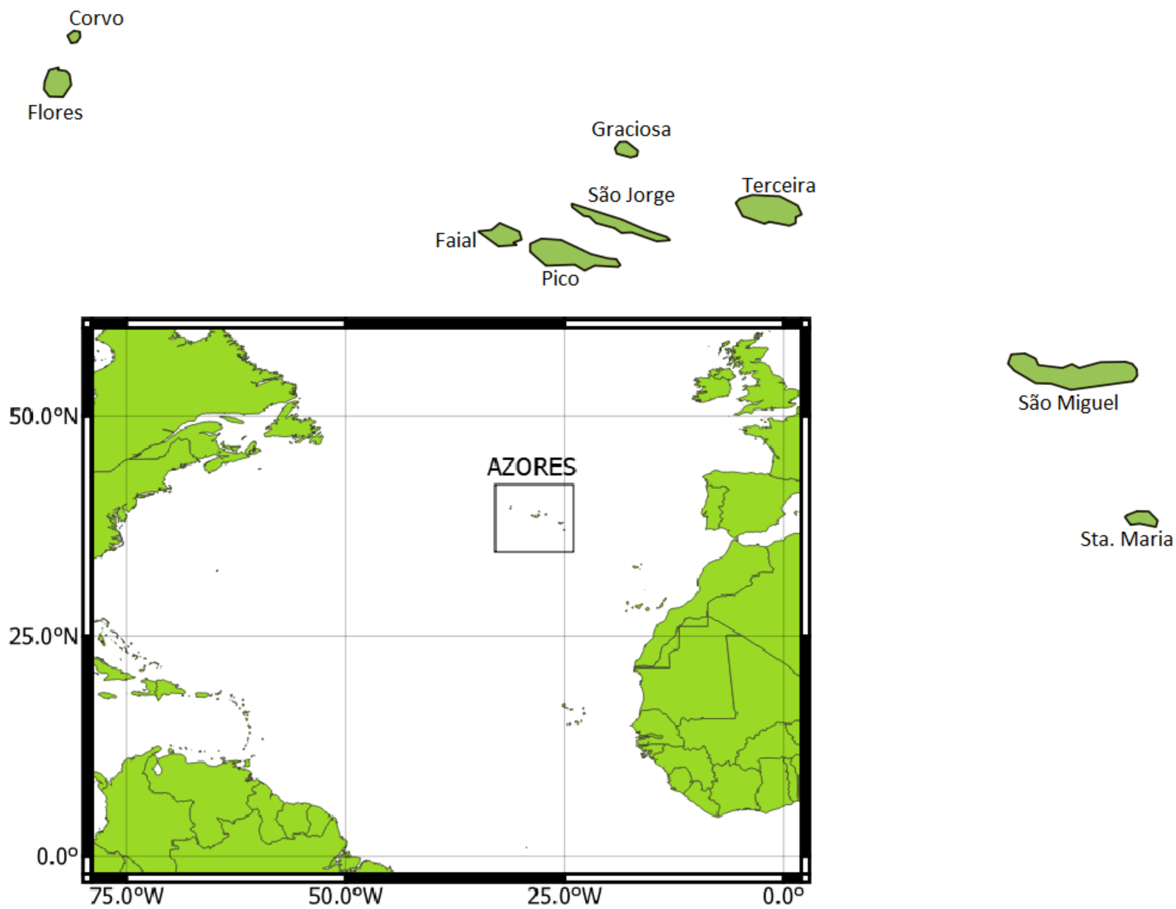

Figure 2.1.: Azores archipelago in the middle the Atlantic and the nine islands of the archipelago enlarged. The Azores (located 36-40°N, 24-32°W) is the most isolated archipelago of the North Atlantic. On the right side of the archipelago, only 1400 km away is Portugal, while on the left at 2000 km there is North America. The archipelago is divided into three groups of islands.

The data analysed in this study was collected in the south coast of São Miguel Island (Figure 2.2) which accounts for a wide range of habitats due to the complex bathymetry that includes narrow island shelves, steep island slopes, shallow seamounts, submarine canyons and vast areas of abyssal plain (Figure 2.3) (González García *et al.,* 2018). Furthermore, there are two major currents that influence the Azores: the cold southern branch of the North Atlantic Current formed from the Gulf stream and located north of the archipelago, and the warm Azores Front/Current system consisting of water with high salinity and temperature and located south of the Azores (Pérez, 2003). Average sea surface temperature varies from 15 to 25ºC every year, with maximum in summer and minimum in winter. The complex features and oceanography of the area are a major factor to why the Azores have such a rich diversity of species (Ballance *et al.*, 2006; Redfern *et al.,* 2006; Sala *et al.,* 2016).

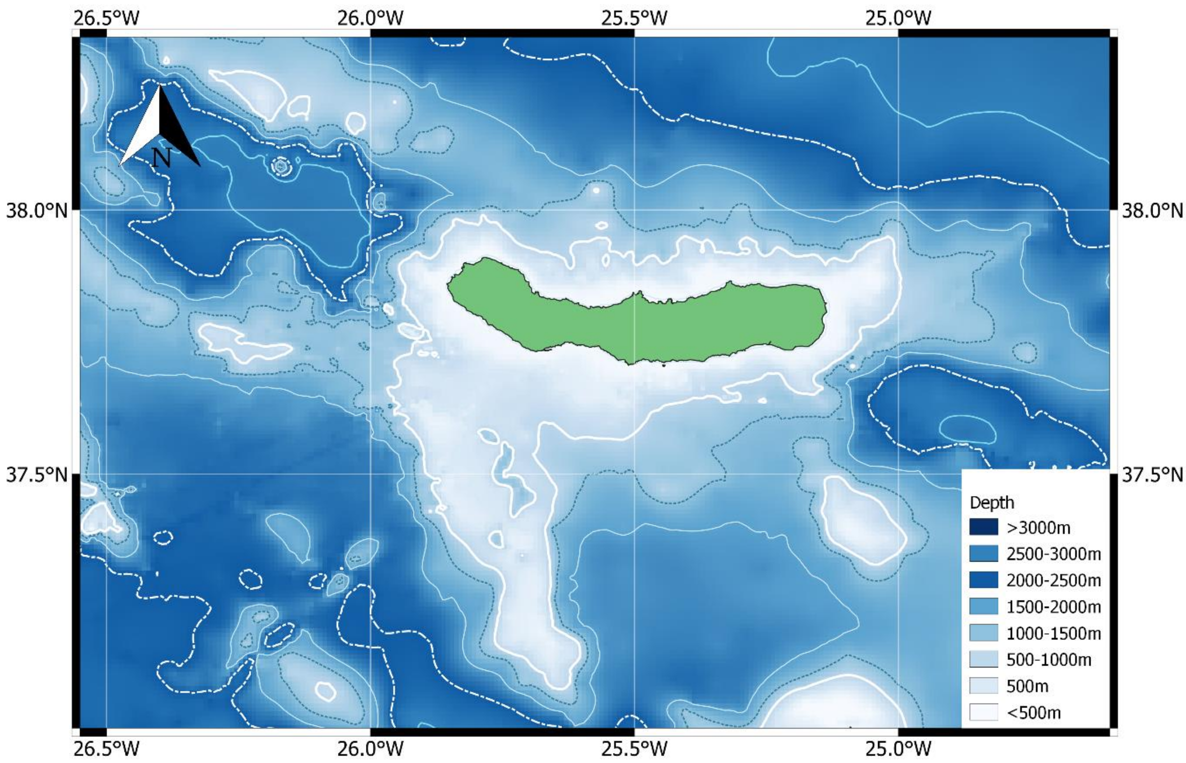

Figure 2.2.: São Miguel Island with bathymetry data. The area surveyed was the sea south of the island.

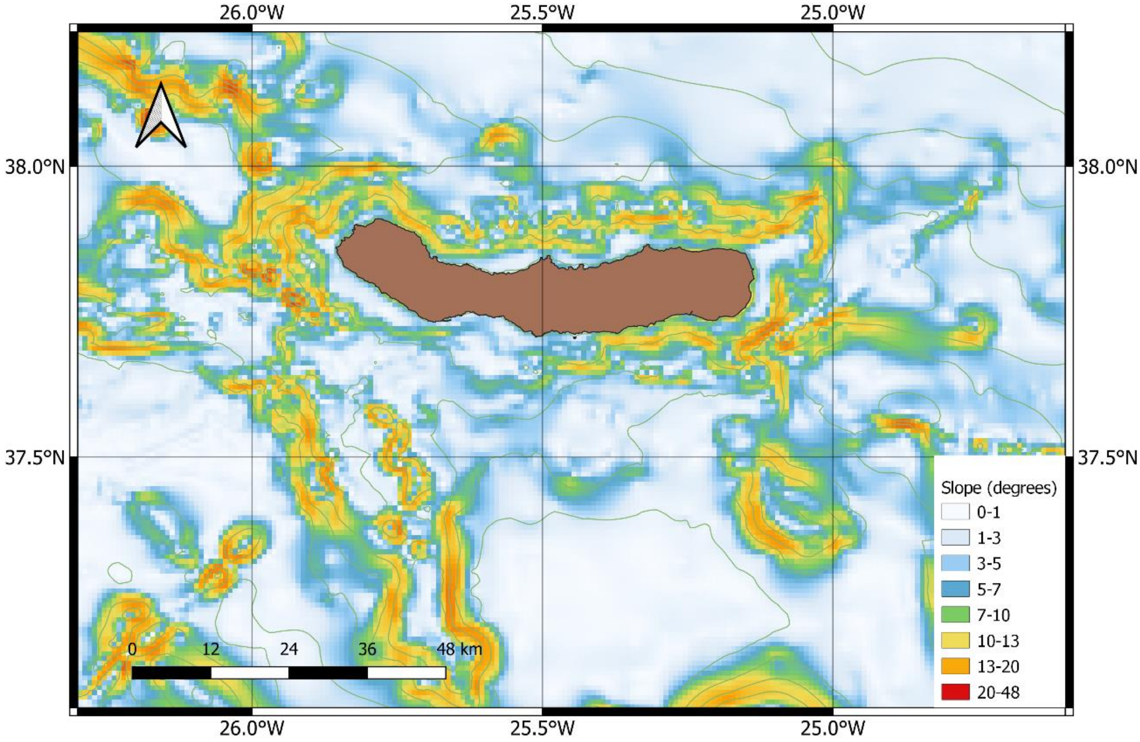

Figure 2.3.: The slope around the island of São Miguel. Lower slopes are more abundant in the south coast of the island.

2.2 Bottlenose dolphin occurrence data and survey effort

Occurrence data of bottlenose dolphin were recorded over 10 years (January 2010-December 2019) in the south of São Miguel Island from opportunistic platforms of observation, i.e., from whale watching vessels belonging to Futurismo Azores Adventures, and mostly departing from Ponta Delgada harbour. Futurismo Azores Adventures is a company that has been operating mainly in São Miguel since 1994. Futurismo runs daily trips usually twice a day for 3h (9-12 h and 13:30-16:30 h), but dependent on a minimum number of tourists and good weather conditions. Only if both conditions are checked, whale watching trips will be conducted. To look for whales and dolphins, the technique used was the same used by whalers a century ago. The lookouts (in Portuguese called "vigias") (Figure 2.4), people located on land in strategic points (with good visibility and spatial cover) around the island, work with powerful binoculars (Steiner 20 x 80 mm) trying to find the animals from land.

Whenever they found an animal, they would contact the boat via VHF radio and give it instructions to get to the place where the animals were seen. Some of the most used viewpoints in the south coast were: Escalvado, Ferraria, Candelária, Feteiras, Relva, Aeroporto, Água de Pau-Caloura, Pisão and Ponta Garça (Figure 2.5).

Figure 2.4.: Lookout (vigia) searching for cetaceans with powerful binoculars from land, to share after the location of whales and dolphins with the skippers via radio. Source: Futurismo Azores Adventures.

When the boats approached the animals, they had to follow certain rules in order to respect their welfare. The current legislation is in force since 1999 (DLR 9/1999/A) and has been updated in 2004 (DLR 10/2003/A). The company follows as well the responsible whale watching guidelines suggested internationally by the World Cetacean Alliance (WCA, 2013). Among the main rules, boats need to stay at least 50 m away from the animals (unless the animals themselves approach the boats) and always approach from the back or from the sides. Duration of the sighting, speed of approaching and number of boats in the area are also limited according to the legislation in force. During the encounters, the biologists on board register the GPS coordinates, species name, time of the sighting, behaviour, number of individuals, group composition (presence of adults, juveniles and calves), visibility and sea state, and took pictures of the animals whenever possible. Once on land, the data is uploaded to an existing database which is daily updated.

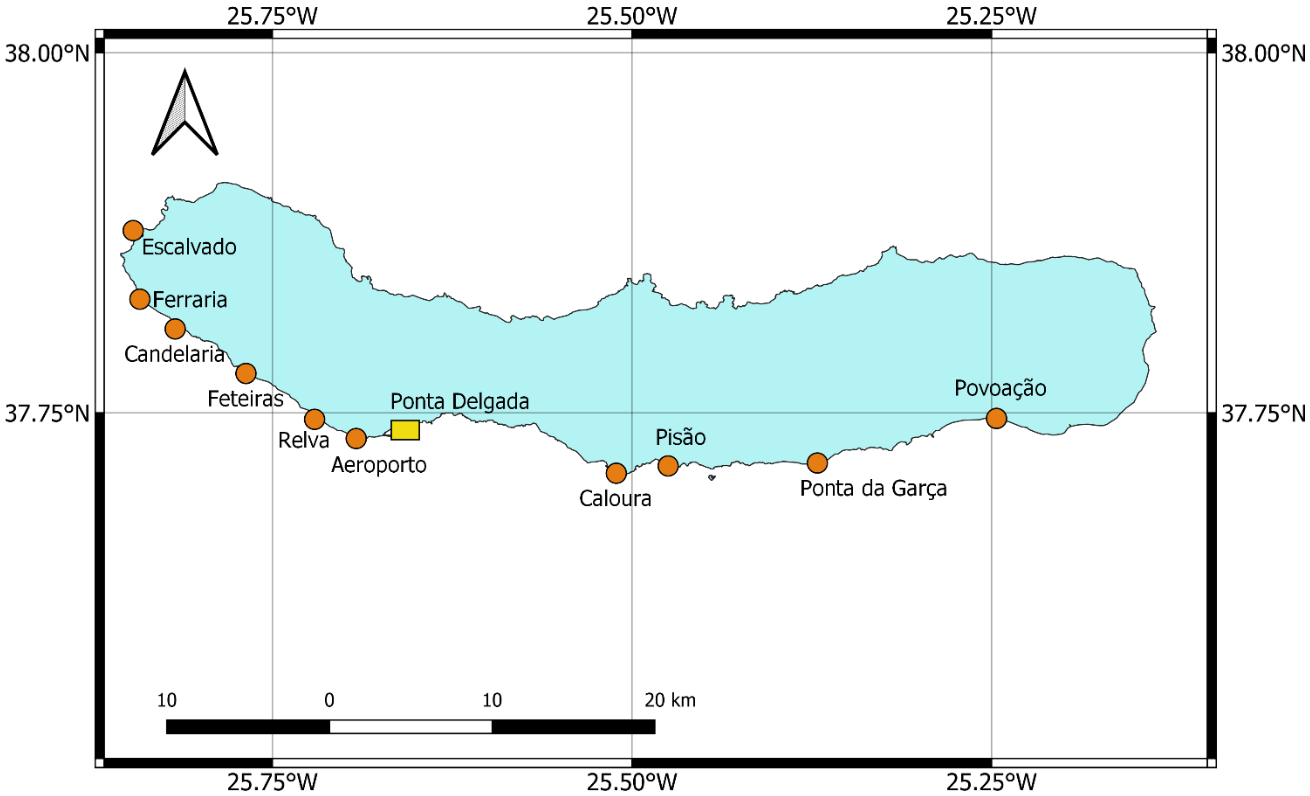

Figure 2.5.: Strategic points on land used for the lookouts to find the animals. The circles in orange represent the lookouts on the south coast of São Miguel. The yellow square shows the marina of Ponta Delgada where every trip started.

Effort was measured as the number of trips per season or year, since the animals were found by the lookouts on land and boats are directly piloted to them, so trajectory of the boat or time spent at sea cannot be considered as an absolute search effort due to the opportunistic nature of data collection.

2.3 Environmental variables

Local bathymetric features and oceanographic variables have a great influence on marine mammals' distribution by affecting primary production which in turn, controls prey abundance and conditions for upper trophic levels to occur (Cox *et al.*, 2013; González

García *et al.*, 2018). Since oceanic processes around the archipelago of the Azores are deeply complex, it is of high importance to include different topographic and environmental variables in the study in order to have a better understanding of the distribution of bottlenose dolphins. Depth, slope and distance to the coast values of sighting points were analysed in order to look for spatial distribution patterns. We considered Sea Surface Temperature (SST) and chlorophyll-a (chl-a) as dynamic oceanographic variables. Temporal variation of SST and chl-a were compared with temporal distribution of dolphins to understand if they could be related. Static variables such as depth (m), slope (degrees) and distance to coast (km) associated with each sighting point were extracted through Geographic Information System (Q-GIS) tools. Depth was obtained from the General Bathymetric Chart of the Oceans (GEBCO www.gebco.net, 2020) with a 15 arc-second grid resolution. Distance to the coast was calculated by converting the coastline polygon (taken from the *Instituto Hidrográfico de Portugal*, 2020) into points and then using the Distance Matrix tool on QGIS to calculate the distance from each of the sightings to the closest point on the island. Slope was processed from the bathymetry raster applying the terrain analysis tool of QGIS.

SST and chl-a (a proxy for phytoplankton biomass) were obtained from Giovanni (https://giovanni.gsfc.nasa.gov/giovanni/), an online platform for the display of geophysical parameters. Acquired from Moderate-resolution Imaging Spectroradiometer (MODIS), a key instrument on board NASA's Aqua satellite, the spatial gridded resolution of each variable is approximately 4 km. Area averaged time series for monthly SST (at 11 microns) and chl-a were plotted for the approximate area covered by the surveys (37.5-38ºN, 26-25ºW).

2.4 Photo-identification procedures

The photographs used in this study were taken during whale watching trips from 2014 until 2019. Only good quality photographs were considered, thus, for each encounter, photographs with a good focus, perpendicular angle of the dorsal and no bluriness were chosen. The selected photos were placed in folders named according to the date (day/month/year) they were taken. Once all the pictures were sorted into the proper folder the next step was to crop the dorsal fins present on each picture and separate them in order to have one dorsal fin per photo to later be processed. To crop the fins, the original photographs were uploaded to the online program "Photo-id ninja", a project created by researchers from the Massey University (New Zealand). This online programme has proven to be an important tool in photo-identification given that it identifies the fins in the photograph, extracts them and delivers a cropped version of each fin of the original photograph to download.

Before new dolphins were added to the catalogue, they were compared to all the previously identified individuals by using the open-source R package *finFindR* (Thompson *et al.,* 2019). The finFindR allows to extract the trace of each dorsal fin, therefore a different algorithm defining the shape of each dorsal fin is automatically created, providing an excellent filter to sort similar traces among all the ones considered. Image type should be selected as input, and after traces are calculated, should be saved. The package allows us to compare our "reference image directory", i.e. the fins already in our catalogue, with the "query directory", i.e. the new fins that need to be compared. As a result, a list of similar fins according to the trace algorithm and sorted by similarity will be shown. Both pictures, i.e. the new fin to check, and the selected identified individual in the catalogue to compare with, are shown side-by-side making easier for the user to confirm if it is a match or not. If it is, the date of the recapture will be included in the Excel sheet that contains the name of the individuals and the dates when they were seen. If it is not a match, the new individual will be added to the document and to the catalogue.

The best photograph of each individual (dorsal fin) was selected and given a code name that included TT (as in *Tursiops truncatus*) followed by the number of the individual. For example, TT002 would correspond to the second individual added to the catalogue. If the two sides of the same fin were found, each photograph would be named TT002_L and TT002_R ("L" for "left" and "R" for "right") and added to the same catalogue folder. For this study, only distinctive fins were added (with marks, nicks, cuts, bended or even missing a part) (Figure 2.6) in order to increase the reliability of the matches (Würsig & Würsig 1977; Wells & Scott 1990). Fins not marked (all grey, without any mark) were not accounted.

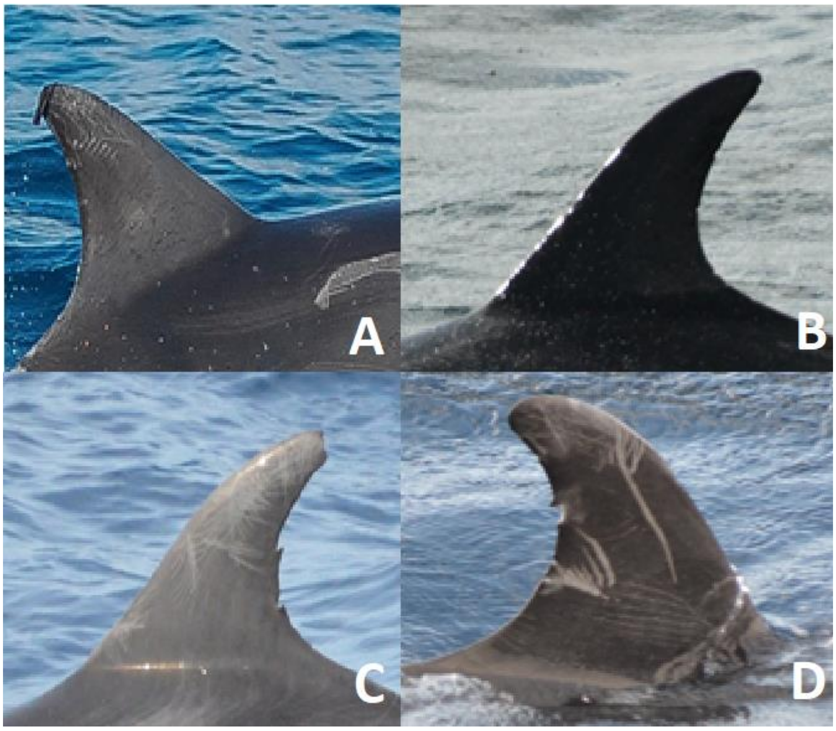

Figure 2. 6.: Four fins with distinctive marks. Each fin presents different levels of marks: A-white patterns, B-small nicks, C and D- cuts with white patterns. A-TT014; B-TT049; C-TT160 and D-TT207.

2.5 Data Analysis

2.5.1 Spatial distribution

Three different histograms were created on Excel to visualize distribution of bottlenose dolphins in relation to the depth, slope and distance to the coast. In order to determine the differences in spatial distribution for each season, three dispersion graphs, for the same variables were also created on Excel. Five density maps, one per season plus one for all the sightings, were also built on Q-GIS using the “heatmap” tool with radio space of 0.03 degrees and pixel size of 0.01 degrees. Colours were set as warmer colours for areas with high density of sightings and cold colours for low density.

2.5.2 Temporal distribution

An encounter rate (ER) was calculated in order to account for the relative effort carried out along the study period. This way, the ER allows us to compare occurrence of the desired species within the study period, for instance, between seasons and years to look for possible differences in time. Months were grouped into seasons according to similarities in oceanographic conditions: winter (January – March), spring (April – June), summer (July – September) and autumn (October – December) (Silva, 2007). The data used for temporal distribution was collected from 2010 until 2019 and contain a total number of 2079 sightings of bottlenose dolphins, in 3918 trips. The values were plotted in Excel, in order to identify seasonality and interannual differences. Temporal series along the study period were plotted for ER, number of sightings and for SST and chl-a. They were then compared to look for any potential similar patterns.

2.5.3 Residency and site fidelity

Once the catalogue was finished, the sighting frequency (number of sightings of each individual) and number of years observed were used to assess their degree of site fidelity to the south coast of São Miguel. Site fidelity is defined as the tendency of an individual to return to the same area repeatedly or to remain in an area for a long period (White and Garrot, 1990). The fidelity degrees were given to each individual based on their capture history and they consisted of four different levels: residents, migrants, transients, and non-residents. The first three designations have already been used in other studies (e.g Silva, 2007; Dinis *et al.*, 2016). In this study, residents were defined as individuals seen during three seasons in one year and at least two consecutive years (adapted from Dinis *et al.*, 2016); migrants were seen in less than three seasons for consecutive or non-consecutive years; transients were seen during a few days in one year and non-residents were seen one time only (Pereira, 2012).

Recapture rate was also calculated as the number of individuals recaptured in one year divided by the number of them identified in the previous year. This parameter was useful to assess how many new individuals were added each year. If recapture rate is low, either we are working with high numbers of new identified dolphins or with low site fidelity individuals, if it is high, individuals we could be working with residents or migrants. Individuals who were recaptured only in the year they were first identified, were not take into consideration.

2.5.4 Associations

Within the individuals categorized as resident, in an attempt to verify the existence of associations between animals, the dolphins were grouped based on the dates they were recaptured. Here, the term “group” was used to imply possible long-term associations of its members. In each group there was an individual considered as the “key individual” of the group, mainly because it was the most sighted and/or was the most distinctive. Individuals were added to a group according to the dates in which they were sighted together with the key-individual of that group, and if they did so in at least two years. This information was always confirmed by pictures of the individuals together and/or time of the pictures (if they were taken during the same sighting).

3. RESULTS

3.1 Survey effort and sightings

A total of 3918 trips were registered between 2010 and 2019. Whale watching trips occurred in every month of the study period, but higher effort took place during June, July and August, mainly due to favourable weather and sea conditions and higher presence of tourists in the Azores (Figure 3.1). Effort shows 2017 and 2016 turned out to be the years when it was higher with 452 and 451 trips recorded, respectively. The year with lowest effort was 2011 with 300 trips (Figure 3.2).

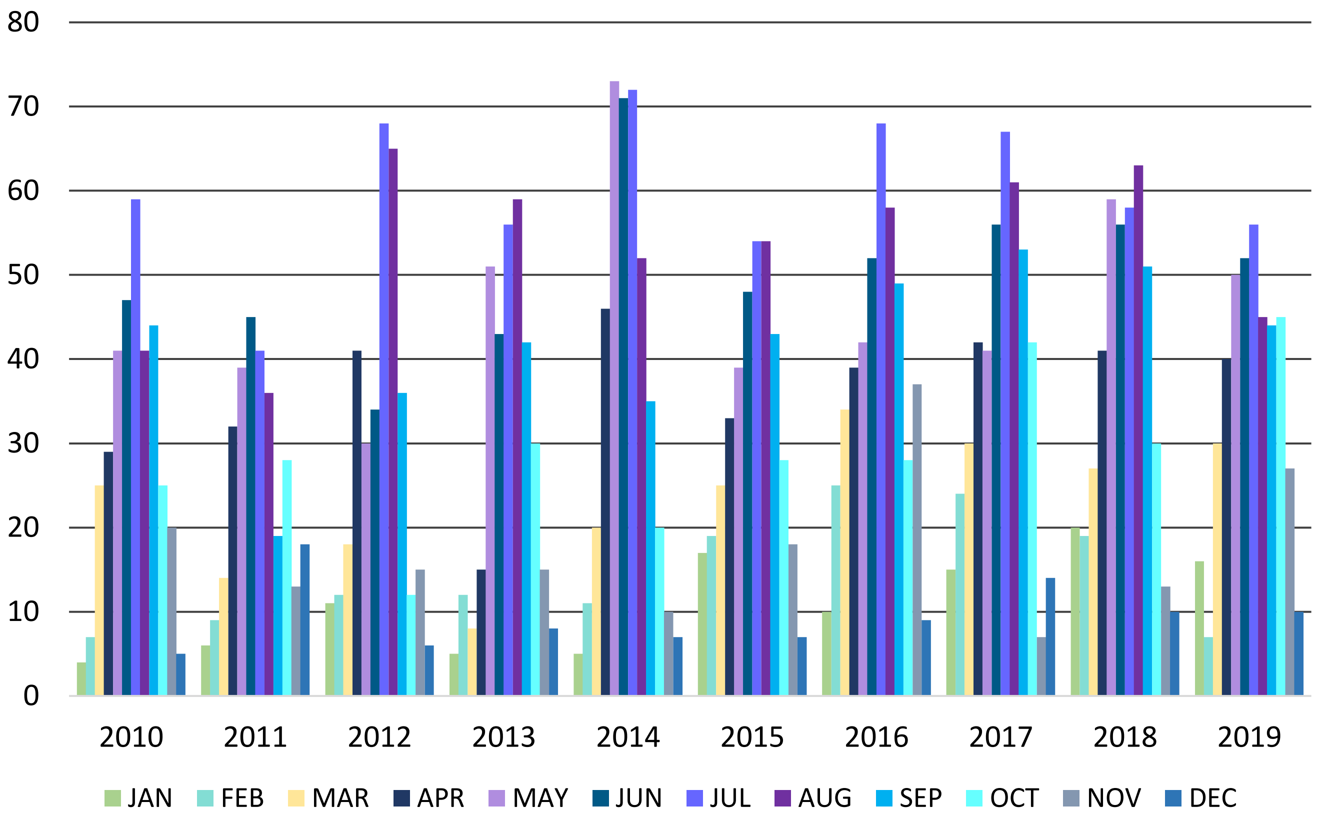

Figure 3. 1.: Summary of the number of trips (effort) per month and year in the study area during the sampling period (2010-2019).

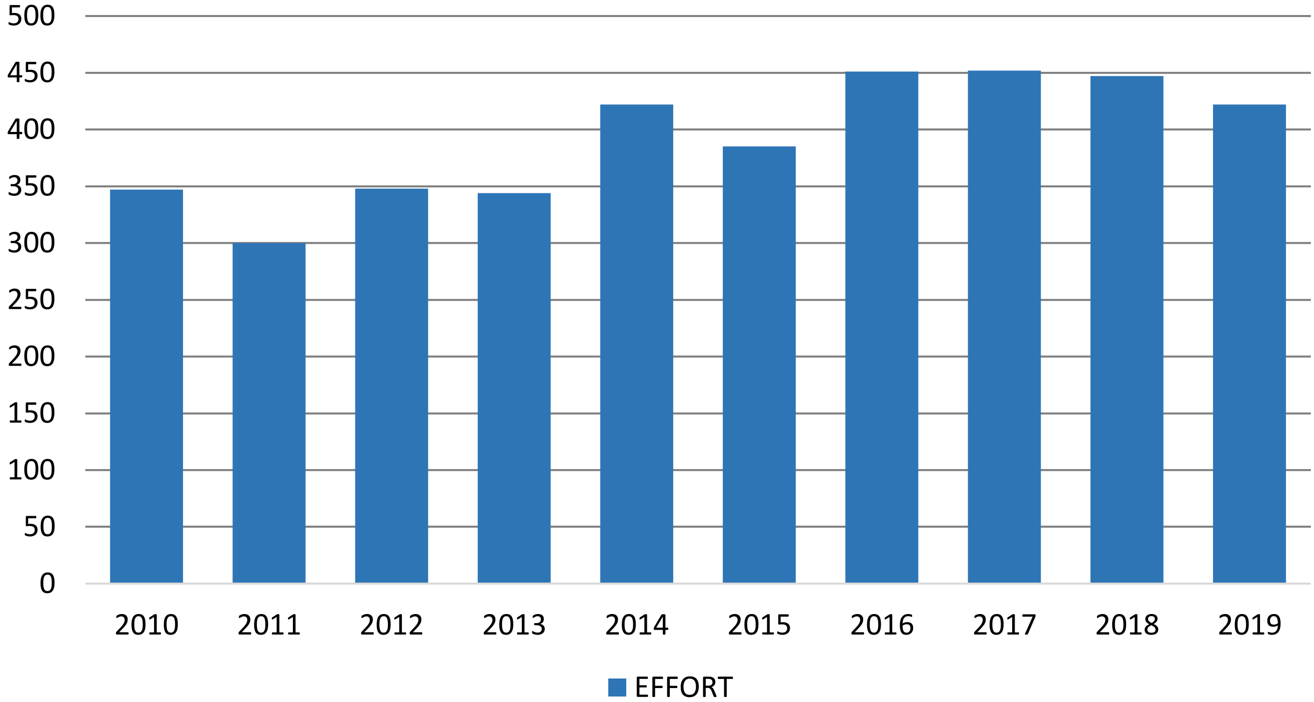

Figure 3. 2.: Summary of the number of trips (effort) per year in the study area during the sampling period (2010-2019).

3.2 Spatial Distribution

Occurrence of bottlenose dolphins is recorded all over the study area south of São Miguel, however there is a higher density of sightings in the area between Ponta Delgada and Caloura with a maximum concentration south of the former (Figure 3.3).

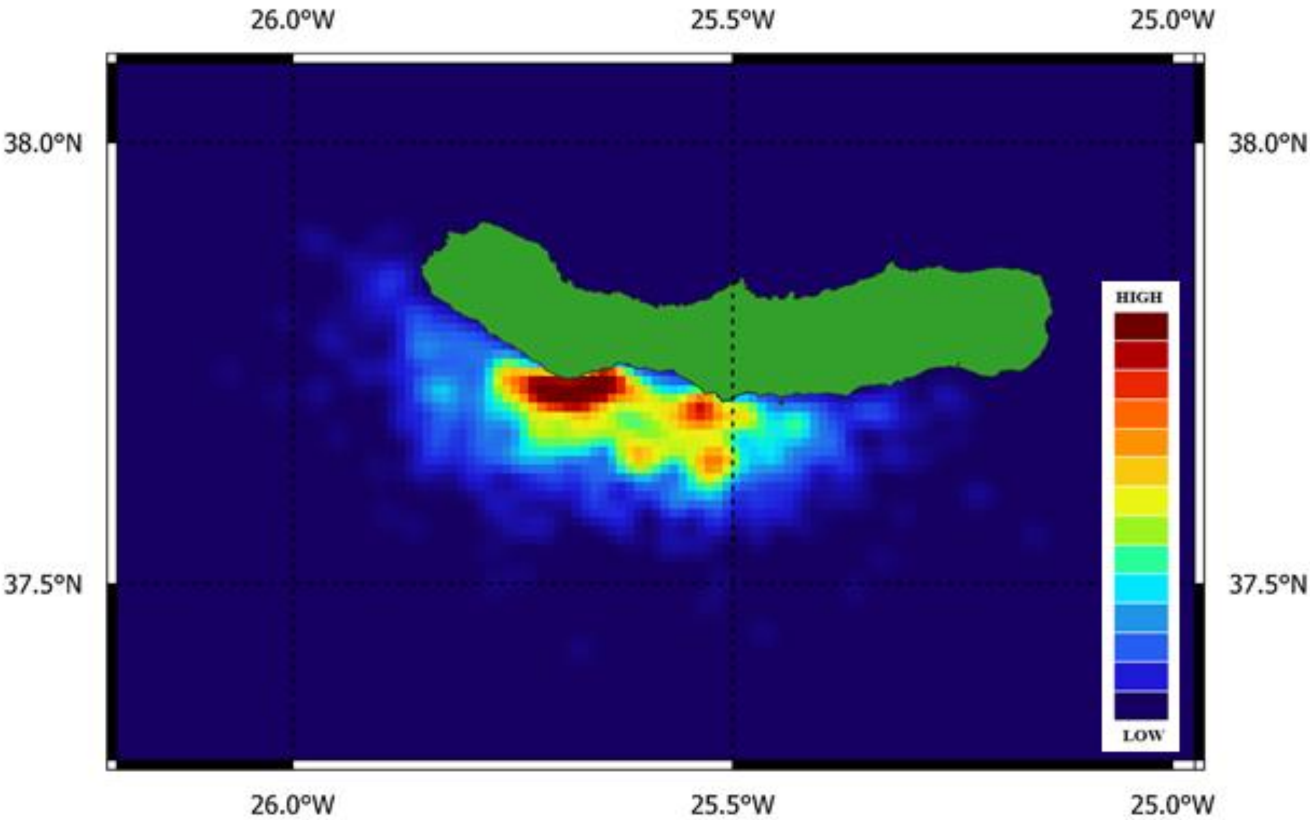

Figure 3. 3.: Density map of all the bottlenose dolphin sightings recorded around the island of São Miguel from 2010 to 2019. Warmer colours represent areas with higher numbers of encounters, while colder colours represent areas with lower number of sightings.

A higher concentration of sightings occurs south of Ponta Delgada in every season (Figure 3.4), nevertheless it is more pronounced during the spring and summer. A second hotspot can also be observed more to the east, south of Lagoa-Caloura. In this second area the concentration of sightings is closer to the coast during spring, while during the summer it spreads out more. During the spring, more sightings are recorded near the coast, whereas on the other seasons they are more dispersed. Winter and autumn present the lowest sightings density, as expected.

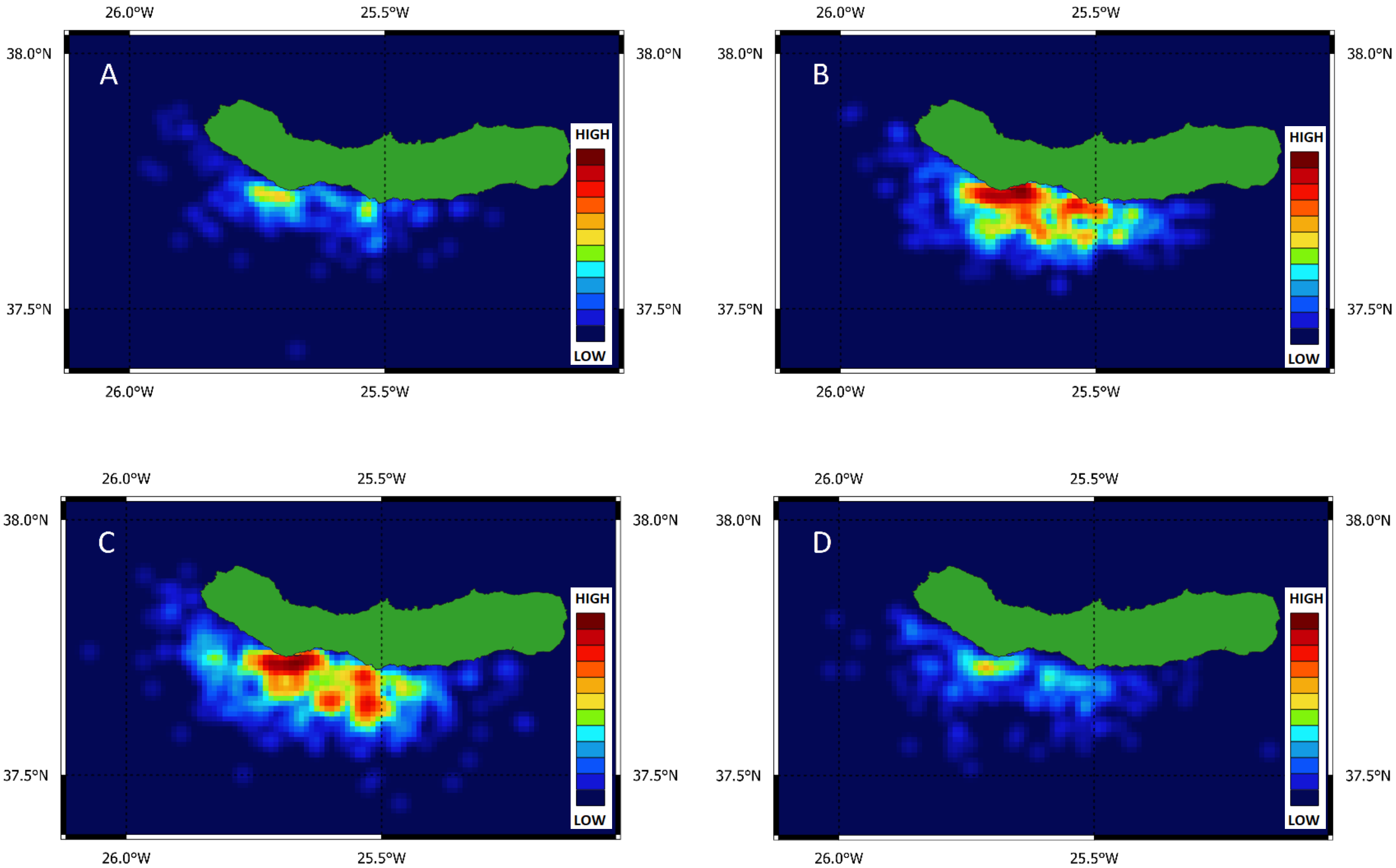

Figure 3. 4.: Density maps for every season to identify areas with higher concentration of sightings. A: Winter; B: Spring; C: Summer and D: Autumn.

Most of the sightings occur within 4 km. Only 5.14% of the sightings occurred further than 14 km from the coast (Figure 3.5).

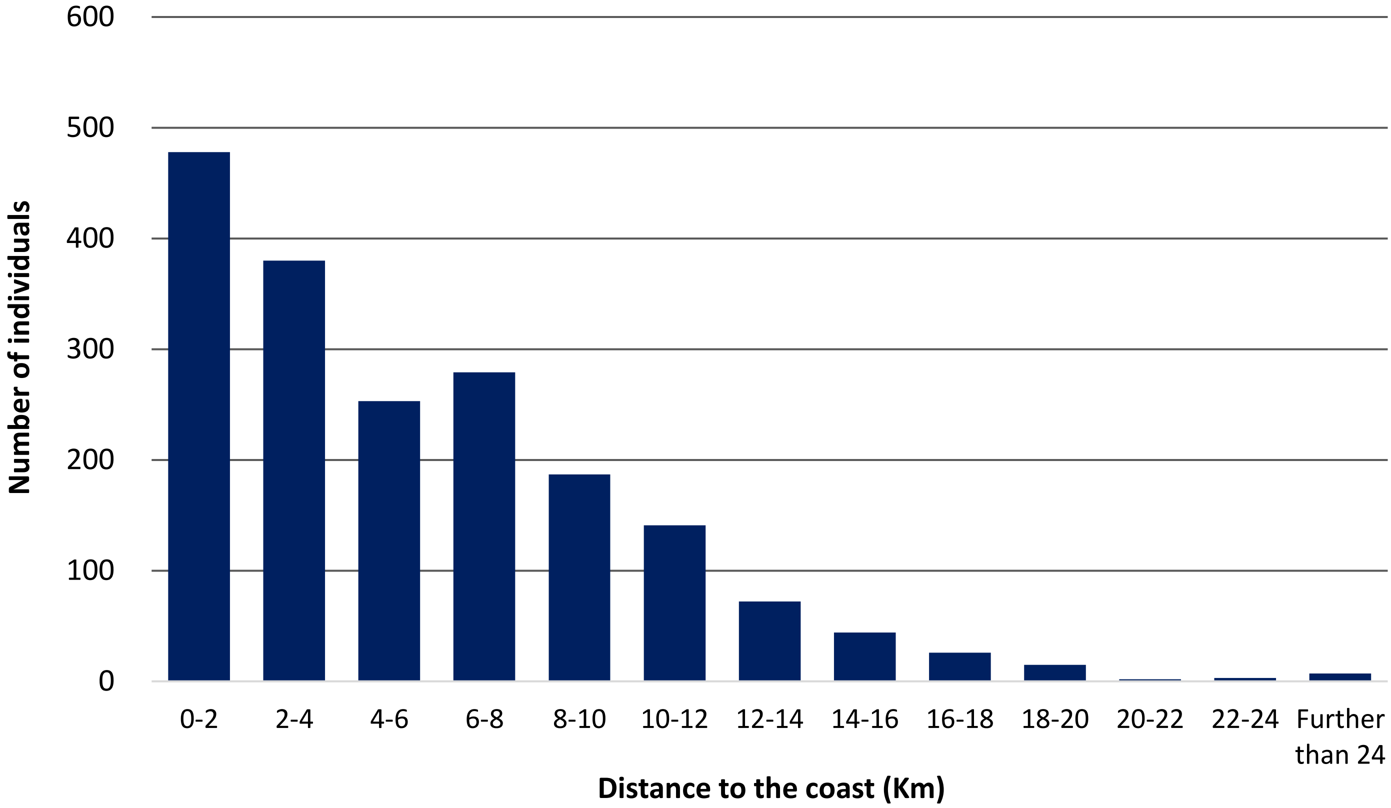

Figure 3. 5.: Histogram showing distance to the coast.

Distance to the coast slightly increases between summer and autumn surpassing the 20 km away from the shore (overall range: 0.04-35.1 km; median: 4.9 km), however the most distant sighting happened during March 2016 at 35 km away from the coast (Figure 3.6).

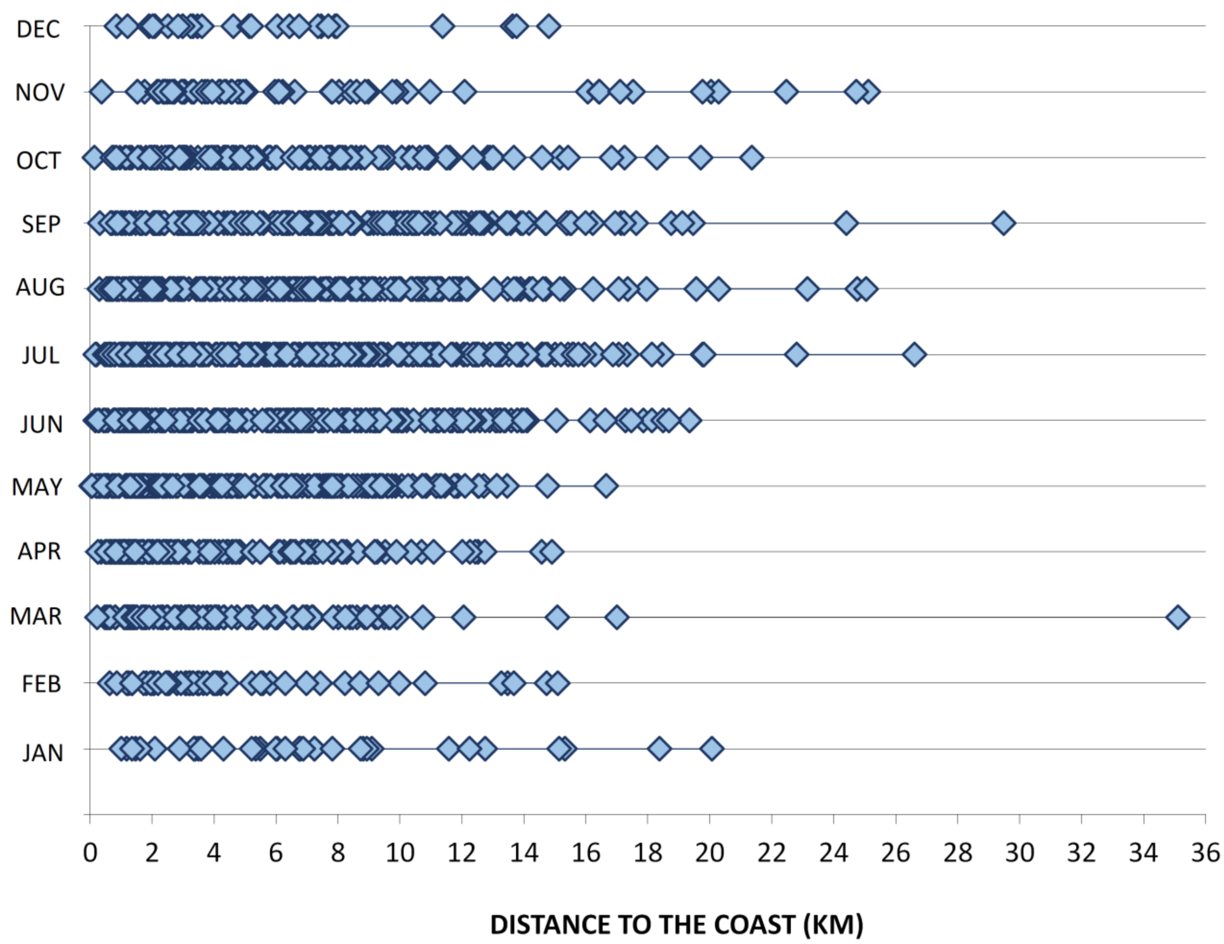

Figure 3. 6.: Distance to the coast per month.

The majority of the sightings (56.66%) was recorded in waters shallower than 400 m deep and only 4.95% occurred in waters deeper than 1000 m (range: 1-1934 m, median: 353 m) (Figure 3.7). During spring and summer dolphins reached the deepest waters (Figure 3.8). The deepest waters bottlenose dolphins were found in was at 1934 m deep, during the spring of 2019. Dolphins were mostly found (67.96%) where slope of the bottom was between 2º and 8º (overall range: 0.13-23.81º, median: 4.92º) (Figure 3.9). Occurrences on slopes steeper than 10º made up 10% of the sightings. Looking at the slopes during the different seasons it is possible to observe that values above 20º occurred only during the summer (Figure 3.10).

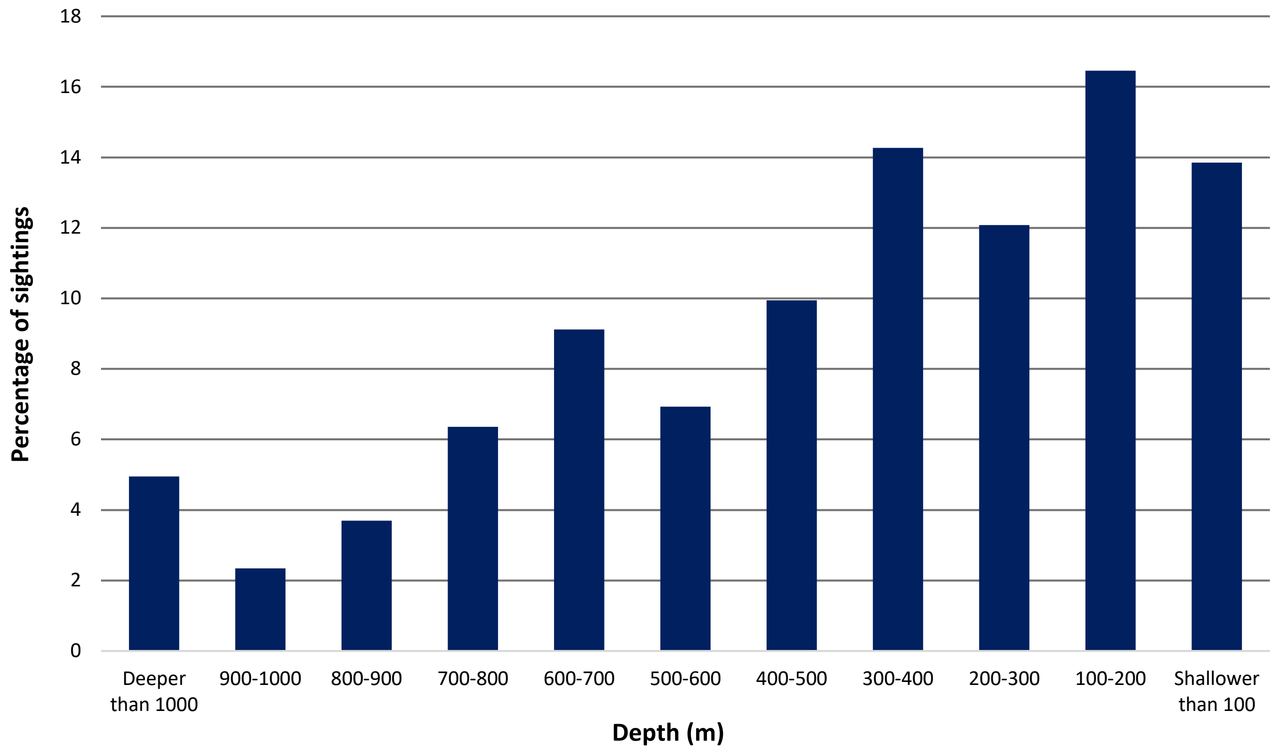

Figure 3. 7.: Histogram showing the percentage of the sightings at different depths.

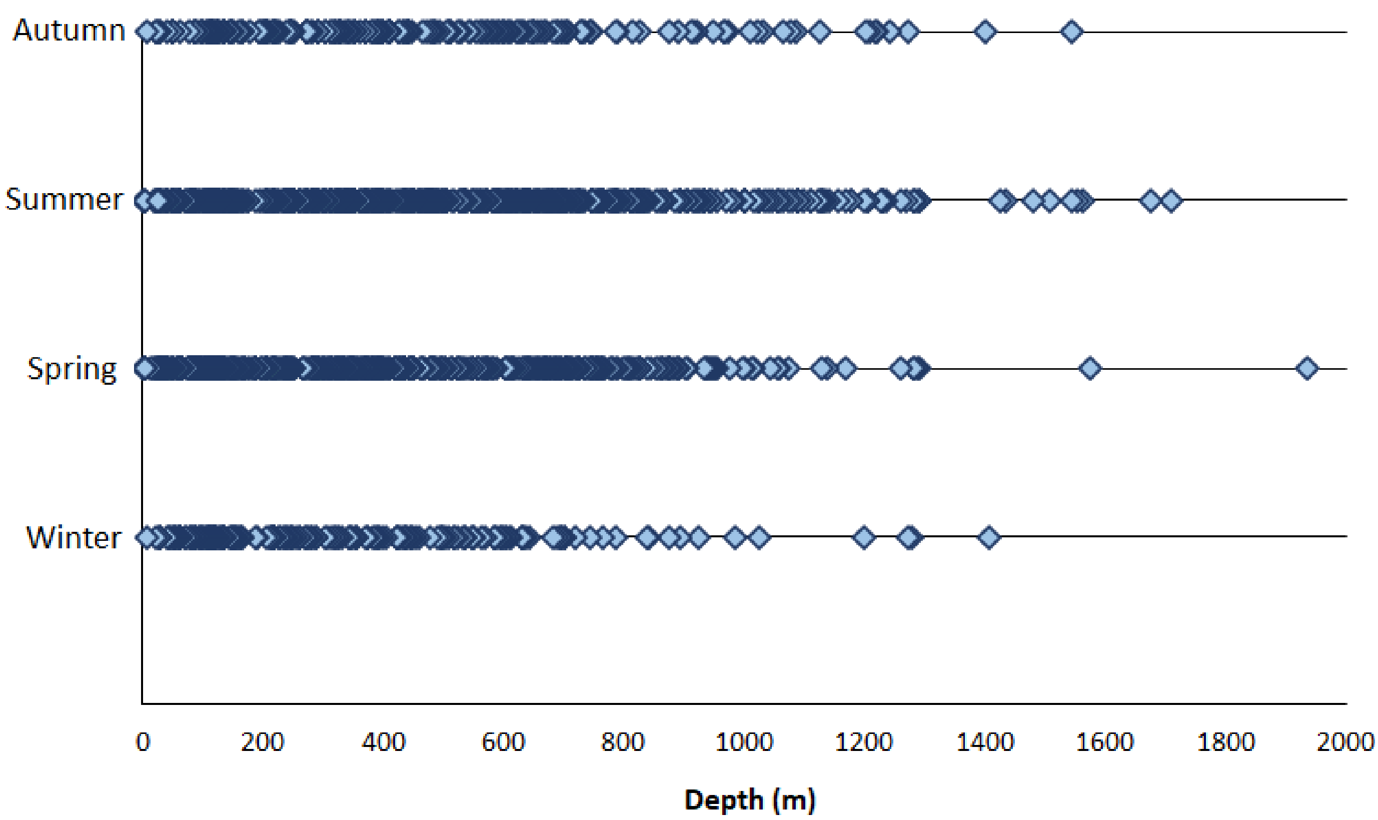

Figure 3. 8.: Depth per season.

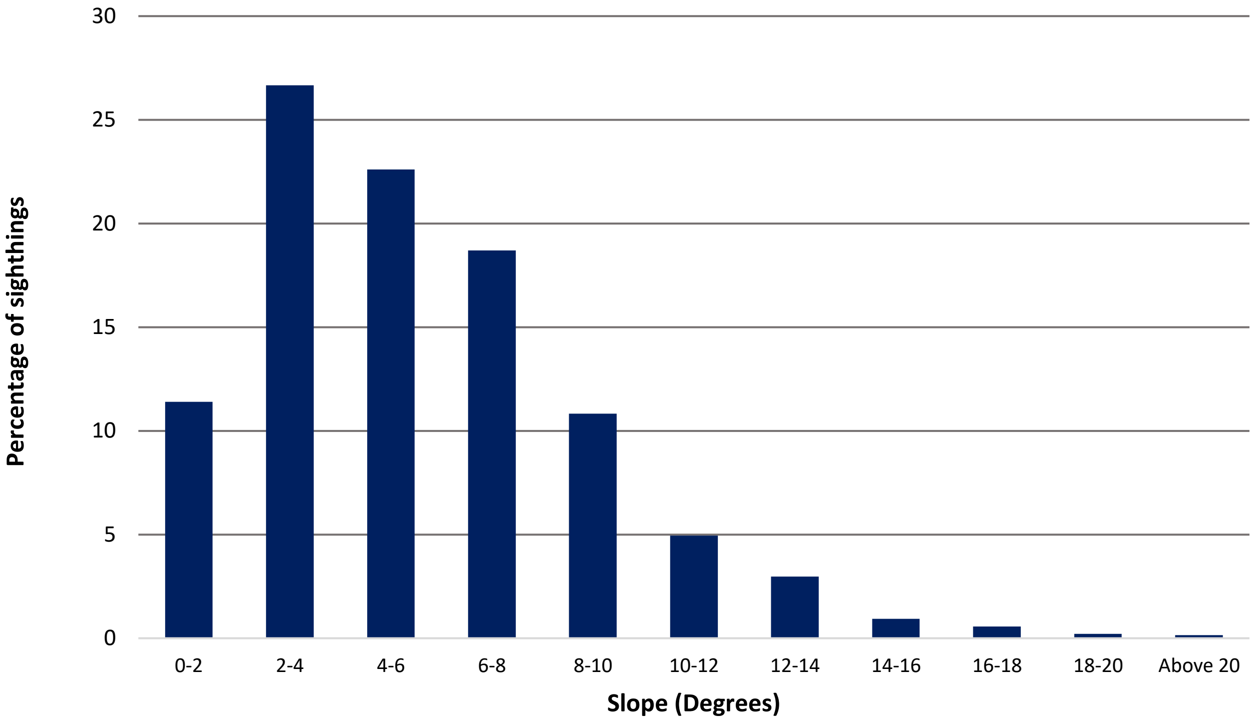

Figure 3. 9.: Histogram showing the percentage of sightings per slope.

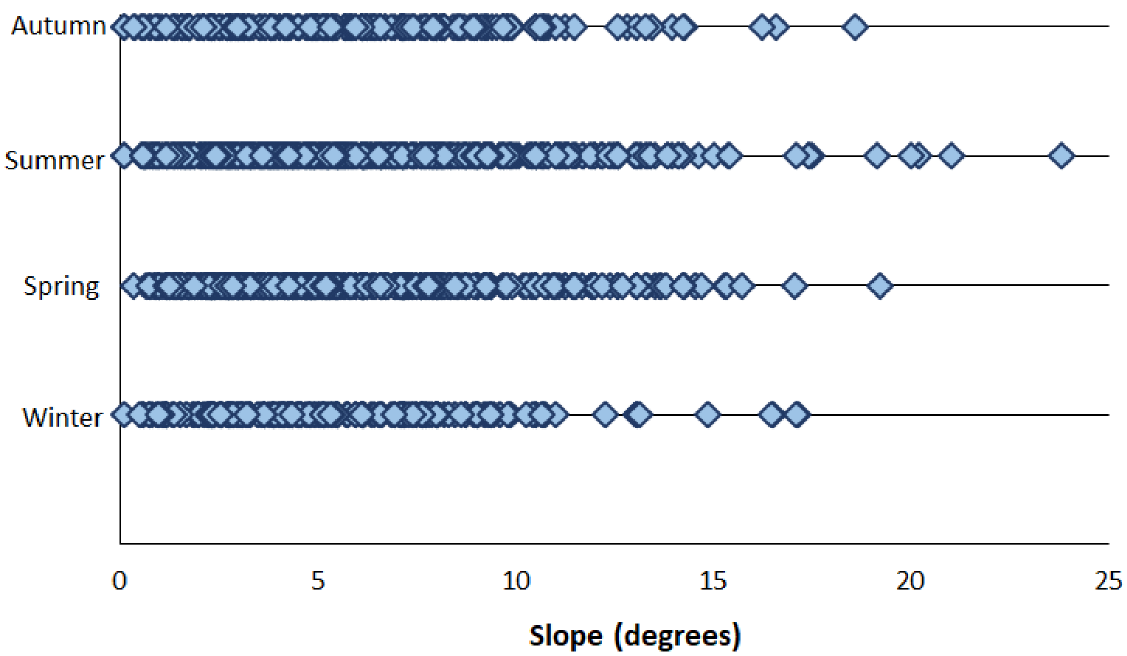

Figure 3. 10.: Slope of the sightings per season.

3.3 Temporal Distribution

The highest ER occurred in March 2015 with a value of 1.28 sightings/per trip and the lowest was 0.00 sightings/per trip in January 2010, 2012, 2013 and December 2010 and 2013 (Figure 3.11). No pattern was found for monthly encounter rate per year. When looking at seasonal ER the results obtained were higher during summer and spring (0.544 and 0.543 sightings per trip, respectively) and lower during winter and autumn, however the former was still higher (0.532 and 0.463 sightings per trip, respectively) (Figure 3.12).

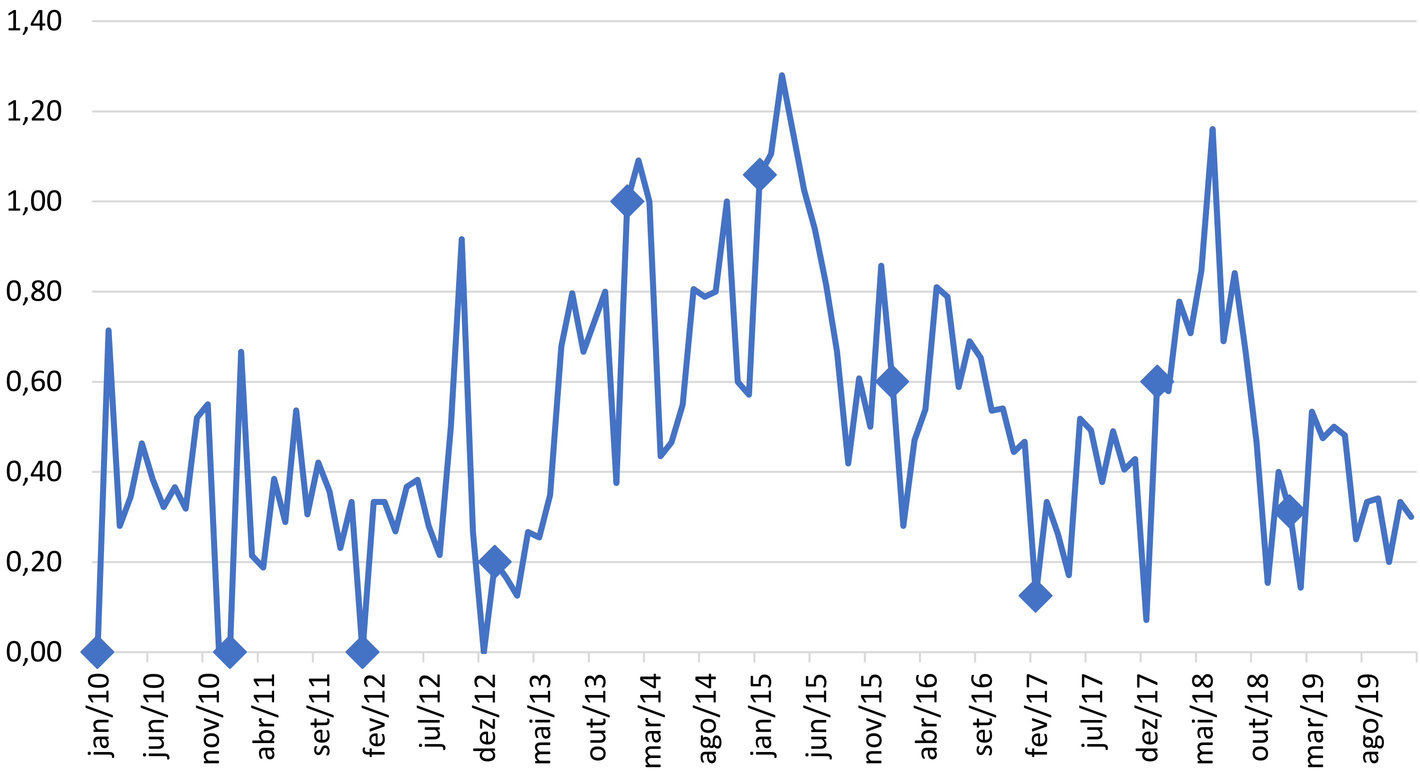

Figure 3. 11**.:** Monthly encounter rate per year.

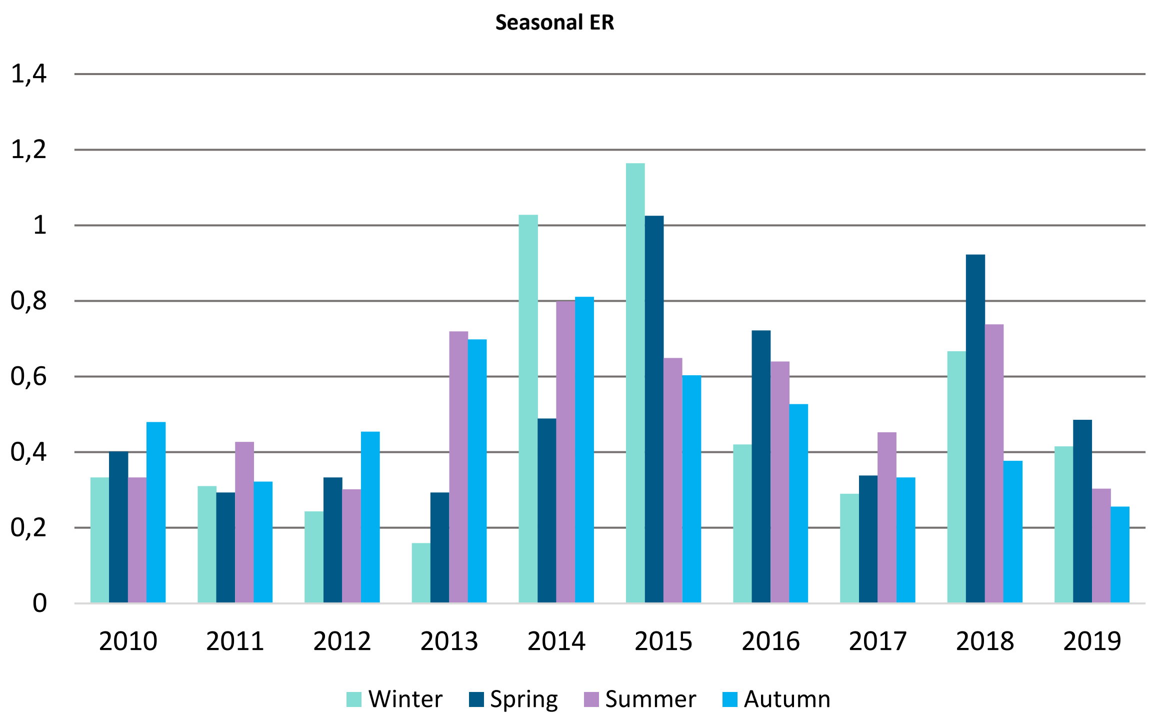

Figure 3. 12.: Seasonal encounter rate per year.

Bottlenose dolphins were sighted 2079 times in the south coast of São Miguel during the study period. They were encountered in almost every month, with the exception of January 2010, 2011 and 2012 and December 2010 and 2012 (Figure 3.13). The year of 2018 had the highest number of encounters (335), while 2011 had the lowest (103). Winter months always had few encounters, however there was always an increase towards spring and summer and a peak between June (2015, 2016, 2018, 2019) and July (2010, 2011, 2012, 2014, 2017) except for 2013 when it occurred in August. Seasonally, the number of sightings was higher during the summer and spring (40.55% and 34.63%, respectively) while during the winter and autumn it was lower with only 12.41% of the sightings for each.

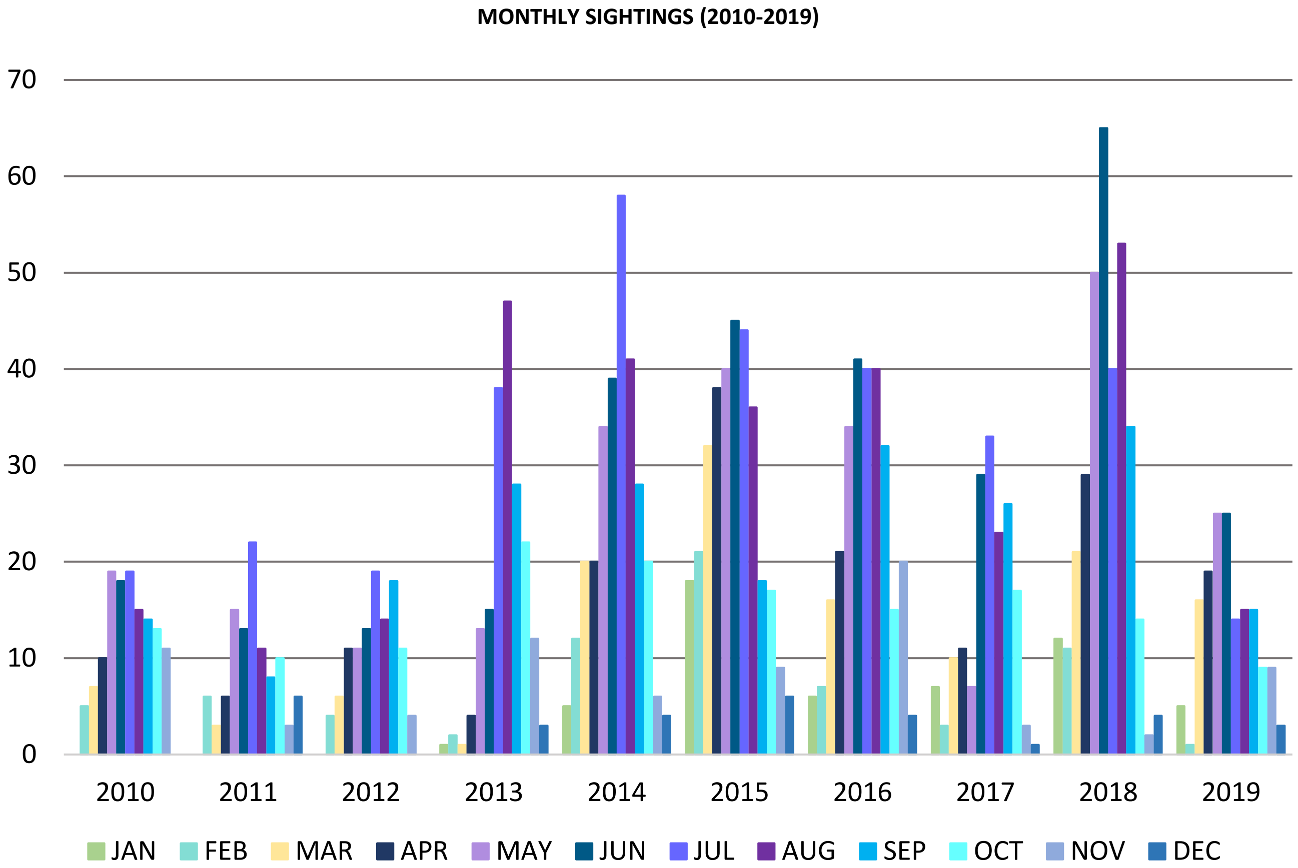

Figure 3. 13.: Bottlenose dolphin monthly sightings during the study period (2010-2019).

During the study period (2010-2019), SST ranged from 15.18ºC (monthly average) in February 2010 to 24.28ºC in September 2018. Every year SST rises during the spring and summer months, peaking at the end of the summer in August and September, except for 2014 and 2015 when it peaked earlier in July and August (Figure 3.14) The warmest year was 2018, reaching higher temperatures than other years in winter, spring and summer. In parallel to SST, Chlorophyll-a tends to decrease during the warmer months, therefore the lowest values occurred during late spring and summer with a mean of 0,11 mg/m^3 (range: 0.09 - 0.17mg/m^3) (Figure 3.15). Nonetheless, late winter and beginning of spring was the time when chlorophyll-a concentration was higher in the water with a mean of 0,44 mg/m^3 (range: 0.19 – 1.16 mg/m^3). Chlorophyll-a had its highest value during April 2010 and its lowest value during September 2013 and in the summer of 2018.

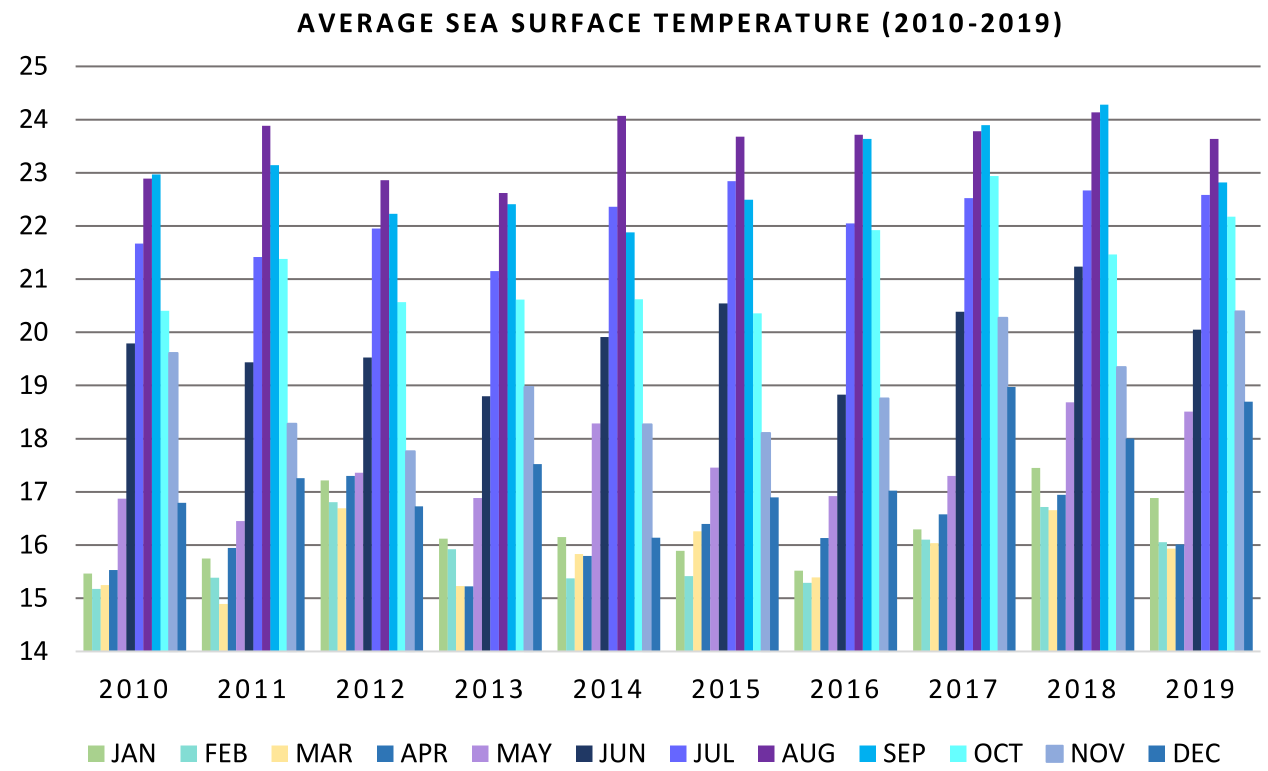

Figure 3. 14.: Sea Surface Temperature around São Miguel represented by monthly means during the study period (2010-2019).

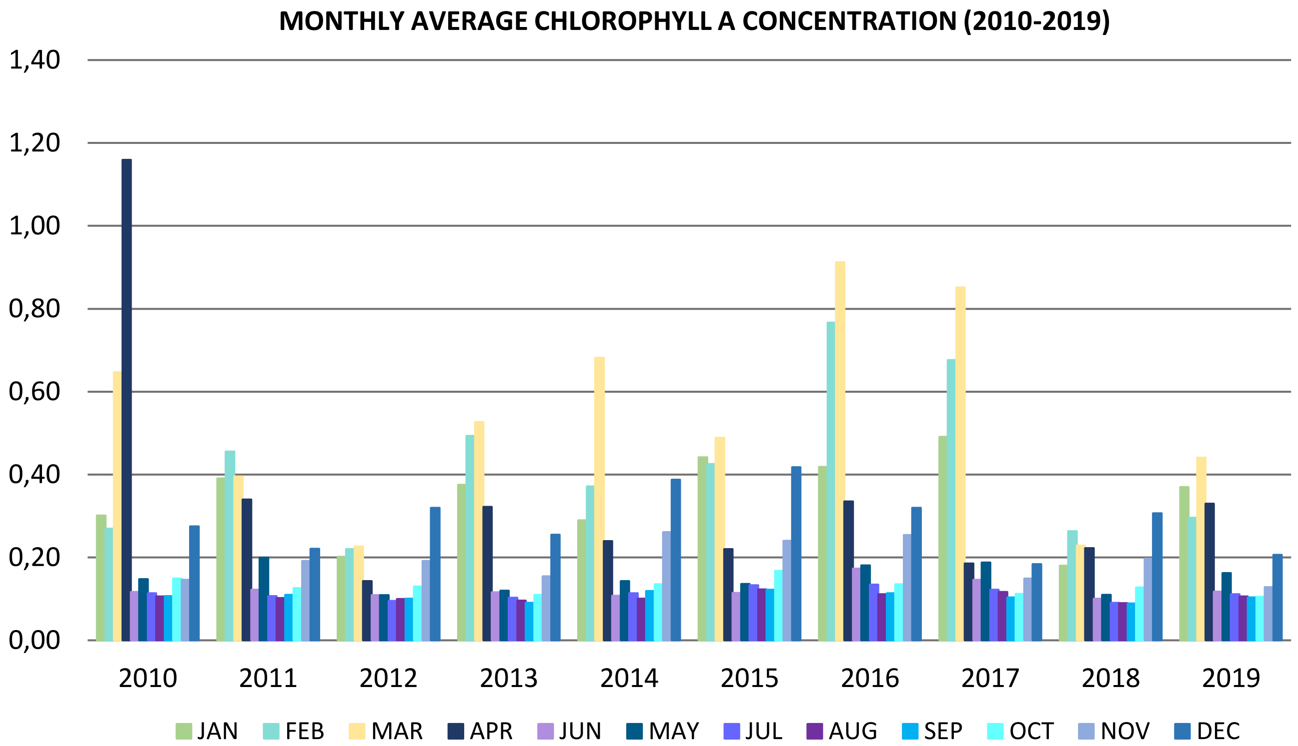

Figure 3. 15.: Monthly chlorophyll-a around São Miguel during the study period (2010-2019).

3.4 Photo-identification and associations

Overall, a total of 22387 pictures were analysed from a 6-year dataset (2014-2019). The year with more pictures analysed was 2014 with 11592 pictures taken, a considerably higher number than in the other years (Figure 3.16). However, in 2015 the days with pictures was the highest (141) the number of pictures analysed was also the lowest (562).

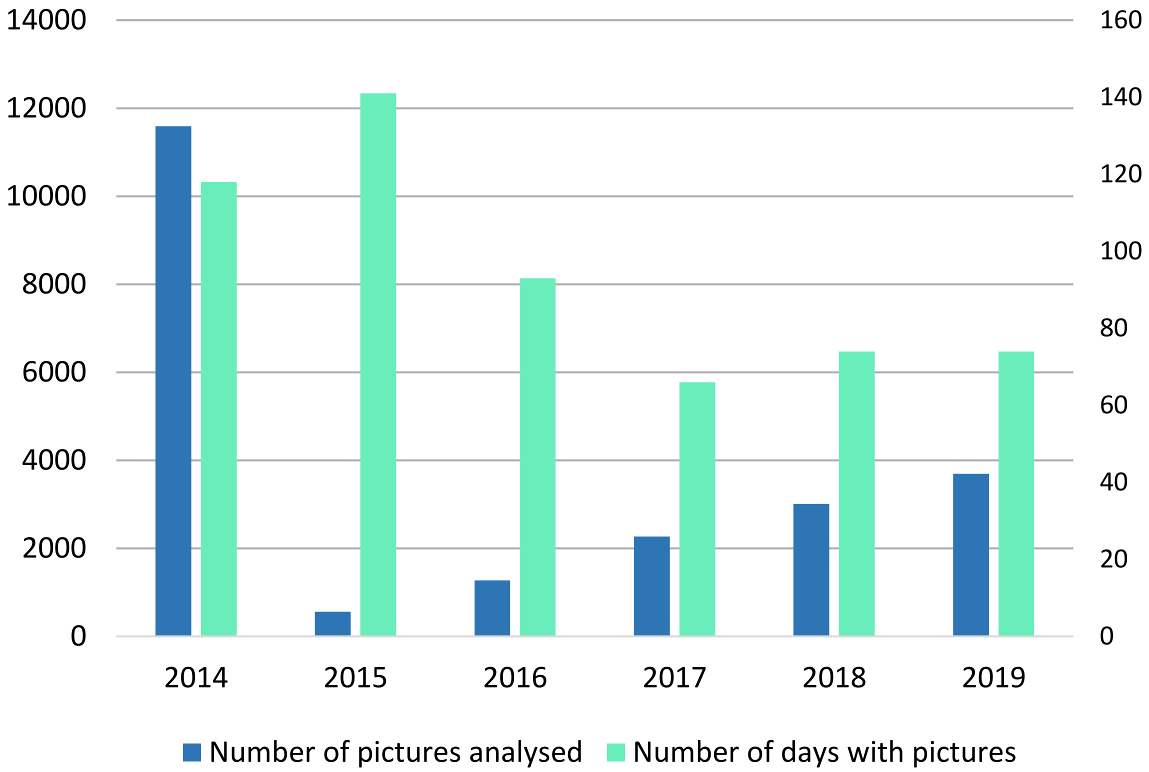

Figure 3. 16.: Number of pictures analysed and the number of days with pictures during the 6-year study (2014-2019).

The number of dolphins identified and included in to the catalogue was 505. Forty-three percent of them were identified by both right and left side pictures of the fins. The number of times each individual was encountered varied from 1 to 100. Most of them were recorded only once (n=199) or twice (n=176) (Figure 3.17). Almost 11% (n=54) of the dolphins identified were seen in more than 10 encounters, while only 2.97% were seen more than 20 times, including an individual that was encountered 100 times.

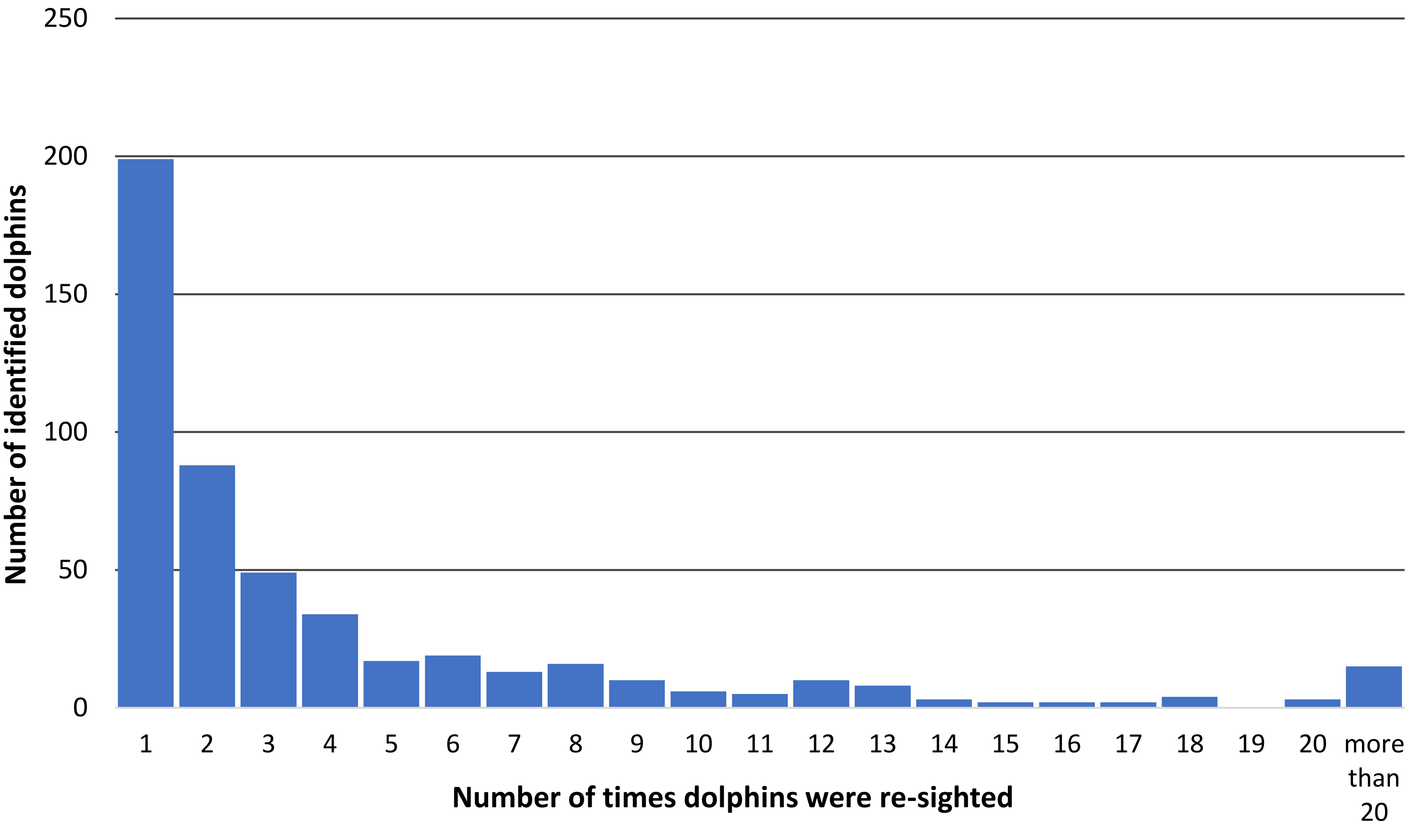

Figure 3. 17.: Number of re-sightings of individuals catalogued from 2014-2019.

The cumulative number of new individuals identified increased during the study period (Figure 3.18). The first year of the study (2014) had the highest number of individuals identified (258), while 2015 had the lowest (12). The increasing trend of the discovery line suggests the possibility that more individuals would be found with more trips. The number of individuals identified and recaptured on the following years varied greatly per year (Table 3.1). The year of 2014 had the highest number of individuals identified and around 60% recaptured by the end of the study. While the year of 2015 had the lowest number of individuals identified (12) but the highest recapture rate (75%). From 2016 until 2019, the number of individuals identified increased (235), nonetheless the rate of recapture decreased indicating probably a more temporal occurrence in our study area. The recapture rate in the year following the identification varied between 10.85% (from 2014 to 2015) and 34.37% (from 2016 to 2017).

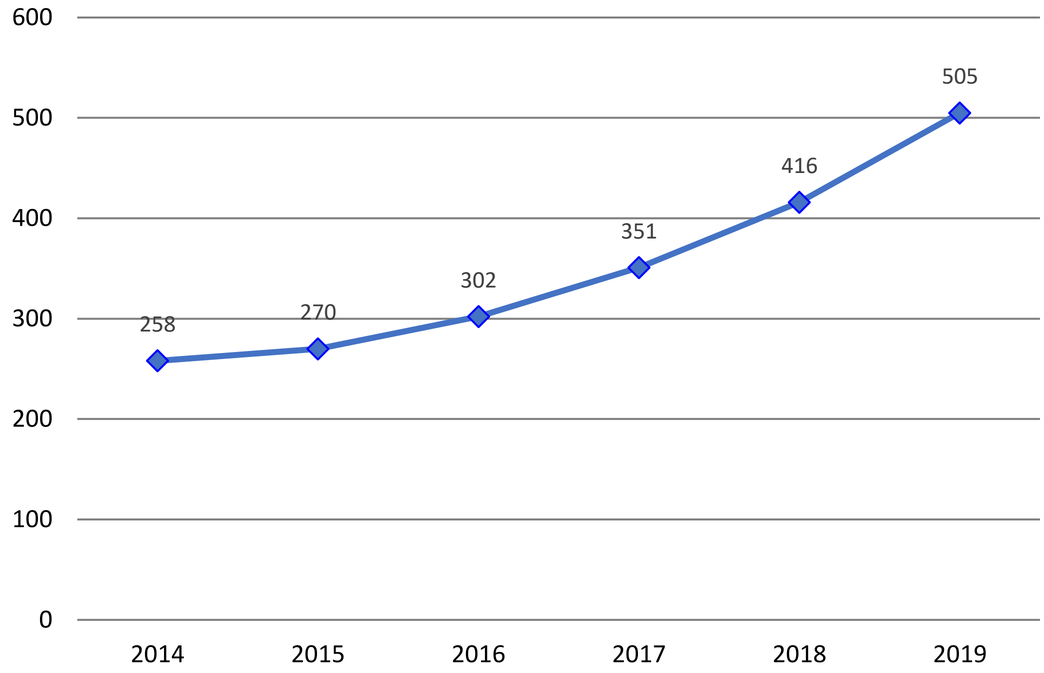

Figure 3. 18.: Discovery curve of the bottlenose dolphins identified in the study area between 2014 and 2019.

Table 3. 1.: Number of individuals identified per sampling year, recapture numbers and recapture rate from the following years.

Sampling year	Individuals added	2015	2016	2017	2018	2019	Total recaptured
2014	258	28	46	35	18	27	154
2015	12		3	1	3	2	9
2016	32			11	1	5	17
2017	49				14	6	20
2018	65					19	19
2019	89						
Total	505						219

The large majority (56.63%) of the individuals was observed in a single year and 43,36% were observed in more than one year (Figure 3.19). Only 26 dolphins were seen in five or more years. The longest time between re-sightings was five years, six months and 16 days for TT203, while the shortest time was one day and was observed in several dolphins. During the analysis of the pictures, it was possible to see evolution in marks from the first year individuals were seen to the last year they were re-sighted. Individual TT106 was first encountered in 2014 with less white marks than when it was re-sighted in 2019 (Figure 3.20). The nicks maintained through time.

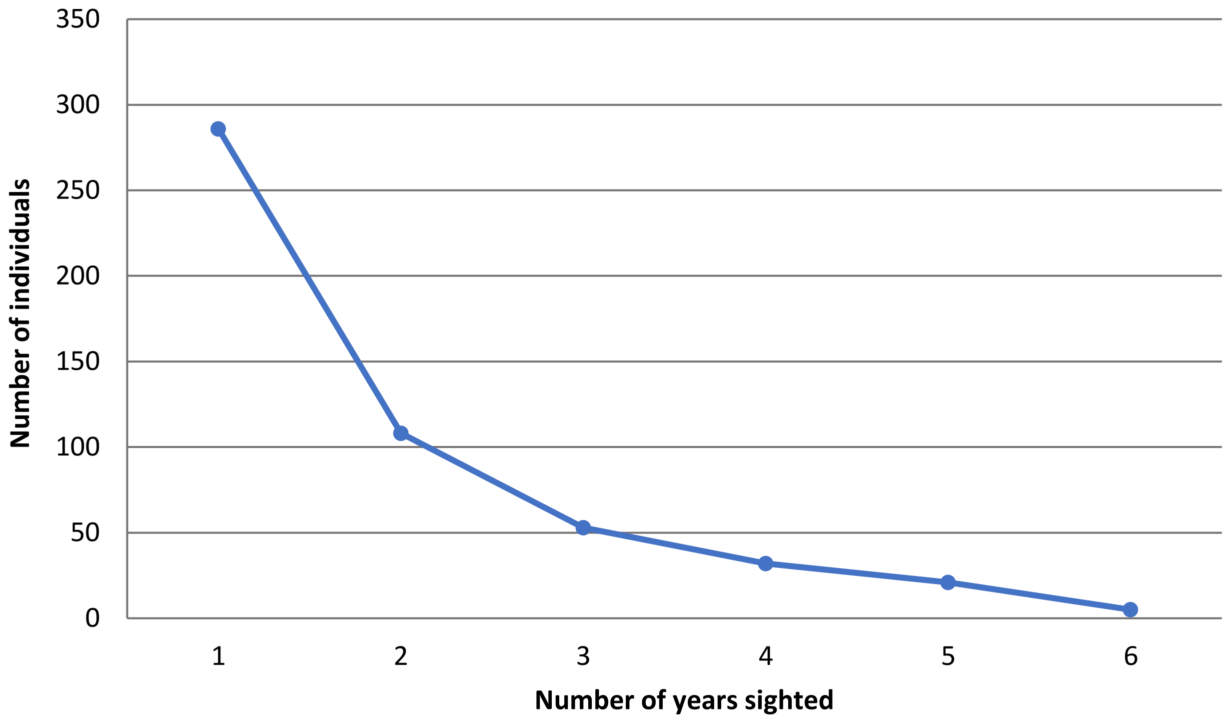

Figure 3. 19.: Graph showing the number of individuals encountered from one to six years.

Figure 3. 20.: The first two images show individual TT106 in 2014 and the last two in 2019. The evolution in terms of markings is clear while it is also possible to verify the preservation of nicks through the study period.

Fifty-two dolphins were sighted in at least two consecutive years and three seasons in one year, and therefore they were considered residents (Appendix A). These dolphins were allocated into four potential groups- yellow, blue, green and purple - according to the dates they were encountered on (Appendix B). For each potential group, at least one "key-individual" was selected. The yellow group included a very well-known dolphin nicknamed Bubble maker (TT002) (Figure 3.21). This individual was encountered 100 times between 2014 and 2018 and was the most easily identifiable dolphin of the group. Ten other individuals were assigned to this group. The blue group consisted of 16 individuals and was the largest one, TT010 was the dolphin identified more times for this group. The green group had two very well-known individuals- Egyptian (TT041) and Submarine (TT235)- due to their peculiar dorsal fins, these two dolphins were easily spotted. Eight individuals were assigned to this group. The purple group was the smallest one with only five individuals, with TT103 as the most identified dolphin of the group. In addition, eleven individuals were encountered with different groups on different dates, and therefore they were not assigned to any group.

Figure 3. 21.: Key-individuals from each group.

One hundred seventy-two individuals were identified as migrants and were seen in less than three seasons and in consecutive years or not. Eighty-one individuals were transients and were observed for small periods in only one year, while 200 individuals were non-residents and seen only once.

4. DISCUSSION

4.1 Platforms of opportunity and their limitations

This study used whale watching boats as platforms of opportunity for cetacean data collection. This strategy does have advantages that support its use, nevertheless, the limitations can lead to biased results, for that reason it is important to interpret them with caution (Vinding *et al.*, 2015; González García *et al.*, 2018). These companies represent a significant source of economic income for the different regions that developed this activity. In the Azores whale watching is one of the main activities tourists look for (Amaral, 2017). The growth of these companies led to an increase in availability of opportunistic data since it can be collected during whale watching trips run on average two times per day, year-round on a regular basis and with good spatial cover, and last but not least, with no extra cost involved for the main activity. However, the major goal of touristic boats is to satisfy tourists, and for that reason the lookouts search for all cetacean species. This implies a lack of real effort recorded at sea, as boats are directly piloted to the animals, and therefore no exact effort as miles or searching time can be considered. Other limitations to take into account are: (1) misidentification of species, however other species of bottlenose dolphins do not have a distribution near the Azores and the staff on board is very qualified, so this potential error is not likely to happen here; (2) animals can present elusive behaviour, so the boat will move on to more active species decreasing chances of getting photo-ID data; (3) there is a general preference for species that are rarely or less frequently seen than bottlenose dolphins (e.g. baleen whales, orcas, etc.); (4) sightings within shorter distances to the coast are usually preferred; (5) weather conditions, which makes opportunistic data collection vary with sea conditions and between seasons. In this study it was not possible to calculate the real effort like in other studies (e.g. Silva *et al.*, 2014 and Correia *et al.*, 2015) since the animals were first seen from land and the boats knew where to find them. Therefore, the number of trips per month and year were used for that purpose, providing an approximation of the effort differences carried out between years and seasons. Notwithstanding the limitations, different studies have proven the importance of opportunistic data collection (Hauser et al., 2006; Moura et al., 2012; Vinding *et al.*, 2015; Olson *et al.*, 2018). Advantages such as low-cost and long-term data series, provide information in places where it is scarce or non-existent and even about rare species occasionally sighted (Redfern *et al.*, 2006; Alves, 2013; Hupman *et al.,* 2014, González García *et al.,* 2018).

4.2 Spatial distribution of bottlenose dolphins

Two main areas with higher densities of sightings were noticed, one just outside the base port, and other in front of the main lookout, which can somehow bias our results. The same result was obtained in González García (2019), however in that study maps for other species show different areas with high densities of sightings. Bottlenose dolphins were mainly found in shallow waters and not far from the coast as in Seabra *et al.,* (2005); Silva (2007) and González García (2018) in the Azores and Carrillo *et al.,* (2010) in the Canary Islands. The Azorean islands are volcanic therefore deeper waters are reached near the coast, so it favours a higher concentration of sightings close to the island (rather than in the open ocean), despite the great area surveyed. Additionally, oceanic islands are known to generate up-welling phenomena and trapping of nutrients that will in turn develop conditions for primary production to increase and consequently concentrate food resources for dolphins (Cañadas *et al.*, 2002; Davis *et al.*, 2002; Silva, 2007). By staying close to the island, the dolphins can feed on demersal fish besides schooling fish and cephalopods (Silva, 2007) but also, in these areas animals will be more protected from predators and competition (Wells *et al.*, 1980). This distribution suggests that prey availability is a very important factor for bottlenose dolphins (Fortuna, 2007). In this study for São Miguel sightings, the slope was lower (2º-8º) than the one observed in other study in the Azores (higher effort in Pico and Faial) (10º-16º) (Seabra *et al.,* 2005). This difference is probably related with the topography of the study areas since the lower slopes presented in figure 2.3, were also the location of the higher concentration of sightings shown in figure 3.3.

Distance to the coast increased from July to November, this occurrence was reported in another study in the Azores (González García, 2019) and also in New Zealand (Constantine, 2002). This is likely connected with the birth of calves, and it was hypothesized that females travel away from the coast to give birth (González García, 2019). Furthermore, Silva (2007) also mentions that dolphins around islands might be forced to look for other feeding grounds, as further distances were recorded in months with more sightings of other dolphin species too in González García (2019), which may be related with higher chances of competition. The spatial distribution of bottlenose dolphins seems to accompany the patchiness productivity of the ecosystem (Suryan *et al.*, 2006; Silva, 2007). The association between animals and habitat shown here supports the idea also reported in other studies that dolphins maintain a close but indirect relationship between certain bathymetric features and important hydrographic processes (Yen *et al.*, 2004; Balance *et al.*, 2006; Palacios *et al.*, 2006). Further information and analyses are needed to test these hypotheses.

4.3 Temporal variability of bottlenose dolphins

Bottlenose dolphins were observed every year, however, the temporal distribution revealed differences in number of sightings between years and between seasons. The seasonal pattern indicates that there are more sightings during late spring and summer and the same results were obtained in González García (2019). This could be related to the higher effort during those seasons since the sea and weather conditions are better and it is generally easier to find the animals. Larger groups in summer might be due to the association of residents with migrants and transient dolphins (González García, 2019). This interaction between the different groups was also supported in Silva (2007). During winter and autumn, the number of occurrences was lower which could also be related to the lower effort and less favourable conditions at sea.

Our results agree with Silva (2007), supporting the Azores bottlenose dolphin population as a mix of dolphins with different site fidelity levels, from year-round residents to animals just sighted once. Therefore, not all dolphins show all year-round residency, and these can leave the island and explore other habitats, exhibiting seasonal migration (Balance, 1992; Ingram & Rogan, 2002). All categories, resident, migrants, transients and non-residents are attracted to the island in the summer by the good habitat conditions of the area and the concentration of prey. However, once the conditions start to change these dolphins may leave and look for other areas, leading to a decrease in the number of bottlenose dolphins around the island and consequently, of sightings. Dolphins can travel long distances for long periods of time until they find areas with more appropriate environmental conditions. In Silva (2007) the lack of genetic differentiation found between different groups of islands (in the Azores) and the high genetic diversity, are indicators of an open population with high levels of mixing between animals from various groups of islands and from the Madeira Archipelago. This hypothetical migration could be an answer to the decrease in the number of sightings during winter and autumn, however, the evaluation of these scenarios requires further studies.

Seasonal ER differed greatly interannually. Given the higher number of sightings in spring and summer a higher ER was expected during those seasons. However, that did not happen in every year. Higher seasonal ER in autumn and winter (2010, 2012, 2014, 2015) was usually related with lower number of trips in these seasons. On the other hand, lower ER in spring and summer were usually linked to a much higher survey effort (due to better conditions), and furthermore to the presence of different species (especially migratory) around the island which could favour encounters with them rather than with the species that can be seen all-year around.

Various studies have suggested water temperature and prey availability as two of the main factors that influence the distribution and seasonal movements of dolphins (Shane *et al.*, 1986; Passadore *et al.*, 2018; La Manna *et al.*, 2020). In this study, SST and concentration of chl-a were used in order to understand how both could influence the distribution of bottlenose dolphins. The results indicated higher chl-a values during winter and autumn, when SST and encounters are low, while lower chl-a occurs during late spring and summer when SST and the number of encounters is high. Chl-a concentration was used as a proxy for prey abundance and distribution. Higher concentrations trigger an increased grazing pressure on phytoplankton by primary consumers but once it starts decreasing the succession from primary to secondary consumers occurs (e.g., pelagic schooling fish) (Ware & Thomson 2005; Kämpf & Chapman, 2016). Consequently, when chl-a was high the abundance of prey is still low. Considering bottlenose dolphins are described as opportunistic feeders and take advantage of locally available prey, it would not be unexpected that their numbers would increase once secondary consumers are abundant in the area (Barros & Odell, 1990). Other studies have confirmed the same pattern for different cetaceans' species, the Bryde´s whale (Alves *et al.*, 2010) and short finned pilot whale (Alves, 2013) also had a higher occurrence around the south coast of Madeira Island when chlorophyll a concentration was low. In the case of blue and fin whales passing by the Azores it was obtained that both preferred intermediate to high chlorophyll concentrations which is when krill (which is a lower level than bottlenose dolphin prey on the trophic chain), their main prey, is most abundant (González García *et al.*, 2018; González García, 2019).

SST also seems to affect temporal distribution of cetaceans by indirectly influence cetaceans' prey availability (Neumann, 2001; Redfern *et al.*, 2006; Henderson *et al.*, 2014). When SST was low, chl-a was high which is related to colder waters presenting enhanced primary production and consequently higher chlorophyll concentrations (González García *et al.*, 2018). When SST is low, deep waters filled with nutrients will easily mix with sunlit surface waters where phytoplankton will use them for primary production, however when sea surface water starts to get warmer, the water column will start to stratify and nutrients from bellow will be retained (Yılmaz & Tuğrul, 1998; Elçi, 2008; Johnston, 2012). Furthermore, water temperature seems to influence bottlenose dolphins birth season since different studies have reported a peak of births within the warmer season (Würsig, 1978; Bearzi *et al.*, 1997; González García, 2019). Further studies are necessary to comprehend if this higher number of sightings during the summer is a response to an increase in the abundance of prey or if both were primarily responding to changes in oceanographic conditions.

4.4 Residency

Variation in the number of photographs analysed each year affected the number of individuals added to the catalogue. In 2014, 258 new individuals were added and 60% were recaptured by the end of the study, these individuals were either residents or migrants, since those are the only categories that stay for more than one year. That year had the most pictures analysed and was the first year of the study, so the chances of recapture were higher. However, 2015 had the highest recapture rate, mainly due to the few added individuals (lowest number of pictures analysed) that were mainly residents or migrants, since the majority was recaptured. Results from photo-identification indicate out of the 505 individuals identified, only 52 were seen frequently around the island, in different seasons and years and were considered residents. This low number of individuals that show high site fidelity seems to be common around these types of studies, in the neighbouring archipelago of Madeira of the 501 individuals identified only 15 showed long-term fidelity to the area (Dinis *et al.*, 2016) also in São Tomé e Principe 140 individuals were identified but only 11 were considered residents (Pereira, 2012). Individuals considered migrants also showed some degree of site fidelity to the island and could be part of the Azorean population but from other islands or from Madeira. Transient individuals, seen a few times for one year, and non-resident dolphins seen only once are likely just passing by the archipelago. The productive waters around the island act as an "oasis" for different cetaceans' species that use the area as a feeding ground, to forage or as a migration stop (González García, 2019). This variety in fidelity pattern seems to be very frequent among bottlenose dolphin populations and was also found in the Madeira Archipelago (Dinis, 2016), east of the islands of Losinj and Cres (Adriatic Sea) (Bearzi *et al.*, 1997), São Tomé e Principe (Pereira, 2012) and in coastal Setubal Bay (Portugal mainland) (Martinho *et al.*, 2015). However, a deeper analyses of residency patterns and site fidelity for the identified individuals is needed to confirm the results obtained here.

4.5 Associations

Bottlenose dolphin populations around the world have been described as fission–fusion societies, in which individuals associate in small groups that change their composition several times per day (Connor *et al.,* 2000). This type of social structure seems to be a strategy to reduce feeding competition by spreading out (Connor *et al.,* 2000). In most bottlenose dolphins' communities, long term associations are less frequent (Wiszniewski *et al.,* 2009; Daura-Jorge *et al.,* 2012; Louis *et al.,* 2015). However, in this study strong associations occur between several individuals leading to the division of the residents individuals' into four potential groups based on the dates they were seen together. The associations found prevailed for many months and years contrary to what was obtained previously in Madeira where no long-term association were found between individuals and the social structure of the population was dynamic and typical of a fission-fusion pattern (Dinis *et al.,* 2016). In São Tomé e Principe long-term associations were present in groups of large and small sizes (Pereira, 2012) and in Setubal Bay (Portugal mainland) long-lasting associations that remained throughout the study period were also found and connected with the environmental stability (Martinho *et al.,* 2015). There were, however, eleven individuals not assigned to any specific group because they were seen with all the groups on different dates, suggesting that these do not establish long-term relationships and have a more dynamic behaviour.

The bond between individuals is influenced by environmental factors, food resources, presence of predators, mating, sex and age (Norris & Dohl, 1980; Würsig,1986). The long-term bond between resident bottlenose dolphins in São Miguel is likely related with the productive waters and low trophic competition.

5. CONCLUSION

- Bottlenose dolphins on the south coast of São Miguel are sighted year-round and seem to prefer shallow waters and stay close to the coast suggesting that the productiveness of this type of environment plays a key role on the spatial distribution. Furthermore, temporal distribution varied between warm and cold seasons, with a clear preference for spring and summer, when survey effort was higher. Chlorophyll-a and sea surface temperature likely influence this distribution through a trophic cascade and/or simply favourable conditions.

- Photo-identification revealed different degrees of site fidelity among the individual identified including (1) residents, (2) migrants, which may come- from other islands, (3) transient individuals that spend short periods, and (4) non-residents, attracted to the productive waters of the archipelago. Furthermore, favourable habitat conditions, including its productivity higher than in open ocean surrounding waters and lack of competition allows the majority of the resident individuals to make long-term associations.

Understanding the distribution patterns and the structure of the population of bottlenose dolphin around the island of São Miguel is essential to develop appropriate management strategies and protected areas. This study represents the first assessment focused only on bottlenose dolphins in São Miguel and the first one presenting a catalogue. However, it is important to continue studying this population since they seem to rely on waters near the shore, they are also more subject to human activities. We have identified resident individuals around São Miguel, and it would be of interest to confirm if the individuals catalogued maintain their residency status over time.

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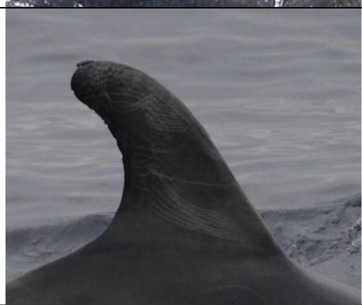
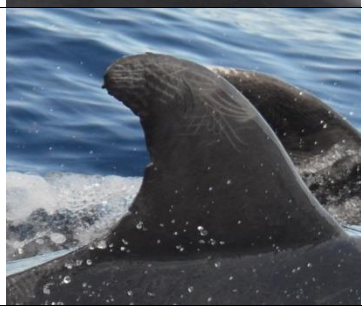
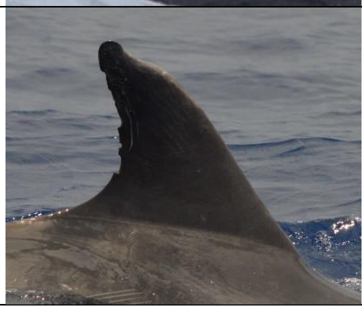
APPENDIX A- Catalogue of residents

ID	LEFT SIDE	RIGHT SIDE
TT002		
TT003		
TT005		
TT007		

TT008		
TT009		
TT010		
TT011		
TT022		

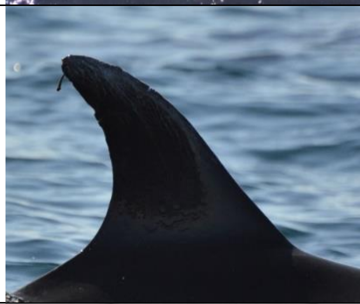
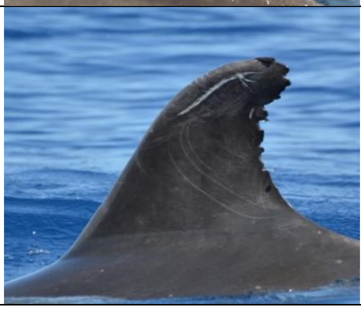
TT023		
TT031		
TT036		
TT039		
TT041		

TT05 1		
TT05 2		
TT05 3		
TT05 5		
TT06 8		
TT08 8		

TT103		
TT104		
TT106		
TT144		
TT145		
TT146		

TT14 7		
TT15 4		
TT15 5		
TT15 6		
TT15 7		
TT15 9		

TT161		
TT163		
TT166		
TT168		
TT169		
TT235		

TT239		
TT240		
TT260		

APPENDIX B- Associations

Group name	ID	Number of years seen	Number of years encountered with the group
Yellow group	TT002-Bubblemaker	5	4
	TT003	4	3
	TT005	4	4
	TT007	3	3
	TT008	5	2
	TT022	5	2
	TT023	4	4
	TT036	5	2
	TT039	2	2
	TT239	2	2
	TT240	2	2
Blue group	TT009	6	4
	TT010	5	5
	TT011	5	5
	TT031	4	3
	TT051	3	2
	TT052	3	2
	TT053	5	3
	TT055	2	2
	TT144	4	2
	TT145	5	2
	TT146	3	2
	TT147	3	2
	TT161	4	2
	TT168	4	3
	TT169	5	3
	TT260	3	3
Green group	TT041-Egipcio	6	4
	TT154	5	4
	TT155	5	4
	TT156	5	4

	TT157	6	4
	TT159	3	2
	TT163	3	3
	TT166	4	2
	TT235-Submarine	5	4
Purple group	**TT068**	3	2
	TT088	4	2
	TT103	5	5
	TT104	4	4
	TT106	5	5