Ramona Negulescu

Spatial and temporal distribution and photo identification of short-finned pilot whales (*Globicephala macrorhynchus*) off São Miguel Island, Azores, Portugal

Mestrado em Biologia Marinha

Supervisors:

Dr. Laura González García (Futurismo Azores Adventures)

Prof. Rita Castilho (University of Algarve)

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Declaração de autoria de trabalho

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.

__________________________________Ramona Negulescu

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Contents

Abstract

The Azores archipelago is home to 28 different species of cetaceans, among which the long- and short-finned pilot whales (*Globicephala melas* and *G. macrorhynchus*). Of the two species, the latter is more frequently spotted in the area and, as a consequence, it is the subject of the current study. The species is vulnerable to threats resulted from anthropogenic activity, such as boat strikes, underwater noise or being caught as bycatch, which makes the assessment of their status essential for conservation.

The aims of this master thesis were to evaluate the spatial and temporal distribution of pilot whales along the south coast of São Miguel island, as well as to compile a photo identification catalogue in order to distinguish the individuals that transit the island, find out whether or not they return to the area and identify specific associations. The study used data collected from a platform of opportunity offered by the whale watching boats belonging to Futurismo, as well as data collected from land by the look-outs working for the company that were responsible for finding the animals and signaling their presence. In addition, photographs taken from the boats were processed and analysed for the identification of individuals.

The results show that short-finned pilot whales are spotted in the south of São Miguel more during the summer season, with higher encounter rates in July, followed by the month of June. They frequent waters between 700 and 1200 m deep, with slopes of 2° to 6° and were encountered between 4 and 20 km from the coast. A total number of 343 pilot whales were identified, out of which 42 were sighted more than once. However, as the re-sighting rate was too low to allow for the analysis of their social structure, further research is needed to assess it.

Resumo executivo

O arquipélago dos Açores é um hotspot para a diversidade de cetáceos. Nada menos que 28 espécies diferentes encontram nesta região um habitat favorável com águas quentes e repletas de presas abundantes. Dentro das espécies de cetáceos observadas nos Açores, quatro são residentes: o golfinho roaz (*Tursiops truncatus*), o cachalote (*Physeter macrocephalus*), o golfinho comum (*Delphinus delphis*) e o golfinho Risso (*Grampus griseus*), sendo as restantes espécies migratórias. As baleias-piloto de nadadeiras longas e curtas *(Globicephala melas* e *G. macrorhynchus*) são encontradas ocasionalmente ao redor do arquipélago. A baleia-piloto de nadadeira curta é, das duas espécies, a mais frequentemente encontrada nos Açores, e constitui o objeto do presente estudo. Como predadoras de topo, as baleias-piloto de barbatana curta ajudam a manter o equilíbrio das populações de lulas e peixes no seu habitat natural. Porém, embora tenham sido recentemente classificados como "Menos preocupantes" na Lista Vermelha da IUCN de espécies ameaçadas de extinção, eles são vulneráveis a ameaças resultantes de atividades antrópicas. Alguns exemplos incluem choques com barcos, ruído subaquático ou captura acidental. Isto significa que é essencial para a avaliação do seu estado de conservação na região da Macaronésia e, mais especificamente, na ilha de São Miguel nos Açores, a sua monitorização.

Os objectivos desta dissertação de mestrado foram avaliar a distribuição espacial e temporal das baleias-piloto de barbatana curta ao longo da costa sul da ilha de São Miguel, bem como criar um catálogo de identificação fotográfica para distinguir os indivíduos que transitam ao redor da ilha, para determinar se há fidelidade ao local e se formam alguma associação específica entre si. O estudo usou dois conjuntos de dados: (1) dados recolhidos numa plataforma oportunisticaoferecida pelos barcos de observação de cetáceos da 'Futurismo Azores Adventures', e (2)dados recolhidos em terra pelos vigias da empresa que são responsáveis por encontrar os animais e assinalar a sua presença na zona. Para criar uma representação mais precisa do habitat preferido das baleias-piloto de nadadeira curta ao redor da ilha, usaram-se coordenadas GPS para criar mapas de distribuição no QGIS a fim de representar a distribuição espacial das espécies ao redor da ilha ecada ponto foi posteriormente analisado em termos de profundidade, declive e distância à costa para. A distribuição temporal foi determinada pela percentagem de avistamentos de baleias-piloto por temporada, tamanho do grupo, bem como a presença de crias em relação ao dia do ano. Além disso, as fotografias tiradas dos barcos foram processadas e analisadas para a identificação dos indivíduos. Esse processo envolveu recortar, ajustar o brilho e comparar os cortes e perfil da

barbatana dorsal de cada indivíduo para encontrar correspondências. Este método tem vários desafios, entre os quais (1) a limitação do tempo das saídas de barco para observação de baleias, (2) a inexistência de saídas em condições climáticas desfavoráveis ou (3) a o reduzido número de câmeras para coleta de fotos para identificação. No entanto, houve também vantagens muito importantes que devem ser mencionadas, como o facto de existir uma boa cobertura da costa sul da ilha e também a recolha de dados durante todo o ano.

Os resultados mostram que as baleias-piloto de barbatana curta são avistadas no sul de São Miguel predominantemente durante a temporada de Verão, com maiores taxas de avistamentos em Julho, seguido pelo mês de Junho. A estação do ano não afecta de forma significativa o tamanho dos grupos nem a composição do grupo, sendo que crias e juvenis se encontram presentes ao longo do ano. Embora no Verão se verifique uma maior taxa de detecção de crias e juvenis, essa é também a época do ano em que a detecção de outros indivíduos da espécie As baleias-piloto de nadadeira curta, quando encontradas em associação com outras espécies, foram mais frequentemente acompanhadas por golfinhos nariz de garrafa. O mapa de distribuição exibindo todos os encontros entre 2008 e 2020 continha 248 posições GPS. A análise indicou que a espécie pode ser detectada em águas com profundidades entre 700 e 1200 m e em regiões nas quais os declivesestão entre 2 ° e 6 °. A maioria dos avistamentos de baleias-piloto foram registados a menos de 20 km da costa, mas não se aproximam a mais do que 4 km, principalmente porque preferem águas mais profundas.Na foto-identificaçãoforam analisadas 6473 fotografias, tiradasdurante um período entre 2005 e 2020, com um número total de 343 baleias-piloto identificadas. Destes indivíduos, 42 foram avistados mais de uma vez. A maior janela temporal entre dois avistamentos do mesmo indivíduo foi de 11 anos, enquanto a menor foi de apenas um dia. Mais de 50% dos avistamentos foram registados no mesmo ano e várias baleias foram avistadas com dois anos de intervalo. Devido ao baixo índice de avistamentos (número máximo de três avistamentos do mesmo indivíduo), não foi possível avaliar a estrutura social da espécie.

Em conclusão, o presente estudo oferece perspectivas sobre permanência e os padrões de distribuição temporal e espacial das baleias-piloto de barbatana curta que transitam pela costa sul da ilha de São Miguel. Fica por determinar se as baleias-piloto avistadas pertencem ou não a grupos específicos e se estes grupos também podem ser encontrados nos arquipélagos vizinhos da Macaronésia. Dado que estudos anteriores encontraram os indivíduos comuns entre a Madeira e os Açores, existe a possibilidade de os indivíduos avistados em São Miguel pertencerem à população transitória da Madeira, mas esta possibilidade permanece uma hipótese para uma futura investigação. Também fica por ser determinado se a variação na presença temporal da baleia-piloto ao redor da ilha é influenciada por variáveis oceanográficas, como a temperatura da superfície do mar e se as mudanças climáticas terão um impacto nesta distribuição.

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General introduction

1. The study of cetaceans and their ecological importance

1.1. Order Cetacea

The order Cetacea gets its name from the Greek word "ketos" and its Latin correspondent, "cetus", meaning "sea monster" or "whale". It contains 90 recognised species of whales, dolphins and porpoises that are organised in two sub-orders: Mysticeti and Odontoceti. The former consists of 14 species of "baleen whales" belonging to 6 genera that form 4 families, while the latter is more diverse, with 76 species of "toothed whales" from 34 genera and 10 families (Carwardine, 2019). There are several features that differentiate between mysticetes and odontocetes, of which the most important is related to their feeding structures, adapted to different hunting techniques which allow for catching different types of prey. Mysticetes, such as the Sei whale (*Balaenoptera borealis*) use brush-like keratin structures called "baleen plates" or "whalebone" in order to filter the seawater and thus feed on small fish or euphausiid crustaceans such as krill (Nemoto, 1970) (Fig. 1 A). Odontocetes, in contrast, have teeth which allow them to catch individual prey which for the sperm whale (*Physeter macrocephalus*) (Fig. 1 B) can be bigger fish and squid, or, in the case of the orca (*Orcinus orca*), even large sharks (Visser, 2005) or other marine mammals (Reeves et al., 2007).

A  B

Figure 1. A. Sei whale showing baleen plates; B. sperm whale showing teeth (Photos by Laura González García)

While mysticetes have a symmetrical skull with two blowholes, the skull of the odontocetes is asymmetrical with only one blowhole. The toothed whales have a fatty organ used for echolocation inside their forehead, the "melon", that is lacking from baleen whales which are, as a consequence, not capable of echolocating. The mysticetes live in smaller groups, lacking the complex social organization usually observed in the large groups of odontocetes. They perform annual migrations from warmer regions where they breed during winter to colder waters where they spend the summers feeding (Stone et al., 1990).

1.2. The ecological importance of cetaceans

Whales and dolphins were once considered valuable only in terms of the products they offered after being caught (Roman et al., 2014) such as their meat that was used for consumption (Gibson-Lonsdale, 1990) or the spermaceti oil of sperm whales that was used to make industrial lubricants, hydraulic fluids or candles (Rice, 2009). The strong but flexible baleen of mysticetes was also harvested and used for very different purposes, depending on the culture. The inuits were making amulets, fishing lines, baskets or boot insulation out of baleen, while in Japan the same material was used for making tea trays, sword hilt wrappings or to decorate armors. In Europe and America baleen plates had very diverse applications such as being part of corsets or collar stiffeners, combs, bed webbing, fans, sieves, nets, brushes, picture frames, etc. (Lauffenburger, 1993).

However, it is now known that cetaceans are more than industrial goods, as they are responsible for important changes in their environments such as nutrient fluxes and biodiversity (Roman et al., 2014). There are several ways by which cetaceans have structural and functional effects on their ecosystems, by top-down, as well as by bottom-up effects (Ballance, 2018), most of the time influencing the oceans indirectly rather than directly (Estes, 2009). They affect the structure of the ocean system as consumers of invertebrates and fish. Their large body size and intense metabolism determine them to feed on a large quantity of prey (Ballance, 2018) therefore controlling krill or small fish populations (Roman et al., 2014).

When cetaceans act like prey, they can exert a top-down effect on their ecosystem, for example in the case of large baleen whales that are being predated by orca (Pitman et al., 2015). This phenomenon has also been recorded during the age of whaling when the numbers of mysticetes dropped dramatically up to 90% and thus producing a trophic cascade (Roman et al., 2014). It was observed that when the great whale populations decreased, the orca in the North Pacific declined as well and started feeding more on other species such as sea otters (*Enhydra lutris*). This, in turn, created an increase in the sea urchin population that further produced a decline of the kelp forests they were feeding on (Estes, 1998).

Cetaceans allow other species to feast, not only when they are being consumed, but also by driving their own prey to the surface or disorienting it (Estes, 2009). Such is the case of bottlenose dolphins (*Tursiops truncatus*) from the south-eastern United States that push fish ashore and afterwards strand themselves temporarily to catch them, which attracts the attention of wading birds (Fox &

Young, 2012). Whales and dolphins can also be the hosts of parasitic species or commensals such as barnacles, remoras or whale lice (Carwardine, 2019).

An example of a bottom-up effect of cetaceans is the release of elements such as nitrogen and iron by their faeces. They do so at the surface of the water, after feeding at higher depths, while, in the case of baleen whales, also moving from productive feeding grounds to lower latitudes to breed (Roman et al., 2014). The horizontal and vertical migrations of cetaceans, therefore, help move and introduce these nutrients in an ecosystem they would otherwise not be part of, to be further used by organisms from lower trophic levels, a process known as a "whale pump" (Ballance, 2018).

When cetaceans die, they can either wash up ashore or they sink to the bottom of the ocean, producing what is known as a "whale fall". In the first case they are consumed by other vertebrates, thus sustaining terrestrial food-webs (Estes, 2009), while in the second they will lead to the enrichment of the seafloor with organic matter (Roman et al., 2014). Whale falls sequester a high concentration of particulate organic carbon and, given the succession of organisms upon them, become independent ecosystems (Estes, 2009). They offer nutrition and habitat for chemosynthetic bacteria or invertebrates, many of which are endemic and obligate associates, such as the *Osedax* worms (Smith et al., 2015).

Currently, cetaceans have started to be valued more for their ecosystem services such as the increased productivity they determine, enriching marine biodiversity by whale falls or the help they provide with climate regulation by the whale pump, but also because they can contribute to a blue economy by their role in tourism, culture and conservation, thus attracting important sources of funding (Roman, 2017).

1.3. Studying cetaceans

Whales and dolphins have equally intrigued and fascinated people as well as frightened them, especially in the case of large predatory species like the orca because in the past very little information about these animals was available. Due to their high mobility, speed, ability to cover very large areas in a short time, and above all, because they are spending most of their time in their underwater habitats, these animals were very hard to study and most of the early knowledge about them came from the tales of fishermen and whalers who mostly described them as monsters or fearsome assassins (Mazzoldi et al., 2019). It was only after the first orca was captured and displayed by the Vancouver Aquarium in 1964 that this species lost its killer reputation and became known more as an intelligent gentle giant (Leiren-Young, 2016). Up to that date, other smaller species of cetaceans were being kept in captivity and were the subject of various experiments on topics such as their behaviour (McBride & Hebb, 1948) or communication (Lilly & Miller, 1961). The studies on captive animals have continued up to the present date and offer invaluable insight on the high cognitive abilities and the intelligence of delphinids (Herman, 2010). However, they have also proven that these animals suffer dramatic behavioural changes in captivity such as hyper aggression or stereotypies which lead to the development of depression or other mental illnesses (Marino, 2020), suggesting that life in captivity is not recommended for whales and dolphins.

Currently, modern advances in technology are allowing for more freedom for studying cetaceans in the wild. Surveys can now be performed not only from boats but also from land, by using high-power binoculars, or from the air with the help of drones. Aerial footage can be obtained without disrupting the animals and it can be collected from places that are normally out of reach for humans such as narrow fjords. It can later be analysed in order to determine the distribution and abundance of cetaceans as well as to interpret their behaviour (Aniceto et al., 2018).

High-quality reflex cameras are used for photo identification which is another non-invasive technique that enables the study of social structures in cetaceans by modelling association patterns between individuals (Alves et al., 2018). The same method also enables studying the movements between different areas, when the same individuals are being photographed in different geographical regions. This helps with calculating residency patterns and determining whether specific animals are residents, transients or visitors in certain areas. This type of study has found for example that male sperm whales spotted in the Azores can also be seen in further away regions such as Norway (Steiner et al., 2012).

Acoustic information can be recorded by hydrophones and can help differentiate between species (Baumann-Pickering et al., 2015) or subspecies (Van Cise et al., 2017). It also provides more insight into the cultural lives of these animals, since communication between individuals can differ significantly from one group to another or between different ecotypes. For example, units and clans of sperm whales (*Physeter macrocephalus*) have been proven to use different dialects of their coda (Whitehead, 2003) and the whistles of resident orca were found to be more complex than those of the transients (Riesch & Deecke, 2011). In sperm whales, sounds are also essential in identifying behavioural states since they always emit clicks when they are going for deep foraging dives (Whitehead, 2003).

Satellite tagging is useful for investigating behaviours, location and habitat use of cetaceans (Balmer et al., 2014) and for determining diving patterns in deep-diving species such as sperm whales (Miller et al., 2004) or pilot whales (Baird et al., 2002).

Aspects of cetacean biology can also be investigated in the laboratory by analysing tissue samples extracted from living animals or from dead, stranded individuals. Blubber biopsies can complement stomach content analysis in determining feeding ecology (Herman et al., 2005; Hobbs et al., 2003) or they can help assess the level of pollutants such as PCBs or pesticides (Hobbs et al., 2003). Stress hormone levels can be determined from blood sample analysis and can lead to a better understanding of the response these animals have towards anthropogenic disturbances (Crespo Torres et al., 2016). Blood, skin and tissue samples from internal organs are useful for determining the evolution and phylogeny of species via genetic analyses of mitochondrial DNA (Milinkovitch et al., 1994). Stranded animals are also an important source of information on topics ranging from reproductive biology (Kasuya & Marsh, 1984) to the spread of infectious diseases (Mira et al., 2019).

2. Cetaceans in the Azores archipelago

2.1. Recorded species and their distribution in the Azores

The Azores archipelago is considered to be a hotspot for cetacean life, with 28 different species documented in the area (Silva et al., 2014). These all show a high degree of variability in terms of their temporal and spatial distribution, using large, highly productive areas around the 9 islands, but overall preferring coastal regions and seamount complexes (Tobeña et al., 2016). Some species, such as the sperm whale, the common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*) and the bottlenose dolphin (*Tursiops truncatus*) can be sighted year-round but with different encounter rates depending on the month (M. A. Silva et al., 2014). (Al Abbar et al., 2019; Martins et al., 2019). The same is true for beaked whales of the Mesoplodon genus (*M. bidens, M. europaeus, M. densirostris, M. mirus*), but the number of their sightings is significantly lower than that of the aforementioned species, many records of these animals being due to strandings. Another beaked whale, the northern bottlenose whale (*Hyperoodon ampullatus*), can also be spotted but only in the summer season (Silva et al., 2014). Large baleen whales pass by the Azores while migrating towards their high latitude feeding grounds. Spring is, therefore, an appropriate time for sightings of blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*) or sei whales (*Balaenoptera borealis*), but these species can be seen in the region in late autumn or winter as well (Gonzalez Garcia et al., 2018; Ojeda et al., 2018) Small delphinids such as the striped dolphin (*Stenella coeruleoalba*) and the Atlantic spotted dolphin (*Stenella frontalis*) show a pronounced seasonality, influenced by Chlorophyll-a local variation and the sea surface temperature (Tobeña et al., 2016). Larger delphinids such as the orca or the false killer whale (*Pseudorca crassidens*) have been found to be more influenced by the presence of seamounts, without showing a temporal trend (Tobeña et al., 2016).

2.2. Commercial whaling in the Azores

Commercial whaling started in the Azores in the 18th century as an important economic support for the local population but it soon turned into an essential part of the cultural identity of the archipelago. Whaling was possible here because the favourable environmental conditions provided a suitable feeding and breeding habitat for various cetaceans (Oliveira et al., 2016). Several species of cetaceans were captured, among which the common dolphins (*Delphinus delphis*) were caught rather opportunistically to be sold in markets but also sometimes only to be consumed by the fishermen's families (Clarke, 1981). Long- and short-finned pilot whales (*Globicephala sp.*) also used to be caught occasionally (Clarke, 1981). However, the target species of the whaling industry in the Azores were the sperm whales (Clarke, 1981) (Fig. 2), which were hunted worldwide mainly for their spermaceti oil (Whitehead, 2003). The catches started to decline around 1968 because the whalers were attracted by the better payment they could get from the tuna fishing industry and, mainly in the central group of the Azores, where most of the whaling activity was held, also because a volcanic eruption in 1957 in Faial forced many people to emigrate from the island (Clarke, 1981). In addition, new products were able to replace whale oil so hunting sperm whales was not profitable anymore. Later, in 1986, the hunting of whales for commercial purposes stopped completely when the International Whaling Commission (IWC) placed it under a ban with the aim of preventing the extinction of whales.

Figure. 2. Whalers in the Azores sectioning a sperm whale
(Photo by William Dawbin) (Ellis, 2009)

2.3. Whale watching in the Azores

Whale watching was implemented as an alternative to whaling and the industry has been growing exponentially worldwide (Silva, 2015). In the Azores it began in 1993, one of the main species of interest for this region being the sperm whale (Oliveira et al., 2016). It comes with a series of benefits both for the cetaceans and for the local community, becoming an important tourist attraction and a source of education for the public on the ecology and role of the species spotted in the region. Due to this industry, the way in which cetaceans are perceived has changed and therefore gave rise to the obligation of exploiting them in a sustainable and, above all, ethical way.

Thus, ensuring their protection also provides considerable financial growth in the form of capital income from tourists as well as new jobs for the locals (Silva, 2015).

The whale watching platforms have proven to be also a good opportunity for researching the animals in their natural habitat. Since whale watching is and has been a growing industry in the Azores for a few decades already, various laws and regulations were needed in order to ensure a correct practice in the near vicinity of the animals such as the regional legislation (DLR 10/2003/A) and the guidelines of WCA, namely:

i) a minimum distance of 50 meters that should be kept between the boat and the observed cetaceans;

ii) every encounter cannot be longer than 30 minutes;

iii) the cetaceans must not be chased, surrounded or forced to separate their pods and

iv) they should be left alone if they show any signs of distress (Lewis & Walker, 2018).

3. Species of interest

3.1. Taxonomy

Phylum	Chordata
Class	Mammalia
Order	Cetartiodactyla
Family	Delphinidae
Genus	*Globicephala*
Species	*Globicephala macrorhynchus* Gray, 1846

Figure 3. Short-finned pilot whales. (Photo by Teo Lucas)

The current study is based on one of the largest species of odontocetes from the Delphinidae family, the short-finned pilot whale (*Globicephala macrorhynchus*). Its common name takes into account the external appearance of these animals, as their pectoral fins are shorter than those of the sister-species, the long-finned pilot whale (*Globicephala melas),* whereas the word "pilot" refers to the elderly belief that there is one individual that leads or "pilots" the group, with all the others following it.

3.2. Distribution and habitat

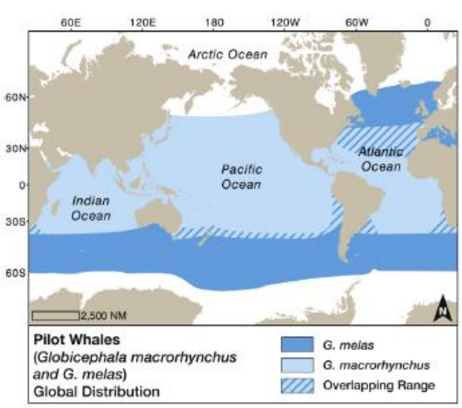

Figure 4. Distribution map of long- and short-finned pilot whales (Adapted by Nina Lisowski from Jefferson, T.A., Webber, M.A., and Pitman, R.L. (2015). "Marine Mammals of the World: A Comprehensive Guide to Their Identification," 2nd ed. Elsevier, San Diego, CA.) (Olson, 2018)

The short-finned pilot whale is found in warm temperate and tropical waters all around the globe (Alves, 2013), ranging within 50° N and 40° S (Minton et al., 2018) with little overlap with *G. melas* that prefers colder waters (Olson, 2018) (Fig. 4). Its favourite habitat consists of deep waters with steep continental slopes and continental shelf breaks (Heimlich-Boran & Hall, 1993). Studies have shown that the short-finned pilot whales show a high degree of variability in their site fidelity with some individuals being residents in certain areas, others transiting different regions while leading an overall pelagic life, while a third group is made of visitors (Alves, 2013; Alves, 2018).

3.3. Morphology

Short-finned pilot whales (Fig. 5) are very easy to identify by their large and globular head with no visible rostrum, reflected also in the name of their genus, "*Globicephala*" ("globi" = round; "cephala" = head). They show a high degree of sexual dimorphism, with females reaching lengths of 5 meters while males can grow up to 7 meters long (Alves, 2013). The melon is bulbous and, in older males, it sometimes protrudes over the mouth (Carwardine, 2019). The body is robust and it has a dark grey-black colour, with a lighter grey-whitish saddle patch on the back and an anchor-shaped pattern on the ventral side. The dorsal fin is sickle-shaped, with a broad base and located around one third away from the head. It is aligned with the pectoral fins which are long and slender but considerably shorter than those of the long-finned pilot whale (*G. melas*) (Olson, 2018). The tailstock is thick and the flukes are pointed with a deep notch in between (Servidio, 2014).

Figure 5. Short-finned pilot whales (*Globicephala macrorhynchus*) external appearance (Photo by Teo Lucas)

3.4. Subspecies

Two distinct morphotypes of short-finned pilot whales (Naisa and Shiho) were described in 1760 off the coast of Japan based on their different external morphologies, cranial structures and distributions (Yamase, 1760). A third genetically different clade diverged from Naisa was discovered in 2015 (Hill et al., 2019) and later on, in 2017, a study on the acoustics of short-finned pilot whales proved that there are enough differences between the Naisa and Shiho forms to be considered different subspecies (Van Cise et al., 2017). More recently, in 2019, mitochondrial DNA (mtDNA) analysis suggested that these two subspecies contain three types of short-finned pilot whales (Van Cise et al., 2019). The Shiho appears in the eastern Pacific Ocean and the north of Japan, while the Naisa short-finned pilot whale is known to occupy wider areas from the Indian Ocean, southern Japan and southeast Asia (Van Cise et al., 2017) (Fig. 6); plus the third distinct form that inhabits the Atlantic Ocean (Van Cise et al., 2019) which is, therefore, the subject of this study. They can be distinguished by the shape of their heads which is more rounded in Shiho, while in Naisa it is more rectangular (Van Cise et al., 2017).

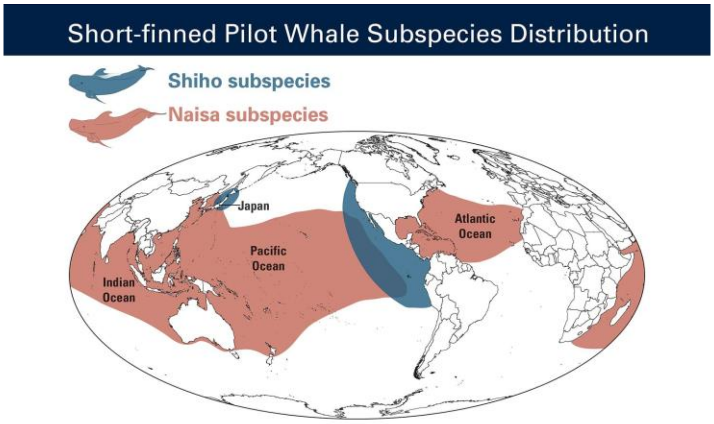

Figure 6. Distribution of Naisa and Shiho pilot whale subspecies
(Map by Natalie Renier, Woods Hole Oceanographic Institution)

3.5. Biology

Based on stomach content analysis of stranded short-finned pilot whales it was proved that they feed mostly on cephalopods such as squid (Seagars & Henderson, 1985) but also sometimes on fish (Mintzer et al., 2008). This is reflected in their reduced dentition of 14-18 teeth on each row, which is adapted for "ram-and-suction" feeding (Olson, 2018). They feed mostly at night when they are four times more likely to go for deep dives in search for vertically migrating prey than during the day when they usually rest, travel or socialize (Baird et al., 2003). They have been proven to perform sprints during the descent phase of their deep foraging dives, thus earning the name "cheetahs of the sea" (Aguilar Soto et al., 2008), reaching speeds of a maximum of 5.5 m/s (Sakai et al., 2011) and staying underwater for as long as 20 minutes (Alves et al., 2013).

Females produce one calf every 3-5 years between the ages of 11 and 40 years old (Taylor et al., 2007), spending the rest of their lives, up to 63 years old (Alves, 2013) in a post-reproductive state, dedicating themselves to raising the young of other females of the group, thus setting the base for matriarchal societies. Males have considerably shorter lives, of only 46 years, which they spend within the matrilines in which they were born (Alves, 2013).

3.6. Conservation status and threats

As recently as 2008, the short-finned pilot whale was listed as “Data Deficient” on the IUCN Red List of Threatened Species. Although in 2018 it gained the status of “Least Concern”, some populations are still lacking enough data to have an accurate representation of their overall situation. This leads to an estimate of a global population of minimum 700,000 animals, with an unknown population trend (Minton et al., 2018). The species still faces several threats, among which bycatch in longline or gillnet fisheries (Minton et al., 2018) or collisions with boats in places where its habitat overlaps with areas of intense boat traffic (Fig. 7). As a deep-diving cetacean, the short-finned pilot whale can be sensitive to sounds and there have been reports of strandings coinciding with military exercises for example in Japan (Wang and Yang, 2006; Yang et al., 2008) and high levels of anthropogenic sounds in North Carolina (Hohn et al., 2006). The blubber of short-finned pilot whales has been tested and found positive for various pollutants such as PCBs, pesticides or mercury. The species is currently listed on Appendix II of CITES (Minton et al., 2018).

Figure 7. Pilot whale injured by a collision with a boat in Tenerife in 2019 (Photo by Francis Perez)

4. Pilot whales globally

Most of the general knowledge of pilot whales comes predominantly from the study of *Globicephala melas,* the long-finned pilot whales, which were more extensively studied, especially in terms of population structure by genetic analyses (Alves, 2013). This species was and still is, to the present date, hunted in Greenland and the Faroe Islands (Minton et al., 2018), where the “grindadrap” or “pilot whale kill” became part of the cultural identity of the people. Up until 1977 around 20-30% of the total meat consumption by the Faroese consisted of pilot whale meat. After this date, however, studies have shown that the pilot whales contain high levels of heavy metals and other toxins so the Faroese Food and Environmental Agency advised against the consumption of liver or kidney that accumulate most of the pollutants. After 2008 the meat and the blubber were also revealed to be toxic, due to their high content of mercury and PCBs respectively that affect the nervous and immune systems and increase the risk of Parkinson’s disease and hypertension in people who are exposed to them (Joensen, 2009). High mercury levels have also been found in animals hunted in Taiji, Japan and consequently in the hairs of the locals that eat them, which confirms the fact that pilot whale products are not healthy for human consumption (Endo & Haraguchi, 2010). Grinds, however, are an important source of information for pilot whale research since they offer a large sample opportunity, with both males and females of various ages and developmental stages (Bloch, 1994). Genetic analyses on hunted pilot whales have shown that the grinds have a stable structure and that they are formed by individuals that are related and who never breed with each other (Fullard et al., 2000). Long-finned pilot whales are, in addition, amongst the species that show a tendency to mass strand and can therefore provide other essential opportunities for researchers to investigate various aspects of their biology such as their diet or the age when they reach sexual maturity (Sigurjónsson et al., 1993).

Studies on long-finned pilot whales are not limited to dead individuals or grinds and they have been conducted also on live wild animals in various regions around the world, including the Faroe Islands (Heide-Jørgensen et al., 2002), the Strait of Gibraltar (Stephanis et al., 2008), the Ligurian Sea (Baird et al., 2002) or Canada (Ottensmeyer et al., 2003). The species is a resident in the Strait of Gibraltar, where it can be recorded mostly over deep waters, preferring depths between 300 and 800 m and sharing its foraging habitat with sperm whales or bottlenose dolphins. There is a non-linear effect of depth on their distribution so they are difficult to find in waters under 300 m. (Stephanis et al., 2008). Baird et al. (2002) found that the whales prefer to spend more time at the surface during the day, mostly socializing with each other or resting, diving only to a maximum depth of 16 meters. During the night they go for deeper dives for feeding, especially after sunset when their prey migrates more towards the surface (Baird et al., 2002). Their distribution can therefore be an indicator of the presence of large squid species that the whales feed on (Stephanis et al., 2008)

The target species of the current study, the short-finned pilot whale, has also been studied worldwide, from Hawaii (Baird et al., 2003; Mahaffy et al., 2015) to Japan (Kasuya et al., 1988), to the Mariana Archipelago (Hill et al., 2019) and Macaronesia (Heimlich-Boran & Hall, 1993; Alves, 2013; Servidio, 2014; Servidio, 2019).

In Hawaii, the short-finned pilot whales were found to be associated with slope waters and to aggregate in higher densities where the depths reach 1000-2500 m. Research done on satellite tagging data revealed that oceanographic variables such as the depth, sea surface temperature, bathymetry and abundance of micronekton influence the presence of the species in the area (Abecassis et al., 2015). The species shows different patterns of site fidelity and residency in Hawaii, with individuals being classified as core residents, residents and visitors. Natal philopatry is characteristic to the short-finned pilot whales which form stable associations on a long-term, but there is little evidence that they breed with individuals from the same group. Based on this observation as well as on genetic analyses, it is believed that there is more than one population around Hawaii (Mahaffy et al., 2015). In the same region, (Baird et al., 2003) found that the depths of short-finned pilot whales dives vary between night and day corresponding to the vertical migrations of their prey, with few, deeper dives (600-800 m) during the day and four times more frequent but shallower dives (300-500 m) during the night. The lighting conditions were found to influence the diving behaviour of the species, with longer, deeper dives being recorded during a full moon, a change in behaviour which could be explained as an adjustment to the change in depth by its prey, the squid (Owen et al., 2019). During the day behaviours such as travelling, socialising or resting and several shallow dives (under 100 meters in depth) were observed but there was no foraging, which is reserved for the night (Baird et al., 2003).

In the Mariana Archipelago, short-finned pilot whales were investigated by a group of researchers that studied their habitat use, their movements and associations as well as their diving behaviour, using data obtained by photo identification, satellite telemetry and genetic analysis (Hill et al., 2019). 191 individuals were identified, with a higher sighting rate during summer, in the north-west of Guam, which was identified as the preferred habitat. 77% of the encounters from the Mariana Archipelago were in 500-3000 m water depths and the animals have been spotted diving during the night only to medium depths, indicating that here, as well as in Hawaii, they are preying on animals that migrate vertically. The population around the archipelago was reported to consist of a main island-associated social cluster and three offshore groups (Hill et al., 2019) that show a high genetic diversity (Martien et al., 2014)

As well as in the case of its sister species, *G. melas,* several mass strandings of the short-finned pilot whales have been reported in various regions around the world, including Nicaragua (Huertas & Lagueux, 2016), Indonesia (Yunus et al., 2017), North Carolina (Mintzer et al., 2008) and Galicia (Gonzalez et al., 2000). Although it is hard to isolate one single variable determining theses mass strandings, various factors have been suggested to act as a cause, among which the conditions of the sea, the social nature of the species and the strong bonds between individuals, infections by various parasites, anthropogenic induced stress or even low levels of oxygen and salinity (Yunus et al., 2017). However, the animals found dead in mass strandings provide valuable opportunities for investigating several aspects of their lives, such as the species that they hunt (Mintzer et al., 2008) or their group composition (Gonzalez et al., 2000).

5. Pilot whales in Macaronesia

Macaronesia is a region in the North-East Atlantic Ocean which consists of the Azores Archipelago, the Canary Islands, Cape Verde and Madeira, an area providing a favourable habitat for over 20 species of cetaceans, among which the short-finned pilot whales. Most of the research on these animals conducted here was focused mainly on the groups that can be spotted around the Canary Islands and Madeira but in 2016, a photo identification study (Alessandrini, 2016) compared individuals from all four archipelagos in order to assess the connectivity within this biogeographic region. Matches were found between Azores and Madeira and between the Canary Islands and Madeira, thus demonstrating that the region plays a significant role for this species. Cape Verde was also included in the study but no matches were found from this region. A more recent study (Alves et al., 2018) has also compiled information from photo ID catalogues and data collected from the entire Macaronesia, aiming to estimate residency patterns of the short-finned pilot whales in the area, to assess their movements as well as their spatial structuring within the region. The movements of the species between the archipelagos in Macaronesia reveal a high degree of connectivity which decreases the genetic isolation of the species, while the variability in residency patterns supports the idea that the species shows spatial structuring. According to the social network diagram resulting from the study, associations were found between individuals with different residency patterns. For example, clusters were found between Madeira and the Canary Islands or between Madeira and the Azores, but never mixing with each other, which reinforces the idea of a complex social and spatial structuring of the species (Alves et al., 2018).

5.1. The Canary Islands

Short-finned pilot whales are one of the most commonly seen cetacean species in the Canary Islands, where they can be observed year-round (Carrillo et al., 2010). As a consequence, they can become vulnerable to various threats resulting from anthropogenic activity, such as the degradation of their habitat, noise pollution or interactions with shipping, fishing or whale watching boats (Servidio et al., 2019). Several studies have been conducted in the area aiming at analysing the social organisation of the species (Heimlich-Boran & Hall, 1993; Servidio, 2014), determining their distribution, habitat use and site fidelity (Servidio, 2014; Servidio et al., 2019), investigating the foraging behaviour of the species (Aguilar Soto et al., 2008) or evaluating the stress response to whale watching activities (Crespo Torres et al., 2016).

In 1993, Heimlich-Boran and Hall identified 46 pods off the coast of Tenerife and classified them into residents and visitors, based on their different ways of using the habitat. He observed that the residents usually travel together and that during the summer months larger groups could be spotted. These are generally made of individuals belonging to different pods and both males and females were proven to prefer associating and mating with individuals from different pods, as a method of avoiding inbreeding (Heimlich-Boran & Hall, 1993). More than two decades later, Servidio (2014) confirmed spotting higher numbers during the summer months as well as the high variability in site fidelity of the species. Two subpopulations were identified: one that is transient and another that is island-associated. Each of these populations is thought to consist of several clans, each of them being made of several pods. The species was found to have a strong social system with long-lasting bonds between individuals. In terms of habitat use, the short-finned pilot whales in the Canary Islands were found to prefer waters of 1000-1500 m depth (Servidio, 2014).

Another group of authors (Aguilar Soto et al., 2008) focused on the strategies used by short-finned pilot whales in the Canaries for hunting prey that live in deep water. They found that the feeding dives are synchronised with the circadian rhythms of the animals and that the whales sprint up to 9 m/s when they chase prey, a behaviour that makes them resemble cheetahs. Vocalizations consisting of echolocation clicks and buzzes were recorded during the foraging dives, indicating that these animals use them while hunting. Fewer buzzes were recorded during the day when the whales were observed diving deeper than during the night (Aguilar Soto et al., 2008).

A more recent study conducted by Servidio et al. (2019) examined the occurrence and distribution of pilot whales in the Canaries, aiming at providing enough information to help determine the impact of anthropogenic activities on the species. The results revealed the short-finned pilot whales have a large degree of site fidelity variability and a non-uniform distribution within the archipelago, with more individuals gathering around the leeward sides of the islands. Different subpopulations were identified in the archipelago but they maintain social interactions with each other and sometimes share their rages. The authors reported that transient individuals or temporary migrants can travel long distances, determined by the competition between or within species (Servidio et al., 2019).

5.2. Madeira

Another region offering favourable conditions for spotting short-finned pilot whales year-round is Madeira. Several studies have been conducted here on the species, analysing its population structure, diving behaviour, distribution and habitat preference as well as its survival and abundance (Alves, 2013). As well as in the Canary Islands, here too pilot whales have shown a high site fidelity variability, with individuals that have been classified as transients, regular visitors or residents, but thought to belong genetically to only one large population (Alves et al., 2014). Photo identification studies complemented by genetic analyses have tested the hypothesis that there are at least one resident and one pelagic community. The island associated community was found to contain less than 150 individuals while 300 other animals with different residency patterns were found to use the south of Madeira from mid-summer to mid-autumn (Alves et al., 2013). The societies are structured based on long-term relationships between individuals. Animals that are related to each other live in small groups called matrilines, showing social philopatry. Larger groups were found to be temporal associations of smaller groups, with 2-3 matrilineal pods coming together to form a clan and several clans interacting for mating purposes and thus forming a population (Alves et al., 2013). In order to determine the spatial and temporal distribution of short-finned pilot whales in Madeira, various biological factors, as well as environmental variables, were taken into consideration such as the behaviour of the animals, the presence of calves or relationships with other species, sea surface temperature, chlorophyll-a, depth, slope and distance from the coast. The encounter rates were found to be higher during autumn and the south-east part of the island was proved to be preferred for behaviours such as socialising, resting, breeding or foraging which indicates that at least in autumn the area is of high importance for the species (Alves et al.; 2014).

5.3. The Azores

Studies based on the short-finned pilot whales in the Azores are scarce. While only one research was found to be dedicated entirely to the distribution and abundance of this species in the archipelago (Mendonça, 2012), it has been included in more general research of occurrence and distribution of cetaceans in the area (Silva et al., 2014; Gonzalez Garcia, 2018) or, as previously mentioned, in studies that investigate the species across the entire Macaronesia (Alessandrini, 2016; Alves et al., 2018).

The short-finned pilot whales can be sighted year-round in the Azores in waters with a depth between 1000-2000 m (Alves et al., 2018). On the island of São Miguel however, the majority of the sightings were recorded in areas between 800 and 1200 m deep, at a maximum depth of 1649 m (Gonzalez Garcia, 2018). They are generally found further than 5 km away from the shore, with a maximum density found 13 km away from the shore in Vila Franca Gonzalez Garcia, 2018). Higher encounter rates were recorded in the month of July which correlates with the higher sea surface temperatures of 22ºC-24ºC that are usually recorded during summer (Gonzalez Garcia, 2018; Mendonça, 2012). Based on multiple yearly records of sightings as well as strandings, Silva et al. (2014) described the species as a “regular visitor” in the area, with varying encounter rates over the months and years which are consistent with their wandering nature and which was also confirmed in 2018 by Alves et al. According to (Mendonça, 2012) 435 animals were identified in the Azores, with 49 re-matches. Some of these animals were spotted over the years, with a maximum period of 11 years in between the sightings.

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Spatial and temporal distribution and photo identification of short-finned pilot whales (*Globicephala macrorhynchus*) off São Miguel Island, Azores, Portugal

Authors: Negulescu, R. (1), González García, L. (2), Castilho, R. (3)

(1) University of Algarve, (2) Futurismo Azores Adventures, University of Vigo, (3) University of Algarve

Abstract

The Azores is one of the regions frequented by the short-finned pilot whales (*Globicephala macrorhynchus*), a top predator in charge of balancing the area's fish and squid resources. Although some studies have been conducted on this species in Macaronesia, they focus more on other sites such as the Canary Islands or Madeira, leaving the Azores open to further research. The present study aims to assess the spatial and temporal distribution of the species in São Miguel Island and to create a photo identification (photo ID) catalogue of the individuals spotted and photographed over a period of eleven years. We aim to estimate residency times and evaluate the role of this apex predator in the North Atlantic, to finally identify any need for conservation measures.

Keywords: pilot whales, São Miguel, Azores, spatial and temporal distribution, photo ID

1. Introduction

The Azores archipelago provides a favourable habitat for 28 documented species of cetaceans (Prieto & Silva, 2010; Silva et al., 2014), including the two pilot whale species (*Globicephala melas* and *Globicephala macrorhynchus*), both of which have been reported within the area (Rui Prieto, 2007). However, studies on these two species in the Azores are scarce, very little is known about their spatial and temporal distribution, or about their residency in the archipelago and even less knowledge is available about these patterns around São Miguel. Only some of the individuals transiting the island have been photographed and identified, which means this area provides a large number of opportunities for research, supported by the effort of whale watching trips which can be used as platforms for data collection. Pilot whales are top predators and have, implicitly, an essential role in keeping the balance of their ecosystem by top-down control, regulating fish and squid populations that represent their primary prey (Aguilar Soto et al., 2008). Their horizontal, as well as vertical movements in search of food, might indicate the migrations of their prey. The population of pilot whales in the Azores has only been briefly investigated in studies focused on the entire Macaronesia (Alves et al., 2018) showing the spatial structuring of the species and the connectivity patterns within the area.

Although the short-finned pilot whale is currently listed under the conservation status “Least Concern” (Minton et al., 2018), the species is still facing various threats produced by human activities, such as whale watching tours, fishing, collisions with boats or noise pollution (Marrero Pérez et al., 2016; Servidio et al., 2019). It is, therefore, essential to assess whether the individuals that transit the south of São Miguel Island may form part of a single conservation unit to implement the correct management techniques for the protection of this species. As delphinids, they can also be categorised as “charismatic megafauna” and therefore a “flagship species”, meaning that any legislation in place to protect them would have an indirect effect on their entire environment (Hausmann et al., 2017). Studies on the pilot whales of the Azores are scarce, and due to the relatively low sighting rate within the archipelago they remain mostly unknown. Although both species have been reported, due to their resemblance it is hard to distinguish between them at sea in the absence of underwater cameras. It is often considered that the short-finned pilot whale (*Globicephala macrorhynchus)* is the one spotted, as it is well known for its occurrence within Macaronesia (Alves et al., 2018). Research about the species population structure, survival and abundance, dive patterns, distribution and habitat preference as well as foraging strategies in the Macaronesia region concentrate mostly on Madeira and the Canary Islands, leaving the Azores and specifically São Miguel available for further investigations.

In Madeira, Alves (2013) has found by photo ID and genetic analyses that the species shows large variability in site fidelity, with individuals being classified as residents, regular visitors and transients (although these might not be genetically isolated) that might be part of a single population. The same author (Alves, 2013) investigated the habitat use of the species in Madeira, proving that even though the pilot whales can be spotted there year-round, the encounter rates are higher in autumn and that they prefer the south-east region of the island. A later study (Alves et al., 2018) assessing the connectivity between the different archipelagos of Macaronesia from 1999-2015 has found that five of the residents of Madeira were seen together with other animals in the Azores. The same study showed that all the individuals spotted in the Azores were transients and that there are associations between groups of pilot whales found in Madeira and Azores and between other groups found in the Canaries and Madeira, but that these two clusters never associate with each other. In the Canaries, *G. macrorhynchus* is found year-round, with a subpopulation of around 50 resident animals associated to the island of Tenerife, with a non-uniform distribution and showing a high degree of site fidelity variability (Servidio et al., 2019). However, the groups that were identified near Los Cristianos, in the south of the island, were found not to mix with the northernmost ones near Anaga (Marrero Pérez, J., Crespo Torres, A., Escánez Pérez, A. y Albaladejo Robles, G., 2016).

In the context of these studies within Macaronesia, although data on pilot whales have been collected in São Miguel consistently since 2008, studies on short-finned pilot whales specific to this island have not yet been conducted, and a brief photo identification (photo ID) catalogue is available on the Monicet website (Monicet ::, n.d.) updated only until 2016.

The present study aims to investigate the occurrence of pilot whales in São Miguel as well as to compile a photo ID catalogue with the individuals sighted in the area. We specifically focus on assessing:

1. the temporal distribution using data taken from whale watching trips and land-based surveys over the course of 11 years (2008-2018).
2. the spatial distribution in relation to depth, slope and distance from the coast, using data taken from whale watching trips over 11 years (2008-2018).
3. the quality and scope of photos taken from whale watching trips over the past few years in view of their use for photo ID.

In accordance with the set objectives, the following hypotheses will be tested:

1. Pilot whales have a seasonal distribution around the island and most of the sightings occur during spring or summer.
2. Pilot whales in São Miguel prefer deeper waters with steep slopes where the abundance of squid that they feed on should be higher. Their habitat preference may also be influenced by dynamic variables such as sea surface temperature.
3. Pilot whales remain for some time around São Miguel island, and some individuals are re-sighted over different seasons and/or different years.

The secondary objectives of this study were to identify any social groups that might be present during the sightings and to check whether there is any influence of the sea surface temperature on the temporal distribution of the pilot whales in the region.

2. Materials and Methods

2.1. Study area

The Azores archipelago belongs to the region of Macaronesia together with the Canaries, Madeira and Cape Verde and it is located in the North Atlantic Ocean, "between 37.1° and 41.1°N, and 25.1° and 31.1° W", crossing the Mid-Atlantic Ridge, over a length of more than 600 km. It is made of nine islands that are organized into three groups: Flores and Corvo in the west, Pico, São Jorge, Terceira, Faial and Graciosa in the centre, Santa Maria and São Miguel in the east. The volcanic origin of the archipelago accounts for a lack of continental shelf, which provides suitable conditions for watching cetaceans at a close distance from the coast (Santos et al., 1995).

The data collection for this study was conducted off the south coast of São Miguel (Fig 1), which is one of the two easternmost islands. It has a mild climate all year round and provides different types of habitats favourable for several cetacean species (Silva et al., 2014).

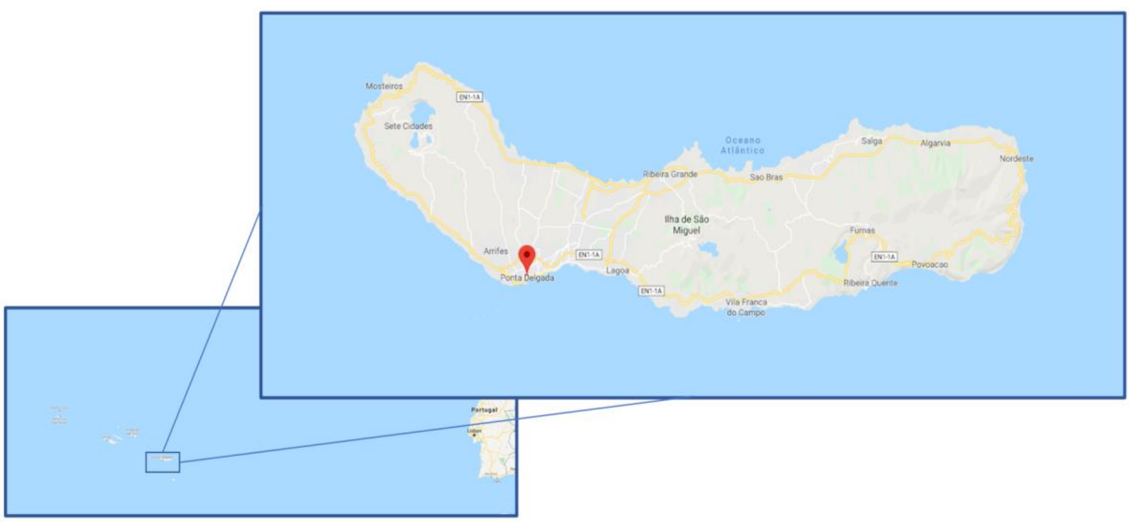


Figure 1. Study area - the coast of São Miguel Island, Azores in the North Atlantic Ocean;
Whale watching trips going out from Ponta Delgada
Provided by (Google Maps)

2.2. Data collection

Two sets of data were used for this study: data collected from whale watching boat-based surveys and from land-based surveys. The search effort was calculated as the number of boat trips performed each month during each year of the research period, starting in May 2008.

2.2.1. Boat survey data collection

Opportunistic boat-based surveys were used for the collection of data at sea, using as a platform different whale watching boats belonging to Futurismo Azores Adventures. Sampling was done for a period of 11 years (2008-2018), by various biologists working for the company, who were instructed to follow a strict protocol in order to minimize human error.

At the beginning of each trip, the date, the name of the boarded boat, as well as the names of the crew members were recorded. Whenever a group of pilot whales was spotted, its GPS position was marked, together with the start time. Data collection was done during the entire sighting and the biologists recorded various parameters related to the group and behaviour of the animals. The group size was approximated by counting the individuals that were close to the boat, as well as those that were further away but still within the sighting area. The group composition was also recorded, considering approximately how many individuals were adults, juveniles, calves or newborns (in which case they present fetal folds and the dorsal fin is bent). Associations with other species were mentioned as well, both in case of associations with other cetaceans and if they were seen together with other animals such as birds.

The behaviours displayed during each sighting were recorded (Table 1) and, starting in January 2019 the reaction to the approaching whale-watching boat as well. The animals could be indifferent (when they do not visibly alter their previous behaviour), elusive (when the whales are moving away from the boat) or approaching (when the animals come close to the boat). The number and types of boats (whale watching or fishing) present at the beginning as well as at the end of the encounter was also marked.

Table 1. Ethogram of cetacean behaviours observed from the boats.

Behaviour	**Description**
Resting	Moving slowly or remaining stationary, with all the animals of the group staying together and facing the same direction.
Socialising	Interacting with other individuals.
Foraging	Surfacing constantly in various directions. In pilot whales however, this takes place during diving and is, therefore not usually observed.
Travelling	Moving in one direction.
Milling	Surfacing constantly in various directions.
Logging	Remaining stationary and floating at the surface.
Bow-riding	Swimming in front of the boat in the waves created by the vessel.
Breaching	Lifting most of the body outside the water.
Lob-tailing	Slapping the surface of the water with the tail flukes.
Other	Any other behaviour not listed above (eg. nursing).

Starting from January 2019, at the end of each sighting, environmental parameters were also recorded, including the Beaufort sea state, Douglas sea state, cloud cover and visibility (Table 2), as these parameters could influence the ability to spot, count the individuals or assess their behaviour and might influence the results of the study. Before 2019 the environmental information collected was less specific. These variables were estimated visually and consulted with the captain. The whale watching trips took place only when the weather conditions allowed for the safety of the clients to be respected and when the lookouts had good visibility to find the cetaceans from land. However, in the highest recorded Beaufort states, some of the behaviours are difficult to distinguish.

Table 2. Environmental conditions collected during boat surveys, starting from January 2019

Beaufort Sea State	**Douglas Sea State**	**Visibility**	**Cloud cover**
0 - Calm 1 - Light air 2 - Light breeze 3 - Gentle breeze 4 - Moderate breeze 5 - Fresh breeze	0 - Calm, glassy, no waves 1 - Calm, rippled (<0.1 m) 2 - Smooth (0.1-0.5 m) 3 - Slight (0.5-1.25 m) 4 - Moderate (1.25-2.5 m) 5 - Rough (2.5-4 m)	1 - < 5km 2 - 5-10 km 3 - 10-15 km 4 - > 15 km	1 -0-25% 2 - 25-50% 3 - 50-75% 4 - 75-100% 5 - covered, raining, dark

The end of the sighting was marked by taking the GPS coordinates again, together with the end time.

2.2.2. Land survey data collection

Searching for the cetaceans was done from land, by experienced lookouts that continuously scan the horizon with powerful binoculars (20x80) from different strategic positions with altitudes between 77 and 178 m that allow for a wide range of visibility: Água de Pau, Escalvado, Cintrão, Capelas, Lomba da Fazenda, Ponta Garça, Arnel, Aeroporto, Miradouro Pico do Vermelho and Mosteiros (Fig. 2). Data used in the current study was collected from the south coast, and mostly from Capelas. Whenever a group is spotted, they inform the boat captain by radio about its location so that the boat could be directed towards the right area. Information about the sighting is also recorded on land, including the time of the encounter, the position of the lookout, total number of animals spotted with an estimation of their general behaviour, as well as environmental variables such as sea state and atmospheric conditions and any useful observations that might bring insight about their state.

Figure 2. Geographical positions of the lookout points around
Sao Miguel Island (created with Google Maps 12th of March 2020)

2.2.3. Photography for photo identification (photo ID)

The photo ID materials were collected from 14 different photographers, each of them working as qualified staff members for Futurismo (onboard biologists/guides or skippers): Barbara Sousa, Carine Zimmermann, Denise Verstraeten, Fadia Al Abbar, Ida Eriksson, Ignacio Rivero, Laura González García, Laura Otero, Mariana Silva, Marina Gardoki, Miranda van der Linde, Rafael Martíns, Ramona Negulescu, Rui Rodrigues. A total number of 6473 photographs covering the following years: 2005-2008, 2010, 2012, 2014, 2016-2020 were used for compiling a photo ID catalogue for the island of São Miguel. These photos, whenever possible, were taken from a close distance, always respecting the approaching rules of the regional legislation (DLR 10/2003/A) and at a 90° angle from the animal and on both sides of the whale (Fig. 3).

Figure 3. Examples of photo ID photos of two well marked individuals, taken from both sides.

2.3. Data analysis

2.3.1. Temporal distribution

Data collected from both land-based and boat-based surveys were used in order to create a graphical display of the temporal distribution of short-finned pilot whales around São Miguel Island. Given that during the colder season whale watching boat trips are not as frequent as during the summer due to rougher sea conditions and the drop in the number of tourists, land data offers a complementary approach to the occurrence of the species recorded from the boat.

The Sea Surface Temperature was recovered from Copernicus website (MyOcean Viewer, n.d.). The Operational Sea Surface Temperature and Ice Analysis (OSTIA) of the UK Met Office provides daily temperature maps built with satellite data. These maps were later processed in MatLab by Laura González García.

2.3.2. Spatial distribution

In order to display the spatial distribution of pilot whales around São Miguel Island, QGIS was used for producing the maps, using the coordinates collected during the opportunistic boat-based surveys and following the internal protocol used for creating monthly maps of sightings. The data collected from land could not be used in this case due to the inaccurate register of the position of each group. One map was generated with all the geographic information about the sightings during the entire study period. Additional maps, for each separate year were also produced. The depth, slope and distance from the coast were represented graphically in Excel.

2.3.3. Photo identification

In order to create the photo ID catalogue, the first step was organizing the photos by date. Those belonging to the same sighting were stored together in a folder named with the following formula: year/month/day. For example, 20190820 corresponds to the 20th of August 2019. In order to keep track of where the photos came from and the stage of their processing, a google spreadsheet was completed with the corresponding information.

After placing the photos in the correct folder according to their date, a first selection was done, where not useful photos were deleted. This refers to photos that do not contain any animals, that contain other species of cetaceans (in the case of sightings of pilot whales together with another species) and photos that are too unclear to obtain any identification information (photos that are too blurry). When different animals from the same photo could not be distinguished from each other, these photos were moved to a folder called “Doubts” used for understanding group sizes.

Photo processing started by cropping individual fins out of each photo with the help of a software called Photo ID Ninja (http://photoid.ninja) and saving each of them separately. Because this process eliminates the date from the file information of the cropped photos, each folder will be uploaded into the software separately. After the photos are cropped, the fins are downloaded into a new folder with the same date (example: 20190820_Cropped). In case the fins in the resulting cropped photos are not bright enough for identification, the contrast can be adjusted to enable it, otherwise, they will be deleted. Only clearly distinctive photographs were used for the photo ID catalogue.

The next step was the identification within each folder, which involved checking how many individuals were photographed during each sighting. The photos were renamed so that each individual could get its own number for the respective sighting. For example, 20190820_GMAC_001_R corresponds to the right side of the individual 001 spotted on the 20th of August 2019. Each photo was compared with all the other photos from the same folder and matching was made initially by considering the notches on the trailing edge of the dorsal fin and then confirmed by afterwards using the shape of the fin or different scars and marks that are visible (Fig. 4).

A  B

Figure 4. Example of two photos of one individual suited (A) and not suited for the catalogue but good for identification (B)

After identifying all the individuals and renaming the photos, the best photo of each animal was selected for further use in the catalogue and a separate folder was made. For example: "20190820_Selection_for_Catalogue". In order to create the catalogue, the "Selection" folders were used, starting in chronological order. Each individual of the catalogue was renamed by assigning it a catalogue code and keeping track of all the dates in which the individual is re-sighted. For example:

PW022_20161014_GMAC_005_L; PW022_20180901_GMAC_001_R; PW022_20180906_GMAC_001_R.

The above example corresponds to the individual (pilot whale - PW) number 001 of the catalogue, followed by the corresponding photo title. This proves that pilot whale 001 was spotted on three different occasions, during two different seasons (2016 and 2018).

Each photo from each selection folder was compared to the newly formed catalogue in order to search for matches and to add new individuals to the catalogue.

3. Results

3.1. Temporal distribution

Both land-based and boat-based data were analysed in order to determine the temporal distribution of short-finned pilot whales around the São Miguel Island. The reason why both sets of data were included was that they complement each other. In some cases, the animals are only seen by the lookouts while they are out of reach for the boats, meaning that if only boat-data was considered, some of the sightings would have been ignored. Similarly, in other cases sightings are only made from the boat but not from land.

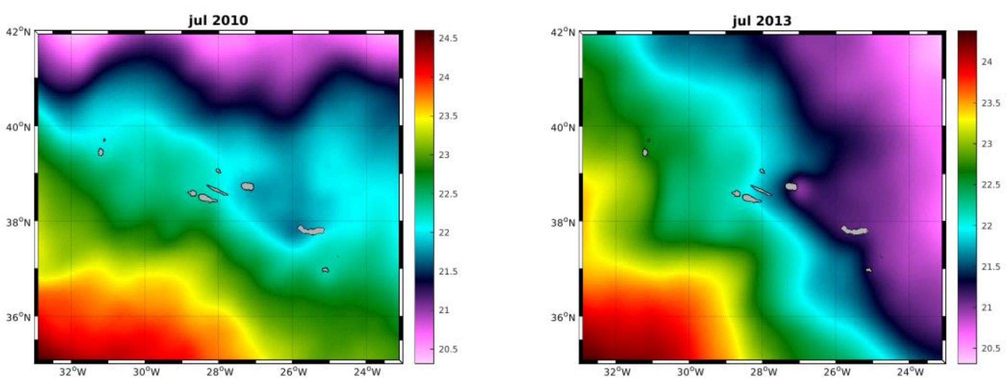
Between 2008 and 2018, the pilot whales were spotted 311 times from land and 235 times from the boat. For most years the number of sightings from the land was higher than the number of sightings from the boat (Appendix I, Fig.1), although the result is not statistically significant (Chi^2 (df=3) = 0.33, p-value = 0.95). The number of pilot whale sightings is generally low varying from year to year, from as little as 4 in 2013 (5 from land) to as many as 68 in 2010 (78 by land). In 2008 the pilot whales were spotted from the boat 8 times but there are no records of land sightings for that year. However, it is important to restate that in 2008 the surveys only started in May. It is also shown that there were more sightings in 2010 and 2011, followed by a drop in encounters during the next years.

The effort was calculated as the number of boat trips that were conducted per year and it ranged from 227 in 2008 to 452 in 2017. The largest number of trips (381) was recorded during the month of July while the lowest (44) was recorded in December (Appendix I, Table 1, Fig. 2). Even if the number of boat trips each year ranged in the hundreds, the sightings only ranged between a minimum of 8 in 2008 and a maximum of 40 in 2011. Regarding the land surveys, sightings with pilot whales were recorded ranging from as little as 4 times in 2018 to as many as 78 in 2010 (Table 3).

Table 3. Number of sightings with pilot whales per month each year between 2008-2018 (boat surveys/land surveys)

Month/Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total/month
January					2/2			1/2			0/1	3/5
February		2 / 2	1 /1		0/4					1/0		4/7
March					3/7							3/7
April				2/1	1/1					0/2		3/4
May		4 /4	1	0/2	0/2		11/18	2/2	1/1			19/29
June	5	8 / 12	10 / 13	17/21	3/5	2/3	6/2	6/7		1/1	5/3	63/67
July	2	6 / 7	18 / 34	10/22	11/9	1/1	2/2	2/5	3/4	1/3	5/0	61/87
August		5 / 4	6 / 11	6/11	2/3		2/4	1/0	1/1	1/2	3/0	27/36
September		8 /8	2 / 5	1/2	0/2		1/2	2/2	0/1	4/9	2/0	20/31
October			5 / 6	2/1	2/1				1/1	2/0	1/0	13/9
November			5 / 7	1/7	0/1	1/1			3/5	3/0		13/21
December	1		3 / 1	1/1			1/6					6/8
Total/year	**8/0**	**33/37**	**51/78**	**40/68**	**24/37**	**4/5**	**23/34**	**14/18**	**9/13**	**13/17**	**16/4**	**235/311**

Both land and boat-based data show that most of the sightings occur during the months of June and July, with 31% of all land sightings (66 in June, 98 in July,) and 24% of the boat sightings (82 in June, 72 in July) (Appendix I). The difference between the sightings from land and from the boat for each month however has been found not to be statistically significant ($Chi^2(df=100)=111$, p-value = 0.31). Considering that the month of July recorded most of the sightings, of all the investigated years, the highest number was recorded in July 2010 (18 in boat surveys and 34 in land surveys), while July 2013 showed the lowest number (only one sighting both from land and boat surveys). Significant differences in ocean temperature were recorded between these two months (Fig. 5).



A B

Figure 5. Sea Surface Temperature in degrees Celsius in the Azores archipelago in July 2010 (A) and July 2013 (B). Images generated by processing data provided by OSTIA in MatLab by Laura González García

The short-finned pilot whales showed a general preference for the summer season, when 66% of the boat sightings and 64% of the land sightings took place (Fig. 6).

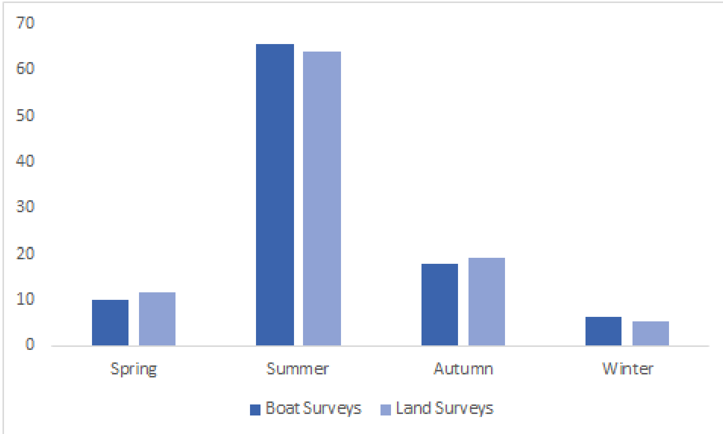


Figure 6. Percentage of pilot whale sightings per season, calculated from land-based surveys and boat-based surveys

The group sizes varied across the encounters with as few as a single whale spotted to as many as 70 individuals seen together, with an average of 20 pilot whales per day. Most of the sightings however (68.7%) were of groups under 20 animals with 27.3% groups between 1 and 10 individuals and 41.4% groups between 11 and 20 individuals (Fig. 7 A). A one-way ANOVA was conducted to check if the group sizes varied between spring, summer, autumn and winter, revealing that there was no statistically significant difference in group sizes across seasons at the $p < 0.05$ level [$F(3,402) = 2.109$, $p = 0.09$] (Fig. 7 B).

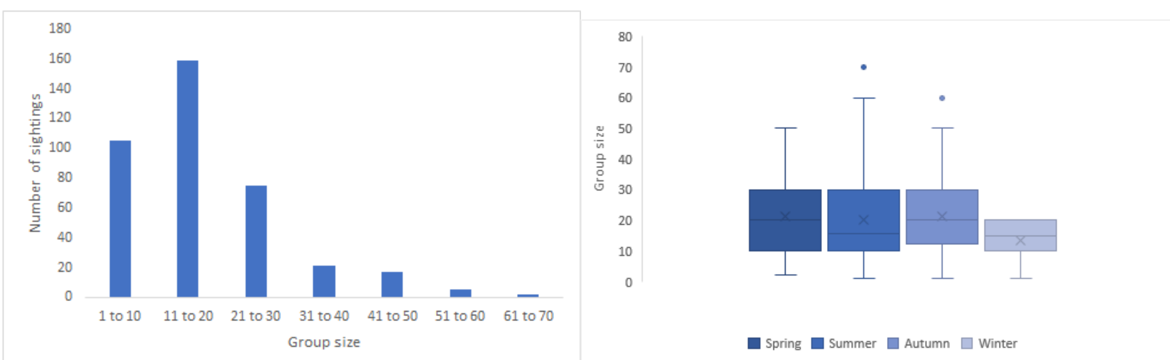
A  B

Figure 7. A Frequency distribution of group sizes; B. Group sizes depending on the season. Box and whisker plots - lower and upper line show the 25th and 75th percentile, the middle line represents the median value, the x is the mean the ends of the whiskers represent the minimum and maximum values and the dots represent the outliers

Calves were present on 250 occasions, accounting for 88% of the total number of sightings. Their presence was recorded regardless of the season, but most of the sightings with calves (68%) occurred during summer, corresponding to the general seasonal preference of the species (Fig. 8).

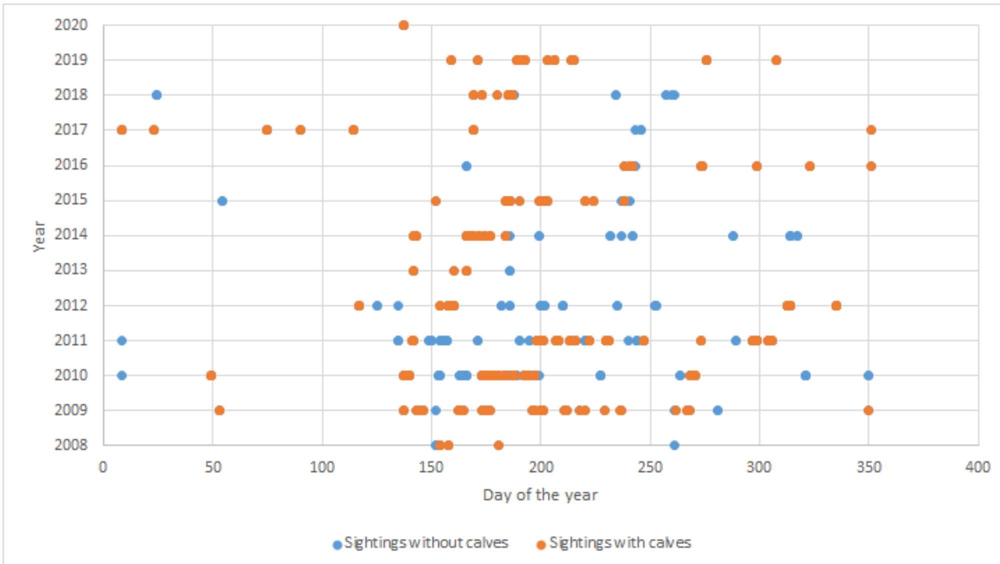


Figure 8. Temporal distribution of pilot whales. Blue - sightings without calves, orange - sightings with calves.

Associations between pilot whales and other species were reported 20 times during the study period. They were spotted in the presence of Risso's dolphins (*Grampus griseus*), striped dolphins (*Stenella coeruleoalba*), Atlantic spotted dolphins (*Stenella frontalis*), common dolphins (*Delphinus delphis*) or sperm whales (*Physeter macrocephalus*). However, the association more frequently recorded was with the bottlenose dolphin (*Tursiops truncatus*) with whom they were spotted 12 times (60% of the associations recorded). On two different occasions, apart from the bottlenose dolphin, Risso's dolphins and false killer whales (*Pseudorca crassidens*) were also present respectively.

3.2. Spatial distribution

248 GPS positions were used to create a distribution map displaying the range of coordinates that were recorded during boat-based surveys with pilot whale sightings from May 2008 to January 2020 (Fig. 9A). Starting in September 2009 the GPS coordinates were recorded both at the beginning and at the end of a sighting, which provides a more accurate representation of the trajectory the whales followed during the encounter. However, only the coordinates recorded at the beginning of the sighting were used for creating the distribution map, in order to avoid introducing the same sighting twice. Individual maps were also constructed for each year between 2008 and 2020, showing the preference of pilot whales for areas between 700-1200 m of depth regardless of the year (Appendix II). Pilot whales were found ranging from 3.70 to 40.70 km away from the coast (median = 10.48). 89% of the sightings were recorded within a distance between 0 and 20 km, usually not closer than 4 km away from the shore (only one encounter was recorded at a distance smaller than 4 km from the coast). Most of the sightings further than 30 km away from the shore were recorded during the summer season (Fig. 9B). Pilot whales were recorded in a variety of depths, from 17.5 m to as deep as 2115 m, with a median value of 1004.5 m and a mean of 1040 m. They were found more often in waters between 700 and 1200 m deep, since most of the sightings (64.86%) were recorded in areas with this depth (Fig. 9C). They were also more frequently found in terrains with slopes between 2° and 6° but they ranged from 0.2° to 28.2°, with a median of 4.5° (Fig. 9D).

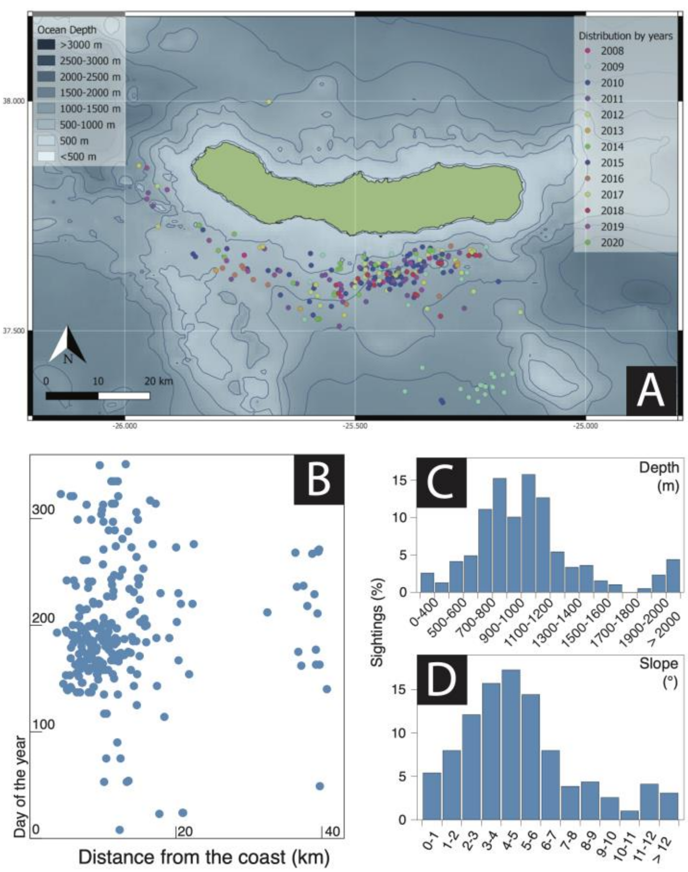


Figure 9. A. Map showing the pilot whale distribution off São Miguel island between 2008-2020. The lines indicate the bathymetry of the region, the points represent the positions of the animals, each colour representing a different year. B. Scatterplot showing the distance from the coast that the pilot whales were sighted according to the day of the year.

3.3. Photo identification

3.3.1. General

The photographs used for assembling the photo ID catalogue were collected during 63 whale watching trips that took place in 62 different days over a period of 12 different years (2005-2020). The sightings, however, were not equally distributed amongst these years: 2005 (1), 2006 (1), 2007 (1), 2008 (4), 2010 (10), 2012 (2), 2014 (12), 2016 (5), 2017 (12), 2018 (8), 2019 (6) and 2020 (1). Twelve of the 63 sightings (19%) contained photos that were too blurry, angled or too far away so they were not used for photo id. These include the only two encounters from 2012, in which no photographs could be used. Thirty-eight (60%) of the sightings accompanied by photos were from summer months (June, July and August). A total number of 6473 photographs were processed and analysed, resulting in the identification of 343 individuals, with 486 photos (7.5%) used to compile the catalogue. While 302 animals (88%) were spotted only once, 42 of the identified pilot whales were sighted more times: thirty-two (76%) were spotted twice, while the other 10 (24%) were spotted three times (Appendix I, Table 2; Appendix III), which is the maximum number of re-sightings recorded in this study. Some of the encounters only provided enough photographs to identify two individuals, while others went as high as 20, with a mean of eight individuals identified per sighting. According to the recorded data, the smallest number of whales spotted was one while the largest estimated was 70, with a mean number of 20 whales per sighting. Therefore, in average, less than 50% of the animals found during an encounter were photographed. In several cases the individuals could be identified from each other within the sightings but the photos were not clear enough or their fins were not distinctive enough to add to the catalogue. This information was kept in order to help with estimating group sizes.

3.3.2. Re-sightings

The longest time distance between re-sightings was 11 years in PW001, which was seen first in 2006 and then twice more, in 2017 and 2020. Two other animals, PW035 and PW069 were also seen 11 years apart, first in 2008 and then in 2019. More than half of the re-sightings (23 / 56%) were recorded within the same year and eight whales were re-sighted two years apart. The shortest time interval was recorded in five pilot whales that were spotted on consecutive days. One whale, PW040, was spotted three times in 2017, once in every summer month (June, July, August). Four of the pilot whales that were re-sighted in two different years were seen during the same month: PW035 and PW069 were spotted on the same dates in June of 2008 and 2019. PW069 was also spotted later, in August 2019. Two other animals were spotted twice during the month of June of 2014 and 2018 respectively: PW098, PW099. PW098 was also spotted in May 2014. PW094 was also spotted twice during the month of August of two different years (2014 and 2017). 20 of the 132 animals identified in 2014 were re-sighted, 16 of them being spotted twice during the same year. 11 of these 16 pilot whales were seen twice in May 2014 and 5 were photographed once in May and once in June 2014.

3.3.3. Social structure

Some of the identified individuals were spotted together more than once. Three of the pilot whales were first sighted in October 2016 as well as two years later, on two different occasions, in July, when they were also accompanied by another identified whale. Another individual seen first in October 2016 was also seen twice two years later, on the 1st and 6th of September, in the company of two other whales. As mentioned earlier, PW035 and PW069 were spotted together twice: in 2008 in June and 11 years later, in 2019 also in June. PW069 was accompanied by two other individuals in August 2019, one of which was also previously seen twice, nine years earlier in 2010. The individual spotted three times in 2017 was accompanied twice by three other whales. Also, in 2017, two individuals were seen in February, while two years later, in 2019 the same animals were photographed in May. In 2014 photos were available for several days from May and June, most likely from the same pod, since there were at least 2 individuals spotted together and matched between each two encounters. A maximum number of five pilot whales were spotted together on more than one occasion. This is the case of PW253, PW255, PW258, PW269 and PW281 that were photographed together on two consecutive days of May 2014. During most of the re-sightings however, only two or three associated animals were found.

4. Discussion

While interpreting the results of the current study we should consider the caveats that may affect them. The first is the fact that the work was based on opportunistic data that was collected from whale watching boat surveys. Opportunistic data collection presents both limitations and advantages. The most serious limitation is set by the duration of the trips which influences the time spent with the cetaceans as well as, in some cases, the possibility of encountering them. However, a very important advantage is that the whale watching platform offers the opportunity of collecting data all year long, covering the entire south coast of the island.

As previously mentioned, the individuals are found first from land by the look-outs who in turn reveal their location to the boat captain. The survey effort is therefore not absolute since the boats are usually from the beginning directed towards an already known location. The number of recorded sightings differs from year to year which might be explained not only by the difference in temporal distribution and/or residence time of the individuals but also by the number of trips performed each year. In 2008 for example, the reduced number of sightings is partially due to the fact that data were not collected during the entire year. Data were only collected on boat surveys from May to September and during the month of December. In addition, data from land in 2008 is not available, so a comparison of the two sets is not available for this year. Among the advantages, it stands out these, it is important to mention the long- term data series that was available for analysis, and in addition, the fact that most of the land-based data was collected by the same person, which is a very experienced look-out.

All observations depend obviously on detection, and individuals are more easily detected when they display more active behaviour and in suitable environmental conditions. The latter influence the ability of the lookouts, skippers and biologists to spot, identify and count the pilot whales, which might mean that, the better the conditions, the further the whales might be found.

4.1. Temporal distribution

The results of the present study partially support the first working hypothesis, that pilot whales are seen more often around the island during summer and spring. They have been found to transit São Miguel in a significantly higher number of days during June and July, but not so much during Spring months. In contrast, the most recent study on pilot whales in Macaronesia (Alves et al.

2018) showed that the sighting rate is higher in the Azores between September and November. However, the data used for that study was collected off Pico island, while the current study focuses only on São Miguel. Sightings Madeira, where pilot whales are more abundant than in the Azores, are in higher density areas during autumn (Alves, 2013).

July was the month with the highest number of recorded sightings but it is also the one with the highest number of boat trips. However, August the month with the second-highest number of trips, does not rank second in recorded sightings. This means that the encounter rate does not directly correlate with the number of surveys.

Several factors can contribute to the observed difference in monthly distribution of the species around the two islands: (1) the migration of their prey, (2) the sea surface temperature or (3) breeding period. Results show that July 2010 is the summer month with the highest number of sightings (13) while July 2013 recorded the lowest number (1). The monthly mean sea surface temperature (OSTIA) of these two months shows colder temperatures around São Miguel in July 2013. While the sea surface temperature usually shows a latitudinal gradient, during this specific month it has a longitudinal gradient with colder waters in the east and higher temperatures in the west of the Azores. This fact can explain the absence of the pilot whales from the south of São Miguel during this period. However, this relationship goes beyond the objectives of the current study and could be a new hypothesis for further investigations. São Miguel island is not considered a breeding area for the pilot whales, despite the fact that 88% of the sightings and especially those recorded during summer months are individuals with calves and/or juveniles. Both births and mating behaviours have not been recorded around the island. Also, the presence of newborns was very rarely recorded (only 11 times during the entire study period).

In the present study, the group sizes ranged from one to 70 whales with a mean of 20 whales per sighting, similar to what was recorded in the Canary Islands where groups consist of one to 80 individuals with a mean of 16 individuals per encounter (Servidio, 2014). Most of the sightings were of less than 20 individuals, a number similar to the one observed in the Canaries of less than 25 individuals (Servidio, 2014). However, although in the present study there was no significant variation in group size between seasons in the Canary Islands groups were larger in summer, particularly around Tenerife island (Heimlich-Boran & Hall, 1993; Servidio, 2014). Similarly, in Madeira, it was detected a significant difference in group size from season to season, with larger groups being spotted from May to October. In Madeira residents are observed all year through, as well as transient individuals that can also be spotted in mixed groups while visitors and mixed groups more often between August and December (Alves et al. 2013). Calves and neonates in Tenerife are seen more often during the Summer months (Servidio, 2014). There are several reasons that might explain the seasonal difference in group sizes of pilot whales in Madeira and the Canary Islands. One, suggested by de Stephanis et al. (2008) as well as by Alves et al. (2013) is that the groups mix for breeding purposes. It is known that the short-finned pilot whales do not mate within their matrilines, avoiding inbreeding. Another hypothesis is that the individuals might come together in larger groups for hunting (Servidio 2014). However, this behaviour alone does not explain the seasonality of these differences, although it might contribute to the explanation if coupled with the migration patterns of their prey.

The pilot whales of São Miguel have been spotted various times in the company of different cetaceans. However, in most of the occasions (60%) they were spotted in the company of bottlenose dolphins. The same observation was recorded in other regions of Macaronesia. In the Canary Islands (Servidio et al. 2019) reported 147 associations between short-finned pilot whales and bottlenose dolphins out of 177 encounters. In Madeira, the most common association was also with bottlenose dolphins, with 91.1% of sightings where more than one species was present (Alves, 2013).

4.2. Spatial distribution

The current study indicates that pilot whales around the island of São Miguel show a preference for waters between 700 and 1200 m deep and regions with slopes of 2° to 6°. Similar findings were recorded in the same region: 800-1200 m and 2.5°-5° of slope Gonzalez Garcia (2018) and in the Canary Islands, where pilot whales are more likely to be spotted in deeper, richer in nutrients and calmer Tenerife, Lanzarote-Fuerteventura waters between 800 and 1200 m deep (Servidio 2014) than in the shallower La Gomera waters (Servidio 2014). In Madeira, the south east of the island is the preferred habitat of the species (Alves, 2013), mainly because it is a highly hydro-dynamic area of upwellings (Caldeira et al. 2002). This same geographic area is also a feeding ground for the island-associated population, which can further explain why the species is frequently found there (Alves, 2013). The same type of habitat was found to be preferred by short-finned pilot whales also outside Macaronesia. For example, in the North Pacific pilot whales are found at a median distance of 6.5 km from the coast, ranging between 0.5 and 344.8 km, in waters with depths between 215 and 4500 m. In that region, no pilot whales were found in waters under 200 m deep (Hill et al. 2019). In São Miguel, the observed short-finned pilot whales were found between 4 and 20 km from the coast.

4.3. Photo ID

4.3.1. Number of photos

The photographs used for identification in the current study were provided by 14 different photographers between 2005 and 2020. However, the photo identification effort was not consistent among years. For example, only one date with available photos was retrieved from years 2005, 2006 and 2007. Even if more photos were taken during those years, they are absent from the Futurismo database. In more recent years there was an increase in the number of available photographs as more biologists got access to high-quality cameras and also showed a growing interest in photography and research. The quality of the cameras improved over the years which in turn led to an increase in the quality of the photos and subsequently were conducive to a higher identification rate. In addition, over the years, the company also acquired more boats and therefore more trips are available each day. As opposed to data collection, that is only recorded on one boat (usually the catamaran Cetus) to avoid recording the same information multiple times, the fact that onboard biologists have access to high quality cameras mean more opportunities to collect photos for the purpose of identification. The exception in the trend of increasing number of photos is the year 2020 due to the COVID-19 pandemic. All whale-watching activities were halted from mid-March until the end of June.

The fact that less than 50% of the individuals of each sighting were photographed might be explained by a series of reasons such as (1) the position of the boat in respect to the group during the sighting, (2) the position of the photographer that might not reach all the individuals or (3) the environmental conditions such as visibility and sea state, or the opportunistic nature of the data collection, which is always under the requirements of the commercial touristic activity. Under low visibility conditions it is difficult to spot the individuals while in tumultuous sea states individuals are harder to photograph, as the fins are not so visible among the waves. Several factors may contribute to and influence the success of the identification process, such as (1) the quality of the photos, (2) the distinctiveness of the fin and (3) the appearance of new notches in time.

Regarding the quality of photos, only 81% of the analysed photos could be used for identification, while the rest were too blurry, angled or taken from a very large distance so that they lost information when cropped. In addition, the easiness to distinguish different individuals depends also on how well marked the fins are. While some pilot whales have very distinctive dorsal fins with easily recognizable notches (for example PW022 or PW023), others are not so easy to distinguish (for example PW133 or PW189). The presence of barnacles (*Xenobalanus globicipitis)* proved helpful to differentiate individ during one sighting but less useful over the years as the pilot whales may lose or get new ones. This was the case of one individual (PW094) that was spotted in 2014 without and three years later, in 2017, with barnacles.

4.3.2. Residency patterns

Due to the fact that not all sightings are accompanied by photos and also that not all individuals are photographed during a sighting, the residency pattern of these pilot whales remains unclear. The probability of photo re-capturing an individual depends not only on the available photographs, but also on the behaviour of the individual or on how distinctive its dorsal fin is. The higher the distinctiveness the higher the chance of matching while analysing the photos (Servidio, 2014). Four of the re-sighted individuals were spotted several years apart during the month of June. This is the case of PW035 and PW069 that were seen in June 2008 and 2019 and also of PW098 and PW099 that were seen in June 2014 and 2018. This might be influenced by the higher sighting rate during summer months, June being the second-best sighting month. However, the consistent sighting in June might also indicate that the same individuals transit together to São Miguel in this time of the year.

Different individuals were spotted during the same year on consecutive days or even consecutive months. One whale was spotted three times in 2017, once in every summer month (June, July and August) indicating a longer residence around São Miguel. The situation is quite different in Madeira, as pilot whales have well known residence patterns and can be classified in three types: (1) transients, (2) visitors or (3) residents (Alves, 2013). It is therefore very common for resident individuals to be spotted more frequently and regardless of the month of the year, while transients and visitors are seen less often. Transient whales were also found to interact with groups that are island-associated in Madeira (Alves, 2013). Generally, the social structure of the species is complex and can be formed of individuals with differences in site fidelity. This is true for Hawaii where a few groups are thought to prefer offshore waters, while the main cluster remains closer to the coast (Hill et al. 2019). In synthesis, the evidence for a seasonal pattern in São Miguel waters is still scarce and the hypothesis must remain open to future studies.

4.3.3. Individual associations

For evaluating associations, it is usually recommended to use only individuals spotted on five different occasions (Whitehead, 2008). However, in the present study, the highest number of re-sightings of the same individual was three, which means there is not enough information for organizing them into well determined groups and analysing their social structure. Associations of individual pilot whales are known to be formed preferentially in Madeira (Alves, 2013) and in the Canaries (Servidio, 2014), but also in regions outside Macaronesia such as Hawaii (Hill et al. 2019). Given the extremely social nature of these individuals it is very likely that more individuals from the same group could have been re-matched if more photographs were available. It is also likely if one individual was spotted on two different dates in the company of two different whales, that all these three individuals belong to the same group. This might mean that the 19 individuals spotted in 2014, as some of them were sighted together in different sightings through the year, they might all belong to the same one group. Likewise, for individuals spotted together in 2016, 2018 and 2019for the same reason. However, the matching is influenced by the sighting rate of the species in the area. While in the Canary Islands this rate is very high and there are only very specific reasons for seeing an animal only once (such as transients that usually go across other areas or individuals that are behaviourally not so active and therefore not very easy to photograph) (Servidio, 2014), the situation in São Miguel is very different. The pilot whales that can be seen in the Azores are transients (Alves, 2018), they are only rarely spotted off São Miguel, so the fact that the majority of the individuals were seen only once is not so surprising.

4.4. Limitations and challenges

The present study has encountered several limitations that have influenced its results:

1. Using whale watching platforms provides for an opportunistic way to survey marine mammals in which the encounters are limited by the trip times, not allowing for the following of the cetaceans over longer periods. Each trip lasts up to a maximum of 3 hours, meaning also that if the pilot whales are spotted late by the lookouts or if they are too far away/out of reach from where the boat is positioned, boat-based data might not be collected. However, trips are carried out year-round, providing a good long-term data series to analyze the occurrence of cetaceans, in this case, of pilot whales around the island with a regular spatial cover in the study area.

2. The trips are dependent on weather conditions such as the Beaufort sea state, to guarantee the safety of the customers. Visibility plays also a key role as the success of the trip often relies on the lookouts, who can encounter difficulties in finding the cetaceans, counting individuals or identifying behaviours, leading to missing information in the data. Sometimes pilot whales are confused with or hard to distinguish from bottlenose dolphins (*Tursiops truncatus*).

3. Land-based data is not collected on days with no trips, which might lead to a biased representation of the temporal distribution, especially during the cold season.

4. Some of the samples were incomplete, for example, they might be missing the GPS coordinates, therefore not all the data could be included for the spatial distribution study.

5. Not all the individuals spotted during a sighting are photographed, therefore some re-matches can be missed.

6. The quality of the photographs increased over the years, as well as the number of available photos. However, the quality is not always good enough for photo identification and for the first years of the study period there are few photos available.

7. The present study has a good spatial cover of the southern region of the island since this is where the whale watching activities are mostly taking place. However, pilot whales are not limited to this area, and although without records, they could be transiting out of our study area (e.g. north side of the island).

4.4. Further research ideas

The present study provides insight into the temporal and spatial distribution of short-finned pilot whales off São Miguel, but to this day there is not enough information to estimate how many individuals frequent the island and what residency pattern they follow. Although the current study was based on a long-term data series, the sighting rate was low and the re-sighting opportunities even lower and therefore associations between individuals could not be properly evaluated. More research and, in particular, more photo ID is needed in order to determine whether there is only one large group transiting the island or several smaller groups that come at different times. It is unknown if individuals seen in Pico can also be spotted in São Miguel. As some individuals have been previously matched between the Azores and Madeira, and Madeira and the Canary Islands, further studies can provide evidence whether there are some regular connections between de Macaronesian archipelagos.

Another possibility is to test is whether the pilot whales from São Miguel belong only to the transient population from Madeira or if they come from other places as well. Genetic analyses of skin samples could be run to identify which population they belong to. If the reason the pilot whales transit the Azores is the favourable habitat and food supply that they can find here it is to be determined why they tend to be spotted in the area more during the months of June and July. It is important to test if there is any significant relationship between oceanographic variables and the temporal and spatial distribution of pilot whales. For example, our preliminary results show an influence of the sea surface temperature on the seasonality of pilot whale sightings and this can be further investigated. Future changes in oceanic temperature are to be kept under observation together with any changes in the temporal distribution pattern in order to see if these two coincide. This is known to be under the scope of the SOCLIMPACT project (https://soclimpact.net), which aims to evaluate the effect of climate change on blue economy, with a special focus on whale watching and cetacean distribution, aiming to create a vulnerability index for different species, including the short-finned pilot whales.

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Appendix I - Tables and figures

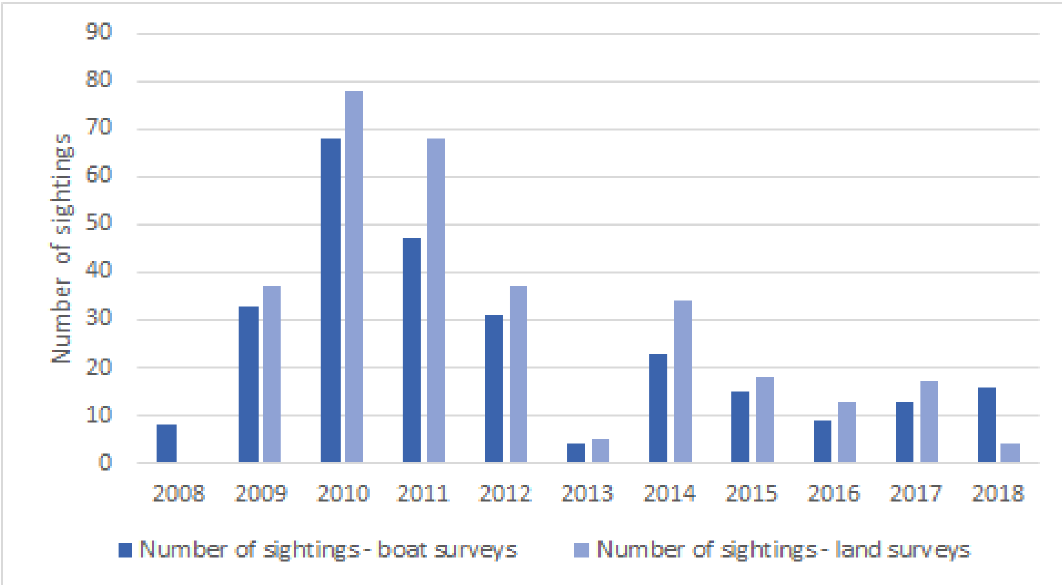


Figure 1. The number of sightings of pilot whales recorded in boat and land surveys for each year between 2008 and 2018

Table 1. Effort shown as number of boat trips per month per year

Month/Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
January	NA	16	4	6	11	5	5	17	10	15	20	47
February	NA	25	7	9	12	12	11	19	25	24	19	76
March	NA	27	25	14	18	8	20	25	34	30	27	112
April	NA	47	29	32	41	15	46	33	39	42	41	210
May	42	44	41	39	30	51	73	39	42	41	59	320
June	48	41	47	45	34	43	71	48	52	56	56	329
July	43	42	59	41	68	56	72	54	68	67	58	381
August	57	55	41	36	65	59	52	54	58	61	63	365
September	24	52	44	19	36	42	35	43	49	53	51	252
October	NA	31	25	28	12	30	20	28	28	42	30	146
November	NA	22	20	13	15	15	10	18	37	7	13	82
December	13	5	5	18	6	8	7	7	9	14	10	44
Total per year	**227**	**407**	**347**	**300**	**348**	**344**	**422**	**385**	**451**	**452**	**447**	**4130**

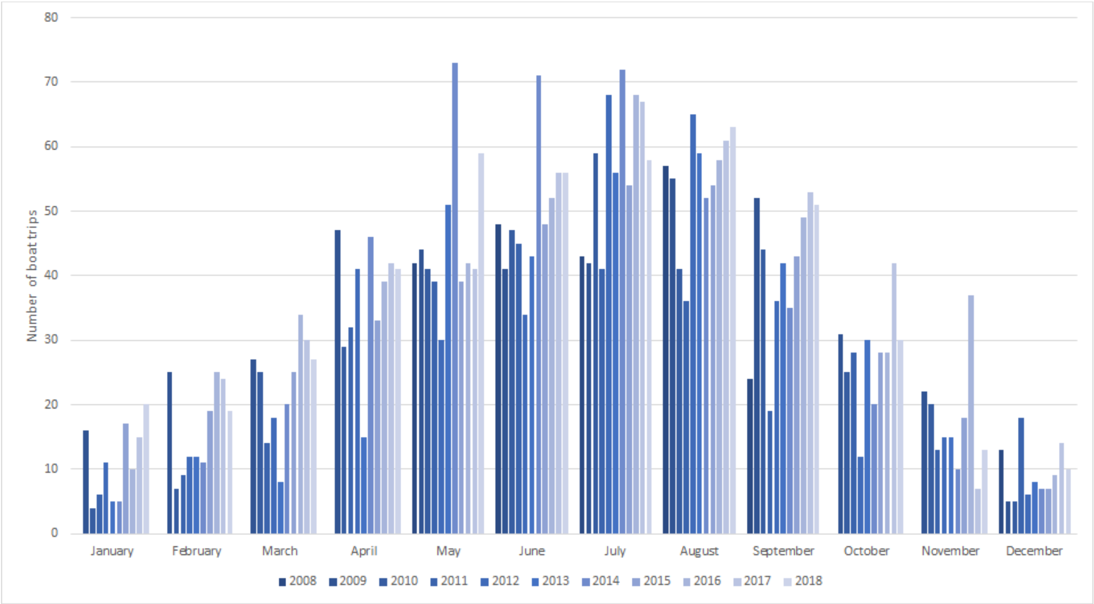


Figure 2. Effort shown as number of boat trips per month per year

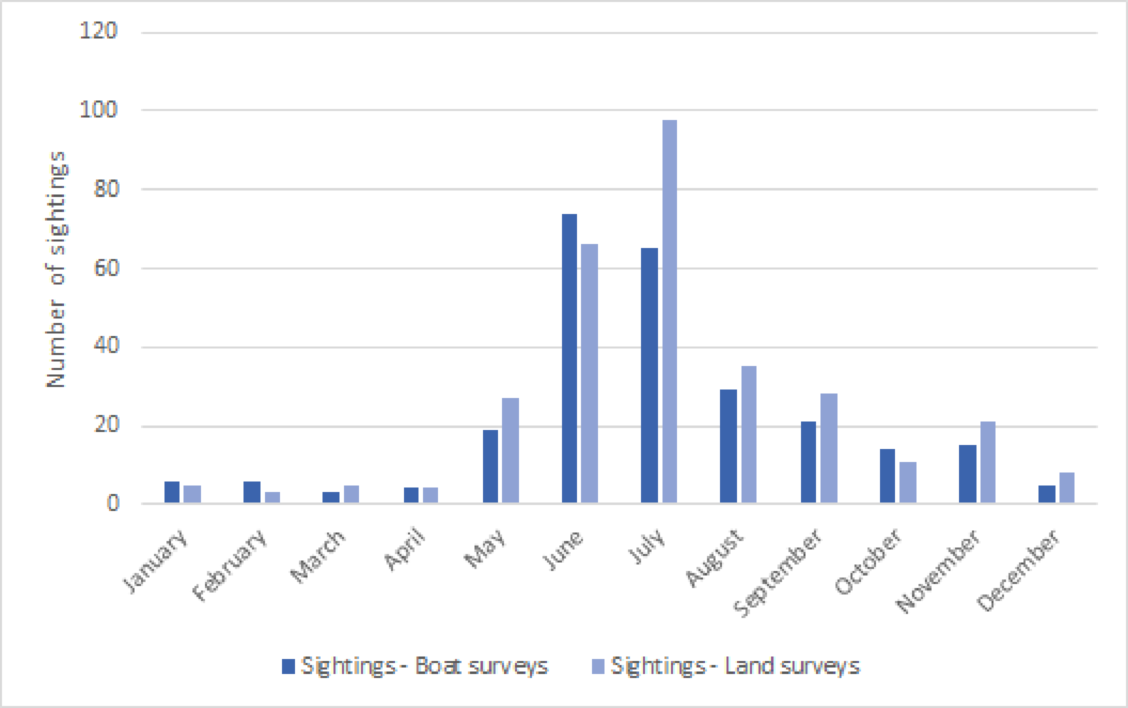


Figure 3. The number of monthly sightings of pilot whales from 2008-2018

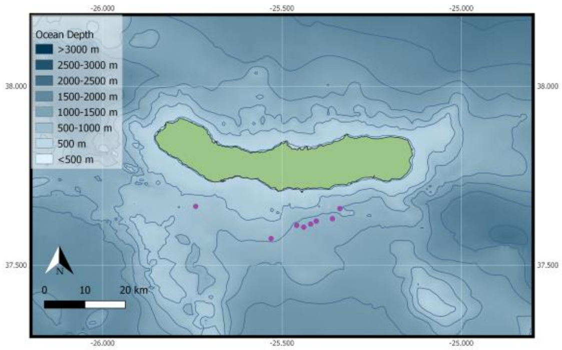
Table 2. Matches. Animals that were seen together during the same days are represented by the same colour

Date/Pilot Whale	PW 001	PW 021	PW 022	PW 023	PW 027	PW 031	PW 035	PW 040	PW 054	PW 057	PW 063	PW 065	PW 067	PW 069	PW 094	PW 096	PW 097	PW 098	PW 099	PW 103	PW 114	PW 131
20060615	X																					
20080606							X							X								
20100710																						
20100904																						
20140517																						
20140519																					X	
20140520																						
20140521																						
20140522																		X				
20140523																						
20140601																		X	X			
20140815																						
20161014		X	X	X	X	X																
20170223											X	X	X									
20170607								X														
20170707								X							X	X	X					
20170822								X							X	X	X					
20171117	X																					
20180619																		X	X			
20180703		X		X	X															X		
20180718		X		X	X	X			X											X		
20180808																					X	
20180901			X																			X
20180906			X																			X
20190515											X	X	X									
20190607										X												
20190627							X							X								
20190820										X												
20190825									X													
20190829														X								
20200124	X																					

Table 2. Matches (continued)

Date/Pilot Whale	PW1 33	PW1 89	PW1 92	PW1 94	PW2 48	PW2 49	PW2 53	PW2 55	PW2 58	PW2 59	PW2 63	PW2 65	PW2 68	PW2 69	PW2 70	PW2 81	PW2 91	PW2 98	PW3 06	PW3 17
20060615																				
20080606																				
20100710		X		X																
20100904		X	X	X																
20140517					X	X														
20140519										X	X	X	X		X				X	X
20140520							X	X	X					X		X				
20140521					X	X	X	X	X		X			X	X	X				
20140522																	X	X		
20140523										X									X	
20140601												X	X				X	X		X
20140815																				
20161014																				
20170223																				
20170607																				
20170707																				
20170822																				
20171117																				
20180619																				
20180703																				
20180718																				
20180808																				
20180901	X																			
20180906	X																			
20190515																				
20190607																				
20190627																				
20190820																				
20190825																				
20190829		X	X																	
20200124																				

Appendix II - Spatial distribution of pilot whales during each year between 2008-2020



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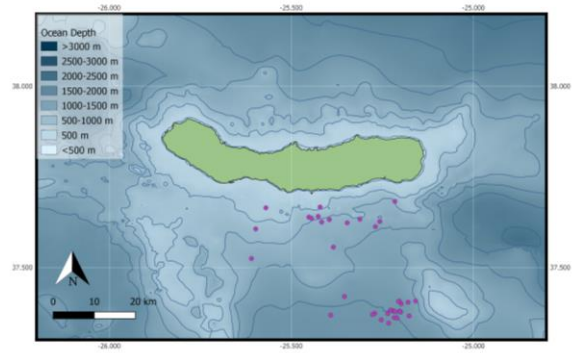

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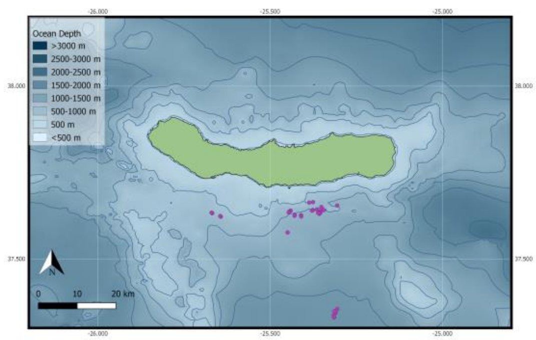

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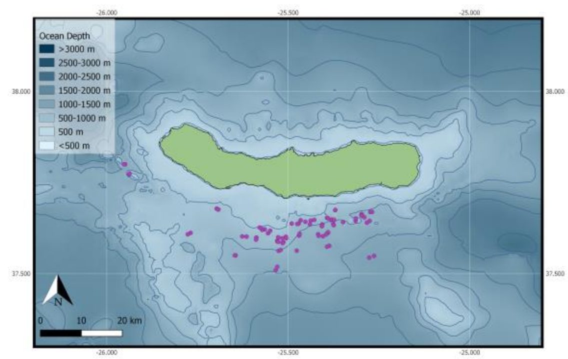
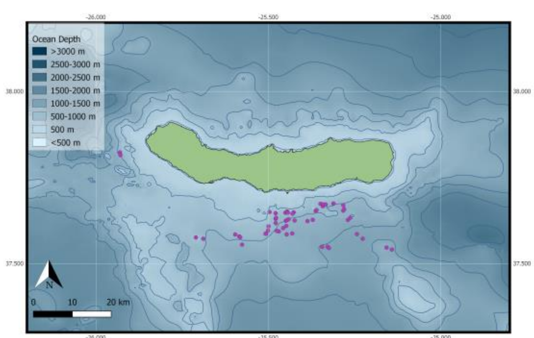
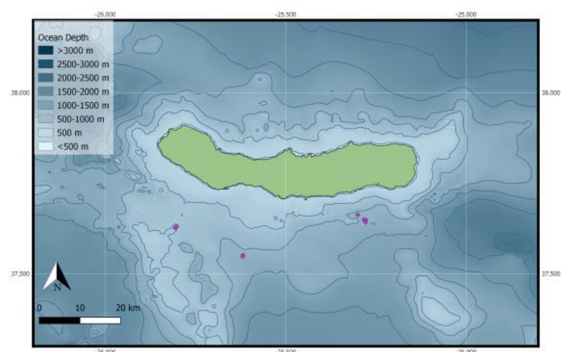


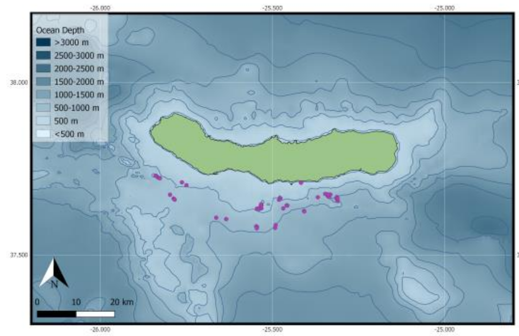
2011



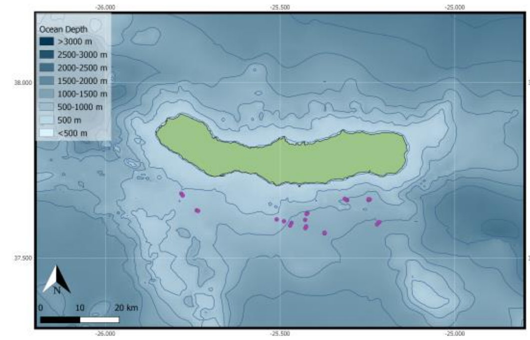
2012



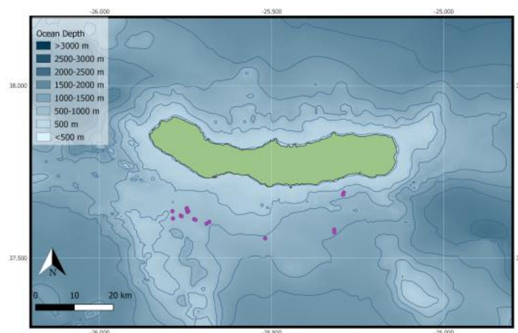
2013



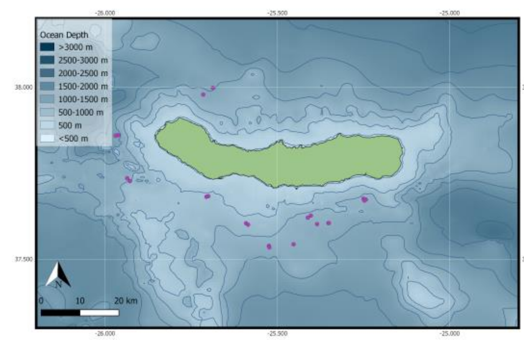
2014



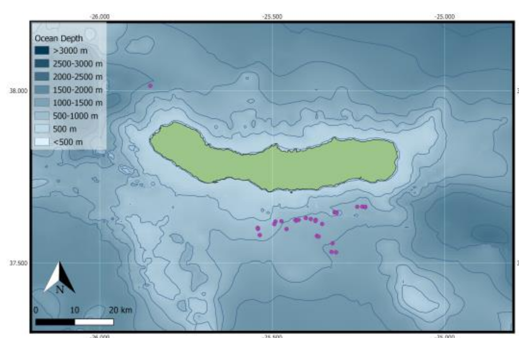
2015



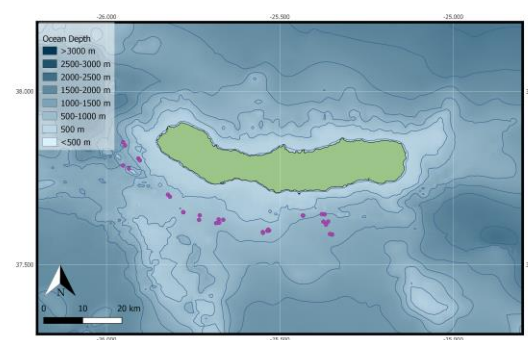
2016



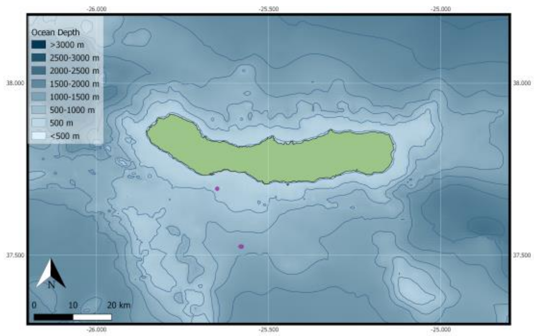
2017



2018



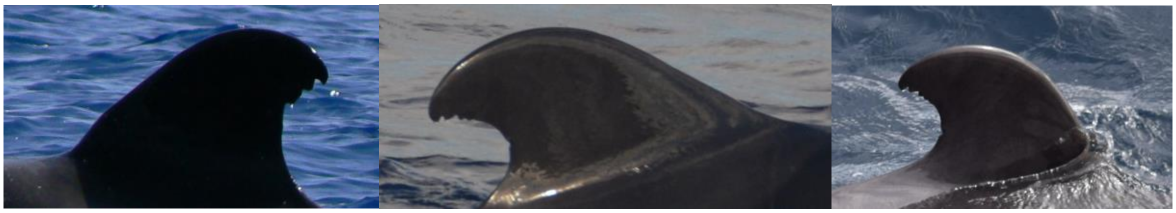
2019


-26.000
-25.500
-25.000
38.000
37.500
Ocean Depth
>3000 m
2500-3000 m
2000-2500 m
1500-2000 m
1000-1500 m
500-1000 m
500 m
<500 m
N
0
10
20 km

2020

Appendix III - Individuals that have been re-sighted during the research period

PW 001- 15/06/2006; 17/11/2017; 24/01/2020



PW021 - 14/10/2016; 03/07/2018; 18/07/2018

PW022 - 14/10/2016; 01/09/2018; 06/09/2018

PW023 - 14/10/2016; 03/07/2018; 18/07/2018

PW027 - 14/10/2016; 03/07/2018; 18/07/2018

PW031 - 14/10/2016; 18/07/2018

PW035 - 06/06/2008; 27/06/2019

PW040 - 07/06/2017; 07/07/2017; 22/08/2017

PW054 - 18/07/2018; 25/08/2019

PW057 - 07/06/2019; 20/08/2019

PW063 - 23/02/2017; 15/05/2019

PW065 - 23/02/2017; 15/05/2019

PW067 - 23/02/2017; 15/05/2019

PW069 - 06/06/2008; 27/06/2019; 29/08/2019

PW094 - 15/08/2014; 07/07/2017; 22/08/2017

PW096 - 07/07/2017; 22/08/2017

PW097 - 07/07/2017; 22/08/2017

PW098 - 22/05/2014; 01/06/2014; 19/06/2018

PW099 - 01/06; 2014; 19/06/2018

PW103 - 03/07/2018; 18/07/2018

PW114 - 19/05/2014; 08/08/2018

PW131 - 01/09/2018; 06/09/2018

PW133 - 01/09/2018; 06/09/2018

PW189 - 10/07/2010; 04/09/2010; 29/08/2019

PW192 - 04/09/2010; 29/08/2019

PW194 - 10/07/2010; 04/09/2010

PW248 - 17/05/2014; 21/05/2014

PW249 - 17/05/2014; 21/05/2014

PW253 - 20/05/2014; 21/05/2014

PW255 - 20/05/2014; 21/05/2014

PW258 - 20/05/2014; 21/05/2014

PW259 - 19/05/2014; 23/05/2014

PW263 - 19/05/2014; 21/05/2014

PW265 - 19/05/2014; 01/06/2014

PW268 - 19/05/2014; 01/06/2014

PW269 - 20/05/2014; 21/05/2014

PW270 - 19/05/2014; 21/05/2014

PW281 - 20/05/2014; 21/05/2014

PW291 - 22/05/2014; 01/06/2014

PW298 - 22/05/2014; 01/06/2014

PW306 19/05/2014; 23/05/2014

PW317 - 19/05/2014; 01/06/2014