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Sei whales (*Balaenoptera borealis*): Photo identification and habitat preferences of a migrant ocean traveller in São Miguel, Azores

UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2021

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Mestrado em Biologia Marinha

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Acknowledgements

I want to thank, firstly, to Futurismo Azores Adventures, that allowed me to do this study and participate and learn on board its boats. I was able to develop an even bigger love for the cetaceans, and was able to learn a lot about them. I want to thank my colleagues from there that supported me and helped on the photo-identification, especially Georgina and Chiara, who already had started the sei whale´s photo-identification. Without them, it wouldn’t be possible to acquire such a deep knowledge and was amazing being surrounded with people with such a big passion for their work.

I also want to thank Dr. Laura González, for all the support, guidance and motivation to do this work, that made this work possible, and all the knowledge shared, learning a lot from her. To Dr. Vânia Baptista, for the availability and the help since the beginning, improving the quality of this thesis.

Finally, a thank you to my friends and boyfriend that stand by my side during all this process, and the emotional support given when I needed, as to my family that always supported, believed in me and encouraged to follow my dreams.

Without all these ones, it wouldn’t be possible to enjoy this experience so much as I experienced. The challenges faced were difficult, but the support of everyone around me, make easier to overcome them.

Abstract

The sei whale (*Balaenoptera borealis*) is a migratory baleen whale that undertakes migrations between breeding grounds in low latitudes to feeding areas in high latitudes. Along its migration path, it was observed passing through Azores. This study uses opportunistic data from a whale watching company located in São Miguel Island, Futurismo Azores Adventures, between 2008 and 2020. The aim of the work is to understand the distribution of sei whales around São Miguel, assessing their movement patterns through photo-identification and their habitat preferences with Generalized Additive Models. As secondary aims, temporal distribution and residence time were assessed. The habitat preferences were studied by performing three models considering (1) all sightings during the study period (2008-2020), (2) sightings from 2008 to 2014, and (3) sightings from 2015 to 2020. Sei whales' sightings were more frequent in spring and summer, with a dominant northwest travelling direction, which agrees with the expected northward migration to the feeding grounds in that season. Along the study period, we suggest they are passing through the Azores later in the season. We could identify eighty-seven individuals with three re-sightings in São Miguel, with short times of permanence (max. registered of one month) in the study area, suggesting predominant travelling behaviour (migrating). Sea surface temperature and gradient were significant variables for the three models considered, although with different influences shown in the smoother graphs. As general choices along the study period, sei whales prefer temperatures lower than 20ºC, low values of temperature gradient (< 0.0005 ºC/km), high values of chlorophyll-*a* (> 0.70 mg/m3) and depth higher than 500m. The model 1 presented a lower AUC (Area Under the Curve) than models 2 and 3, that suggest sei whales prefer different environmental conditions along the time. In this study, we provide a thorough understanding of sei whale occurrence in São Miguel, Azores, essential to support conservation and management plans for this endangered migrant species.

Keywords: sei whale; Azores; photo-identification; habitat preferences.

Resumo

A baleia sardinheira (*Balaenoptera borealis*) é uma espécie de baleia de barbas que migra anualmente entre as áreas de reprodução nas baixas latitudes até às áreas de alimentação nas altas latitudes. Durante a sua migração, estas baleias passam em habitats de latitude média, como é o caso do Arquipélago dos Açores, que é considerado um corredor migratório para diversas espécies de megafauna marinha. A sardinheira é maioritariamente avistada no arquipélago do início da primavera ao final do verão, durante a migração para norte. Os Açores são considerados um hotspot de biodiversidade marinha, contendo 28 espécies de cetáceos, dentro das quais a sardinheira. Isto deve-se à presença de uma variedade de habitats, dada pela topografia do fundo do mar aliada a uma oceanografia dinâmica e o isolamento geográfico.

Para este trabalho, dados oportunistas de uma companhia de avistamento de cetáceos localizada em São Miguel, Futurismo Azores Adventures, foram usados desde 2008 a 2020. Os principais objetivos deste estudo foram: 1) verificar a direção principal de deslocamento das sardinheiras avistadas; 2) atualizar o catálogo de foto-identificação de *Balaenoptera borealis* em São Miguel de 2008 a 2020; e 3) analisar as preferências de habitat em relação a várias variáveis ambientais, como profundidade, declive, temperatura do oceano e dados de altimetria. Secundariamente, pretendemos avaliar a distribuição temporal da sardinheira atendendo às diferentes fases de vida dos indivíduos avistados, e ao tempo de residência das baleias identificadas na área de estudo.

Para ter uma aproximação do esforço realizado, foi calculada uma taxa de encontro como um ratio mensal entre avistamentos e número de viagens. Por cada individuo avistado com um comportamento de deslocação direta, a direção de deslocação foi calculada com base em os oito pontos principais da bússola (norte, nordeste, leste, sudeste, sul, sudoeste, oeste e noroeste). Para comprovar se a direção dominante de deslocação era claramente definida e não aleatória, foi utilizada a simulação de Monte Carlo com 1000 iterações. Os nossos resultados, sugerem uma possível chegada mais tardia das sardinheiras a São Miguel ao longo dos anos, ao longo do período de estudo. Entre a primavera e verão, a principal direção de deslocamento das sardinheiras foi noroeste. Isto suporta a ideia que estas baleias passam pelos Açores em direção às áreas de alimentação, como é o caso do Mar Labrador, na primavera. Contudo, não foi possível observar a sua direção de movimento suficientemente

consistente durante o outono devido ao baixo número de avistamentos, mas esperar-se-ia que fosse sul-sudeste, para as áreas de reprodução.

Para a foto-identificação das baleias sardinheiras avistadas, foram utilizadas apenas fotografias com boa qualidade (focadas e num bom ângulo). A identificação focou-se na forma e marcas da barbatana dorsal (esquerda e direita) e quando possível no resto do corpo também. O catálogo resultante tem associado os registos correspondentes com a informação relativa ao avistamento (localização, número de indivíduos avistados, comportamento, etc.). Para cada indivíduo identificado e reavistado, calculamos o tempo de residência ao redor de São Miguel. Um catálogo de 87 sardinheiras em São Miguel foi criado, apresentando reavistamentos de três indivíduos, com tempos de residência de sete, 11 dias e um mês. O seu baixo tempo de residência, demonstra que estas passam pouco tempo ao redor de São Miguel. Isto apoia a hipótese de que esta espécie está maioritariamente a passar pelas águas de São Miguel e pode estar a utilizar a ilha (e, portanto, o arquipélago) como dica de navegação na sua migração.

Para perceber o efeito das variáveis ambientais estáticas e dinâmicas na distribuição das sardinheiras em São Miguel, ou seja, as suas preferências de habitat, usaram-se Modelos Aditivos Generalizados. Três modelos foram criados: (1) contendo todos os avistamentos obtidos no período de estudo (2008-2020); (2) considerando os avistamentos entre 2008 e 2014; e (3) considerando os avistamentos de 2015 a 2020. Os modelos 2 e 3 foram usados para comparar diferenças na preferência de habitat ao longo do período de estudo. Como variáveis ambientais estáticas, usou-se a profundidade, declive e distância à costa, e como variáveis dinâmicas, a temperatura da superfície do mar, o gradiente de tal, a concentração de clorofila-*a* e "Eddy Kinetic Energy", calculada através dos dados de altimetria, representando fenómenos de mesoescala como remoinhos (eddies) e frentes. Para cada avistamento, foram extraídos os valores semanais de cada uma das variáveis. A escolha de utilizar dados semanais deveu-se ao facto de não poder usar resoluções de tempo mais finas para evitar a falta de dados derivada da elevada quantidade de nuvens, e não se usou uma resolução mais grosseira para melhor captar a dinâmica oceanográfica nesta área.

A análise das preferências de habitat no período de estudo (2008-2020), mostrou a preferência das sardinheiras para temperaturas abaixo de 20 ºC, baixos valores de gradiente de temperatura (< 0.0005 ºC/km), níveis altos de clorofila (> 0.70 mg/m^3) e profundidades

maiores que 500 m. O modelo 1 apresentou um AUC mais baixo que os modelos 2 e 3, sugerindo que esta espécie prefere diferentes condições ambientais ao longo do tempo. Tendo em conta esses dois últimos modelos, a principal diferença foi vista nas variáveis de temperatura à superfície do oceano e o seu gradiente. A temperatura poderá estar relacionada com a clorofila, sendo que as águas mais frias apresentam uma maior produtividade primária. Já no gradiente de temperatura, este está relacionado com a existência de dinamismo oceanográfico, que atuam como mecanismos de agregação de produtividade e, portanto, também dos consumidores.

Neste estudo, proporcionamos um conhecimento aprofundado da ocorrência das sardinheiras em São Miguel, Açores. Este pode ser usado para inferir como a espécie pode reagir a futuras mudanças no ambiente marinho e à pressão antropogénica, portanto, é essencial apoiar planos de conservação para esta espécie migratória ameaçada.

Palavras chave: baleia sardinheira; Açores; foto identificação; preferências de habitat.

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List of abbreviations

AC- Azores Current

AF- Azores Front System

AIC- Akaike Information Criterion

AUC- Area Under the Curve

AVW- Weighted Average method

BRT- Boosted Regression Trees

CGFZ- Charlie-Gibbs Fracture Zone

CMEMS- Copernicus Marine Environment Monitoring Service

EKE- Eddy Kinetic Energy

ENM- Ecological Niche Modelling

ER- Encounter Rate

GAM- Generalized Additive Models

GLM- Generalized Linear Models

GSM- Garver–Siegel Maritorena

IUCN- International Union for Conservation of Nature

IWC- International Whaling Commission

MAR- Mid-Atlantic Ridge

MaxEnt- Maximum Entropy model

NASG- North Atlantic Subtropical Gyre

RF- Random Forests

SDM- Species Distribution Models

SSHA- Sea Surface Height Anomaly

SST- Sea Surface Temperature

VIF- Variance Inflation Factor

1. General Introduction

1.1. Cetaceans

The order Cetacea contains about 90 species of whales, dolphins and porpoises, and it can be divided into two suborders, Mysticeti (baleen whales) and Odontoceti (toothed whales, dolphins and porpoises) (Evans & Raga, 2012; Carwardine, 2020). These animals inhabit, not only in oceans, but also lakes and rivers, with temperatures between 2 and 30 ºC (Ballance, 2002).

Cetaceans are predators that influence the ecosystem structure, function and resilience, by impacting the ecological dynamics of their prey' species, by modifying the nutrient cycle, by top-down and bottom-up effects (Baum & Worm, 2009; Roman et al., 2014). Cetaceans, as apex predators, consume their prey at various trophic levels, from squid and fish to other marine mammals, changing the abundance and community structure of their prey, with cascading effects (Bowen, 1997; Baum & Worm, 2009). In other hand, marine mammals influence the ecosystem by bottom-up control in several ways, as vertical and horizontal mixing, "whale pump" and the sinking of carcasses, changing the nutrient flux/cycling. The whale pump brings the nutrients from deeper waters to the surface, since whales feed at depth and excrete (urea or faecal plume) in the euphotic zone. They provide iron and nitrogenous compounds to phytoplankton, therefore enhancing productivity that in turn benefits higher trophic levels as whales (Bowen, 1997; Roman & McCarthy, 2010). After death, the carcasses of cetaceans sink to the ocean floor, transferring nutrients to the benthic communities on an oligotrophic ocean-floor. Carcasses create organic-rich "islands" at the bottom of the ocean, supporting specialized communities, as hydrothermal vents and cold seeps (Smith, 2006).

Cetaceans are able to reflect the ecosystem variability and degradation (Moore, 2008). They can act as sentinels' animals of the ocean health, alerting for ecosystem disruptions, as chemical pollution and habitat alteration, since they are highly sensitive/vulnerable. They can also act as umbrella species, since they require large areas for foraging and breeding, which promote larger areas to be conserved, sheltering a whole suite of species (Sergio et al., 2008).

Marine mammals by being charismatic megafauna, catch the public attention, that can be valuable for their conservation through public education (Moore, 2008). Since the species have been suffering from fishing overexploitation and anthropogenic ecosystem change, there is an urgent need for conservation. Therefore, research on their physiology, ecology and distribution is necessary (Block et al., 2011).

1.2. How to study cetaceans

1.2.1. Dedicated vs opportunistic data

The distribution of cetaceans is normally difficult to get since they are highly mobile, occupy a wide geographic range and spend most of their life underwater. In order to study these organisms, it is important to perform surveys to collect data, which can be divided in dedicated or opportunistic surveys. Although dedicated surveys have more accurate data on distribution and abundance, due to their complex logistic and the high costs, it is not possible to undertake these surveys on a regular basis or for a long period. Thus, opportunistic surveys offer a more economical way to collect a large amount of data from a particular area, collecting data regularly, often on a daily basis, and involving resource users as fishing vessels, ferries or cargo ships and whale watching boats (Gero & Whitehead, 2006; Alves et al., 2018). This kind of surveys allows to have a broader overview of the cetacean distribution and their biodiversity in a particular area, covering long-term period (Kiszka et al., 2007). This is valuable information specially on the research of monitoring marine populations in remote locations (Goetz et al., 2015).

1.2.2. Photo-identification

Identification in cetaceans can be done by photo-identification, which consists of visual identification of natural marks of each individual (Hammond, 1990; Davies et al., 2001; Carvajal-Gámez et al., 2017). It has the advantage of being cost-effective and non-invasive, overcoming the need to physically capture or tag the organism (Pawley et al., 2018).

This technique has been widely applied on cetaceans, being first used in the 1970s, on humpback whales, by recognition of the pigmentation in the ventral side of the caudal fin (Katona et al., 1979). It has been highly used in well-marked coastal delphinids, as the bottlenose dolphin [*Tursiops truncatus* (Montagu, 1821)], but in poorly-marked species, as the common dolphins (*Delphinus* spp., Linnaeus, 1758), it has been less successful, since it is more difficult to identify the individuals (Pawley et al., 2018). Since image data sets of the species are usually large, photo-identification implies substantial time, effort, and expertise. However, this manual process is susceptible to errors, leading to false positive or false negative, which could be cause by the angle or the quality of the photo (Carvajal-Gámez et al., 2017). Therefore, computer-assisted matching programs have been created, as the Finscan, Highlight method and Europhlukes method (Hillman et al., 2003).

The recognition of the different individuals by photo-identification, allows their long-term monitoring, comparison with photo-identification catalogues of different areas to look for re-sightings, and the determination of temporal changes of distribution in cetacean populations. The photo-identification results, in association with statistics, allows the determination of individual site fidelity, species abundance, social structure and movement patterns (Davies et al., 2001; Carvajal-Gámez et al., 2017).

1.2.3. Species Distribution Model (SDM)

Species Distribution Models (SDM) are used to study the relationship between the species presence and the environment. For instance, between cetaceans and topographic (e.g., depth) and oceanographic (e.g., chlorophyll) variables (Baines & Weirn, 2020). Therefore, by fitting niche models, we can understand which environmental factors influence the species habitat choice and predict potential species distribution on an environmental scale (Pirotta et al., 2011; Prieto et al., 2017). However, the model is influenced by the accessibility of environmental data at appropriate temporal and spatial resolutions (Manocci et al., 2017; Fernández et al., 2018; González García et al., 2018; Peréz-Jorge et al., 2019). Since cetaceans are considered top-predators, one of the main environmental factors affecting their distribution is expected to be the prey distribution. However, due to the lack of data, remotely sensed or *in situ* chlorophyll data is used as proxy for primary production, and therefore a variable influencing prey occurrence. Nevertheless, SDM have disadvantages, as they “only explain a small proportion of the observed variability in animal occurrence” (Pirotta et al., 2011; Peréz-Jorge et al., 2019).

Habitat-modelling studies have been using a variety of models, including machine learning models, as Boosted Regression Trees (BRT), Random Forests (RF) and Maximum Entropy model (MaxEnt); and regression models, as Generalized Additive Models (GAM) and Generalized Linear Models (GLM). The BRT is a combination of predictions from regression tree models, that maximizes the improvement of the performance of the model (Elith et al., 2008). On the other hand, RF is a combination of random tree predictors sampled independently and with the same distribution for all trees in the forest. It has the advantage of not overfitting (Breiman, 2001). Both are strong techniques to study complex ecological relationships, since they can test and fit multiple interactions between predictors and are tolerant to outliers and collinearity (Becker et al., 2020). However, these are considered less accurate than, for example, GAM and GLM, due to the struggle to model smooth functions. This usually leads to uncertainty in their interpretation plus a lower predictive performance (Elith et al., 2008). Other machine learning method is called MaxEnt, which estimates species distribution by presence-only data. It estimates the probability distribution using incomplete data, to find the probability distribution of maximum entropy (with the most dispersed or closest to uniform distribution). Besides only requiring presence-only data, this model present other advantages, as being able to use both continuous and categorical variables and overfitting can be avoided by regularization. However, it presents limitation in use fine temporal scales over a long study period (Phillips et al., 2006).

Among the different SDM existing methodologies, GAM, is a nonparametric extension of the GLM. Both determine the relationship between the dependent variable and a set of explanatory variables (predictors). However, the major difference is that the GAM applies smoothed functions to the predictors, allowing the determination of the shape of the response curve and therefore the additive comparison of the impact of the predictors. GAMs do not assume that the fitting values come from a prior model, in which the available shape of response is limited, as in GLM (Lehman, 1998; Ravindra et al., 2019).

1.3. Sei whale

1.3.1. Morphology and biology

Sei whales (*Balaenoptera borealis* Lesson, 1828) distinguish from the other rorquals specially by their physical characteristics (Figure 1.1). They have a slightly arched rostrum with a single ridge on the top, distinguishing them from the Bryde's whales that have three (Jefferson, 1993; Würsig, 2009). The average size for an adult is around 15 m long, weighting 20 metrics tons, but can reach sizes until 20 m (Würsig, 2009). This species can take dives up to 20 min (Lockyer & Waters, 1986) and produce a blow up to 3 m high (Jefferson, 1993). Their dorsal fin is taller than the one of blue and fin whales, and strongly concave on the edge. Sei whale´s coloration is mainly dark grey, can present some scars and present a white belly. Their baleen plates vary between 219 and 402 on each side, with very thin fringes (Jefferson, 1993; Würsig, 2009).

Figure 1.1- Sei whale (*Balaenoptera borealis* Lesson, 1828) in São Miguel, Azores.

Regarding sei whale reproduction, different lengths or ages have been suggested for females and males reaching the sexual maturity. However, for both sexes maturity age is estimated between 5 and 15 years old (Mizroch et al., 1984). Their mating season lasts around 5 moths during the winter in the North Atlantic, where the peak of conceptions is in December (Mizroch et al., 1984; Würsig, 2009). The gestation period of the females is about 1 year, calving in low latitudes. The calves are born with a length between 4.8 and 5.5 m (Mizroch et al., 1984; Jefferson, 1993). They are normally weaned when they are 6-9 months old (Mizroch et al., 1984).

1.3.2. Migration

Baleen whales are migratory species that undertake seasonal migrations between wintering breeding areas in the tropics and feeding areas in higher latitudes, in the sub poles, during summer (Olsen et al., 2009). The sei whale can be found in shelf areas as in offshore areas, meaning, from continental shelfs to deep waters, being mostly present over slopes and basins situated between banks, in feeding areas (Prieto et al., 2012; Prieto et al., 2014; Houghton et al., 2020). It is divided in two subspecies according to its distribution on the hemispheres, *Balaenoptera borealis borealis* for the northern hemisphere, by Lesson, 1828, and *Balaenoptera borealis schlegellii* for the southern hemisphere by Flower, 1865.

In the North Atlantic, the International Whaling Commission (IWC) defined in 1977 three stocks of sei whales: the Iceland-Denmark Strait stock, the Nova Scotia stock and the Eastern stock (Prieto, 2014). However, there is no sufficient evidence from recent genetic studies supporting its separation (Nieukirk et al., 2020). In the western North Atlantic, sei whales can travel near the United States coast, where they were observed passing through southern New England and Nova Scotia, based on sighting and whaling data, during summer. Travelling to higher latitudes in the Labrador Sea has been reported from data obtained by Fisheries Research Board of Canada, and in Davis Strait and western Greenland reported by whaling boats (Prieto, 2014). In September and October, they return to lower latitudes to breed. Although the knowledge on this autumn migration is scarce (Davis et al., 2020), there is a hypothesis that sei whales coming from Nova Scotia, spend their winter in the Gulf of Mexico (Mead, 1977), but their records on this area have been considered accidental or from stranding events. In the eastern North Atlantic, sei whales travel through the western continental slope of Europe, reaching feeding areas around Iceland and northwest of Scotland, between April and July (Ingebrigtsen, 1929). Regarding the wintering distribution, there are only a few studies that recorded its presence in the South of Portugal (Castro et al., 2013), in Spain (Sanpera & Aguilar, 1992) and Angola (Weir, 2019). Additionally, although with less confidence due to the limited information available, sei whales have been reported in the northwest of Africa (Ingebrigtsen, 1929). There is even evidence of its migration from Madeira archipelago, passing through Canary Islands, in direction to Cape Verde (Jonsgård & Darling, 1977), and from the Azores moving northwest towards Nova Scotia in spring, and southwest towards Madeira archipelago in autumn (Prieto et al., 2014).

Their feeding grounds are located in high latitudes, as the deep waters of the Mid-Atlantic Ridge, the Davis and Denmark Straits, and in southern Greenland (Nieukirk et al., 2020), concentrating in the areas where their preferred prey occurs at higher densities (Peréz-Jorge et al., 2019). In the North Atlantic its preferred prey is the copepod *Calanus finmarchicus* (Gunnerus, 1770), but also the euphausiids, as the northern krill *Meganyctiphanes norvegica* (M. Sars, 1857) and the *Thysanoessa* spp. Brandt, 1851, that aggregate near the surface in dense shoals (Houghton et al., 2020). However, in Iceland, it was observed that sei whales prefer euphaudsiids to copepod and they also feed on fish, for example the sandeel (*Ammodytes tobianus* Linnaeus, 1758), lumpfish (*Cyclopterus lumpus* Linnaeus, 1758) and capelin [*Mallotus villosus* (Müller, 1776)] (Sigurjónsson & Víkingsson, 1997). Also, in the North Pacific, they highly feed on small schooling fishes (Shuntov & Ivanov, 2015). Sei whale techniques to capture prey, are normally engulfing patches of dense prey and skimming on relatively low prey concentrations. This ability to change of feeding techniques is due to their finer baleen fringe, compared to the other rorquals. It also allows to have a varied diet, as seen above (Prieto et al., 2012; Houghton et al., 2020).

During their feeding period, baleen whales store high quantities of energy from the food in the form of fat depots, thus during their migration and in the winter habitats they feed only opportunistically or even harvest, using their energy reserves for their migration and reproduction (Silva et al., 2013).

1.3.3. Habitat

To understand how the oceanographic factors influence sei whale distribution, studies on its habitat preference have been done. This species distribution has been associated with a variety of environmental factors. Skov et al. (2008) study its distribution along the Mid-Atlantic Ridge (MAR). He found that sei whale aggregations were related with small and medium scale processes, as offshore fronts and seamounts, presenting a high habitat suitability in the Faraday Seamounts, in the north-east Atlantic. These oceanographic processes enhanced primary production and therefore secondary production, which in turn attracted and aggregated this species, especially in the upper part of the water column (50-100m) of the Charlie-Gibbs Fracture Zone (CGFZ). This is a feeding zone during May, before the migration to Labrador and to the slopes of Reykjanes Ridge (Skov et al., 2008).

Another study, also in the North Atlantic, applied Generalized Additive Models (GAMs) to study the oceanic drivers of sei whales, considering a full model with all the variables and a simple model with only relief-related variables and sea surface temperature (SST); both over two periods of time: 1987-1989 and 1998-2015 (Houghton et al., 2020). According to them, the strongest predictors of sei whale density are depth, SST (with positive effects when it is 3-11ºC in May), and the Sea Surface Height Anomaly (SSHA), usually negative, related with cyclonic eddies or cold-core rings. This leads to upwelling of nutrients used by the primary producers, and therefore to higher food resources for the predators. The primary production that directly affects the abundance and distribution of zooplankton also influences the whale's distribution. For instance, in west Greenland during June-August, there is a high abundance of krill that overlap with the regions of aggregation of sei whales (Houghton et al., 2020).

1.3.4. Threats and conservation

Sei whale was heavily hunted in the past, between 1950 and 1980, after depletion of other baleen whale species, as fin (*Balaenoptera physalus*) and blue whale *(Balaenoptera musculus)*. The sei whale is classified as an "Endangered species" since 1996, by the United States Endangered species act and IUCN (International Union for Conservation of Nature) (Reilly et al., 2008; Cooke, 2018). Sei whales hunting was first banned in 1975 in the North Pacific by the IWC, but for the North Atlantic, just in 1986. It has been estimated that these whales decreased in abundance at around 20% according to the pre-whaling levels. After that, it is thought that less than 100 kills happened, which occurred from special permissions for scientific whaling, as the Japan presented self-assignment "scientific permit" quotas for the northwest Pacific, or subsistence hunting. In the present days, sei whales are considered endangered throughout their range. However, there are only some estimates of its abundance for restricted areas of the eastern and western North Atlantic, as from the Gulf of Maine to the lower Bay of Fundy (Prieto et al., 2012; Hakamada, 2017; Huijser et al., 2018).

As the other species of baleen whales, sei whale suffers from bycatch, resulting in capture and/or entanglement of fishing gear, which can cause mortality due to the difficulty of foraging when entangled, leading to starvation, plus systemic infections of open wounds or even haemorrhages (Cassoff et al., 2011). The ship strikes can also cause mortality of the whales and are critical when there is overlap between the species range (breeding area, migration routes) and the ship routes (Thomas et al., 2016).

Another relevant threat is the underwater noise, which has increased 2.8 dB per decade from 1966 until 2013, due to shipping and seismic survey, as principal sources of noise below 1 kHz. The vocalization of baleen whales is related with biological processes, as feeding, mating and social interactions. Since their vocalizations are under the same frequency range than shipping, the sound overlaps and masks the species vocalization, consequently affecting the acoustic communication on the whales. It can also have population-level effects, by affecting the growth and survival of individuals due to the behavioural disturbance and physiological stress, since the organisms can start to avoid noisy foraging or breeding areas (Romagosa et al., 2017).

In the last years, with the climate change leading to an increase of water temperature, the distribution of the sei whale´s prey is changing, influencing the whale’s distribution. For example, the Gulf of Maine, an important feeding ground of these baleen whales, is considered one of the fastest warming bodies of water in the world (Pershing et al., 2015). There have been observed shifts of the range of the prey and fish stocks, which may lead to seasonal shifts in the whale’s presence (Davis et al., 2020). In another important feeding ground, the Labrador Sea, it has been predicted an increase of discharge of fresh water by the Artic ice-melt and a warming of the waters of Labrador Sea, which leads to a weakening, or even a shut-down, of deep-water convective mixing (Greene & Pershing, 2000). These changes are likely to influence the planktonic ecosystem and therefore higher trophic levels (Head et al., 2003).

To correctly manage and conserve sei whales from environmental and anthropogenic stresses, it is important to gain knowledge of the ecology and distribution of this migrant species, by studying its abundance, population structure, behaviour, migration timing, routes and habitat requirements (Silva et al, 2019; Romagosa et al., 2020).

1.3.5. State of art

Some of the studies addressing sei whale were done in the south Pacific addressing the vocalization of the species (e.g., Rankin & Barlow, 2007; Español-Jiménez, et al., 2019) and in the Antarctic also focusing on the sounds emitted by it (e.g., McDonald et al., 2005). However, most were done in the North Atlantic, covering feeding ecology, migration or stock identification (Baumgartner & Fratantoni, 2008; Prieto et al., 2012; Davis et al., 2020; Nieukirk et al., 2020). Historical data from the whaling period was widely used to study the species ecology, migration and movement patterns in the North Atlantic (Prieto, 2014). There is a review of sei whales done by Prieto (2014) in the North Atlantic. He suggests a need to understand the role of the species within its ecosystem, plus how changes in the marine environment will influence the species, to properly manage the species and the ecosystem where it lives.

1.4. Azores

1.4.1. Azores characterization

The archipelago of Azores presents a wide range of habitats, given by the seabed topography together with a very dynamic oceanography, the geographic isolation and even the extreme environments associated with hydrothermal vents (Skov et al., 2008; González García et al., 2018). All these features together make the Azores a hotspot of marine biodiversity (Afonso et al., 2020). The oceanographic dynamism of Azores is largely due to its position between the North Atlantic current and the Azores Current / Azores Front System (AC/AF), characterized by strong temperature and salinity across gradients and representing the northern limit of the North Atlantic Subtropical Gyre (NASG) (Pérez et al., 2003; Caldeira & Reis, 2017; González García et al., 2018). The north of the archipelago is largely affected by eddies and meanders from the Gulf Stream, while the south of it (including our study area – São Miguel) is mostly affected by westward propagating of eddies pitching-off and meanders from the Azores Current (Caldeira & Reis, 2017), that can enhance higher biological productivity on these waters. Therefore, Azores provides good conditions for foraging cetaceans and supports a highly diversity of species (Silva et al., 2014; González García et al., 2018), hosting 28 species of cetaceans (Silva et al., 2014).

Whaling started in Azores in the XVIII century, mostly dedicated to the sperm whale (Vieira & Brito, 2009). However, it was replaced by Whale Watching, enacted by the International Whaling Commission in 1986 to protect the whales. Whale Watching has been expanding rapidly and offers, on one side, an increase of demand and supply (economic benefits), and, on the other side, data, and financial support, for cetacean research and citizens education, essential to increase the biodiversity conservation (Pereira, 2008; Silva, 2015). Whale Watching has begun in Azores in 1989, being the main target species the sperm whale (Silva et al., 2003). This Archipelago is considered an ecological important site, from the point of view of cetaceans, since it is possible to observe resident and migratory species (Pereira, 2008).

1.4.2. Sei whales in Azores

Azores is considered an important feeding ground where baleen whales usually stop during their migration (Visser et al., 2011; Silva et al., 2013; Prieto et al., 2014; Romagosa et al., 2017). Acoustic studies indicate a seasonal distribution, with a binomial distribution of acoustic presence in spring and autumn in Azores (Romagosa et al., 2020). Olsen et al. (2009) was the first study to reveal the capability of this species to cross-ocean movements, with not only latitudinal but also wide longitudinal movements, with sei whale starting to follow a strong westerly current in Charlie-Gibbs Fracture Zone (CGFZ), which extends from 30ºW to 38ºW, and ending following a weaker western current with the extent between 50ºW and 53ºW, in direction to Labrador Sea. Yet this was only based on one individual. Along these movements, there is a possible corridor between the Azores and the Labrador Sea (Prieto et al., 2014), with the hypothesis that this feeding ground is not isolated, and it can be linked to other feeding grounds to the east, as the southern of Cape Farewell, in Greenland. This region is characterized by the dominance of the copepod *C. finmarchicus*, which is one of the favourite prey for sei whales during spring and early summer. Thus, leading to the feeding behaviour of sei whales in that area (Sigurjónsson et al., 1991).

Even though one of the reasons for baleen whales to use the waters of Azores is feeding (Visser et al., 2011; Romagosa et al., 2020), in the case of sei whales feeding does not seem the main goal (González Garcia, 2019; Romagosa et al., 2020). According to Prieto et al. (2017), this species does not forage in areas south of 48º, due to the observation of constant speed and orientation, which is indicative of migratory behaviour. Furthermore, Prieto et al. (2017), did not include the primary production variables in their Ecological Niche Modelling (ENM) final results. Thus, these results suggest that sei whale distribution may be related to the variables representing features used as navigation cues to the feeding areas, and therefore, this species can be utilizing the Azores as topography aids in navigation (Prieto et al., 2017). Moreover, there is evidence that sei whales occasionally feed in the Azores, even less frequently than other baleen whales, as noted by González García (2019), who observed sei whales with feeding behaviour, as lunging and swimming on the side with great amounts of water and krill inside their mouth; and registered whale faeces (Ojeda et al., 2019), which is also indicative of feeding. Concluding, the major purpose of the presence of sei whales in Azores is probably related to travelling, more than with feeding.

1.5. Theme justification

Sei whales have been sighted all years in São Miguel, Azores, being one of the targets of the whale watching companies. This can translate the importance of this island in their migration path. The long-term datasets obtained from the whale watching companies, make possible to study sei whales in Azores along the years. Their migration path is not well defined, plus knowledge about their re-sightings, meaning if the individuals passing by are the same or different ones, is scarce.

We expect with this study a better understanding of the distribution, movement patterns and habitat preferences of sei whales around São Miguel, therefore complementing the current information available for the archipelago. The photo-identification catalogue is updated, allowing further steps of comparison with other catalogues from other areas of the archipelago and abroad. Furthermore, it is important to understand the habitat choices for sei whales in order to understand how changes in their ecosystem (e.g., caused by climate change or anthropogenic pressures) could potentially affect the species, and to provide useful information to support appropriate management and conservation plans in the future.

1.6. Objectives

The main aims of this study are:

1. Update the photo-identification catalogue of sei whales (*Balaenoptera borealis*) of São Miguel from 2008 to 2020;
2. Check the main direction of travelling of the sei whales sighted;

3. Analyse habitat preferences of the sei whales in relation to several environmental variables such as depth, slope, ocean temperature and altimetry data.

As secondary aims, we assess sei whale's temporal distribution and residence time of the individuals identified in the study area.

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Sei whales (*Balaenoptera borealis*): Photo identification and habitat preferences of a migrant ocean traveler in São Miguel, Azores

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2.1. Abstract

The sei whale (*Balaenoptera borealis*) is a migratory baleen whale that undertakes migrations between breeding grounds in low latitudes to feeding areas in high latitudes. Along its migration path, it was observed passing through Azores. This study uses opportunistic data from a whale watching company located in São Miguel Island, Futurismo Azores Adventures, between 2008 and 2020. The aim of the work is to understand the distribution of sei whales around São Miguel, assessing their movement patterns through photo-identification and their habitat preferences with Generalized Additive Models. As secondary aims, temporal distribution and residence time were assessed. The habitat preferences were studied by performing three models considering (1) all sightings during the study period (2008-2020), (2) sightings from 2008 to 2014, and (3) sightings from 2015 to 2020. Sei whales' sightings were more frequent in spring and summer, with a dominant northwest travelling direction, which agrees with the expected northward migration to the feeding grounds in that season. Along the study period, we suggest they are passing through the Azores later in the season. We could identify eighty-seven individuals with three re-sightings in São Miguel, with short times of permanence (max. registered of one month) in the study area, suggesting predominant travelling behaviour (migrating). Sea surface temperature and gradient were significant variables for the three models considered, although with different influences shown in the smoother graphs. As general choices along the study period, sei whales prefer temperatures lower than 20ºC, low values of temperature gradient (< 0.0005 ºC/km), high values of chlorophyll-*a* (> 0.70 mg/m3) and depth higher than 500m. The model 1 presented a lower AUC (Area Under the Curve) than models 2 and 3, that suggest sei whales prefer different environmental conditions along the time. In this study, we provide a thorough understanding of sei whale occurrence in São Miguel, Azores, essential to support conservation and management plans for this endangered migrant species.

Keywords: sei whale; Azores; photo-identification; habitat preferences.

2.2. Introduction

Baleen whales are migratory species, that spend the winter in breeding areas in the tropics, migrating to the feeding areas in higher latitudes, where they spend summer (Würsig et al., 2009). The sei whale (*Balaenoptera borealis* Lesson, 1828) is a cosmopolitan species and is distributed in temperate to subpolar waters (Perrin et al., 2009).

Azores Archipelago is believed to be an essential corridor for the baleen whales (Visser et al., 2011; Silva et al., 2013; Prieto et al., 2014; Romagosa et al., 2017). Sei whales were first recorded in Azores in 1989 (Gordon et al., 1990). Most of the sightings in this region were recorded during their northward migration, with records from early spring to late summer (Prieto et al., 2014; Visser et al., 2011; González García, 2019; Romagosa et al., 2020). During autumn, although less frequent, they have also been observed around the Azores, which may be related with their migration back to the breeding grounds (Prieto, 2014; Romagosa et al., 2020).

The individual identification of the sighted whales may be performed with photo-identification. It is a non-invasive and cost-effective technique that permits the identification of sei whales, based on dorsal fin and body marks (Hammond, 1990; Davies et al., 2001; Carvajal-Gámez et al., 2017). This technique permits the study of cetacean's movement, residence time, and connectivity between regions given by re-sightings of the same individual in different areas (Baines & Weir, 2020). Few works on photo-identification have been done about sei whales on the North Atlantic, for example in Falkland Islands, with a catalogue of 99 sei whales identified (Weir et al., 2017), in Angola with 793 individuals identified (Weir, 2019) and in Gulf of Maine, where they identified 60 sei whales (Hammond et al., 1990). In Azores, there is a catalogue 59 sei whales identified until now (Azevedo & Fernandez, 2021).

Sei whale habitat preferences have been studied to address the oceanographic features influencing species distribution. The distribution of sei whales has been associated with small and medium structures, which indicates affinity to cross-seamount and cross-front, given by the current interaction with the bottom topography in the north of CGFZ (Skov et al., 2008). These species have also been associated with steep slopes, for example in Reykjanes Ridge (Skov et al., 2008). According to the temperature, higher densities of sei whales have been documented in areas around 10 ºC, linked to medium and high productivity, in the migration path of sei whales from Azores to higher latitudes (Pérez-Jorge et al., 2019).

The initial knowledge of the ecology, migration and movement patterns of the sei whales in the North Atlantic was mostly from the whaling period (Prieto, 2014). In 1950´s, the whaling industry started to extensively hunt sei whales in the North Atlantic becoming heavily exploited as its abundance decreases (Prieto, 2014; Romagosa et al., 2020). In the last decade, there is an increase of studies focusing or addressing this species in the North Atlantic, regarding satellite telemetry, habitat preferences and acoustics methods (e.g., Houghton et al., 2020; Romagosa et al., 2020). However, the knowledge about sei whales is still incomplete, with gaps regarding its movement patterns, residence and migratory behaviour. Moreover, in the Azores most of the studies were done with data collected mostly in the central group Pico and/or Faial islands (e.g., Olsen et al., 2009; Visser et al., 2011; Prieto, 2014), with less or no information regarding São Miguel.

Therefore, the main aims of this study are: 1) Update the photo-identification catalogue of *Balaenoptera borealis* of São Miguel from 2008 to 2020; 2) Check the main direction of travelling of the sei whales sighted; and 3) Analyse habitat preferences in relation to several environmental variables such as depth, slope, ocean temperature and altimetry data. Secondarily, we aim to assess sei whale’s temporal distribution and the residence time of the individuals identified in the study area. With this thesis, we provide new insights on sei whales habitat use in the Azores, both at individual and at species level, allowing a better understanding of their occurrence in the archipelago and the effects that the environmental variables have on their distribution. This information might be of help to delineate appropriate management plans and potentially foresee how sei whales might react to environmental changes in the future.

2.3. Methods

2.3.1. Study area

The archipelago of Azores is located in the North Atlantic Ocean, more precisely between 37°N and 40°N of latitude and 25°W and 31°W of longitude, at around 1500 km from European continent. It extends about 600 km and is composed of nine volcanic islands, divided in three groups (eastern, central and western). Azores show a wide range of thermal variability. Sea surface temperature (SST) ranges from 17 ºC in winter, and up to 24 ºC in summer. The chlorophyll-*a* present higher values during spring, due to the spring bloom. There is an inverse pattern between SST and chlorophyll-*a*, therefore when the waters are colder, the chlorophyll-*a* concentration is usually higher (Caldeira & Reis, 2017). It also presents a broad variability in the bathymetry, as it presents narrow island shelves, shallow seamounts and steep island slopes. Therefore, the archipelago of Azores presents a wide range of habitats, allowing the sightings of a variety of cetaceans species (Silva et al., 2014).

This study used data collected off São Miguel Island, which is located at 25-26.2˚W and 37.3-38.1˚N. This island has a wide range of depths, from very deep water, reaching 3600 m depth in two oceanic trenches (northwest and southeast of the island), to a shallow platform, on the southwest, extending the offshore line which can lead to retention of water masses (González García et al., 2018).

2.3.2. Field work

Sei whales sighting data and photographs for identification were collected off the south of the coast of São Miguel, Azores, on board the boats of a whale watching company, Futurismo Azores Adventures, with main base port in Ponta Delgada. Data for this study were collected between 2008 and 2020. Every day, if the weather and sea state conditions were good enough, boats went out to the sea in search of cetaceans. Animals were firstly spotted from land, by people called lookouts ("vigias" in Portuguese) located in high strategic points near the coast. They used powerful binoculars (Steiner 20x80mm) to search for the animals. After finding them, they communicated the position of the individuals by radio to the skippers of the boats. This technique is the same used in the Azores to find the sperm whales from land during the whaling times, until 1986. With the given direction, the boats took their course to encounter and approach cetaceans following the current legislation (Decreto Legislativo Regional n˚10/2003/A and DLR13/2004/A), as well as the guidelines of the World Cetacean Alliance for a responsible whale watching (WCA guidelines, 2018). Once with the animals, environmental data was collected, such as visibility and sea state; and also sighting data, including species, date, GPS location, behaviour, number of individuals and association with other species. The behaviour data included travelling, resting, socializing and foraging as the four main behavioural states. Behaviours different than these four were included in this study as "other". The group composition was also recorded, indicating, when possible, the individuals' life stages as adult, juvenile and calf. Besides these data, any other relevant information was noted as comments, and photos with good quality for photo-identification were taken when possible. For sei whales, main photos were of the right and left side of the dorsal fin. For each sighting, initial and ending points were registered. Once on land, the database was updated daily with all the information.

2.3.3. Temporal distribution

Interannual variations on the time of arrival and departure of sei whales around São Miguel were assessed. Timing of occurrence of the different life stages were compared to look for potential differences in the timing of the migration.

To roughly account for the effort carried out, the temporal distribution was assessed based on a monthly Encounter Rate (ER), which is the number of sightings of sei whales each month divided by the number of boat trips that month. In order to avoid pseudo-replication, i.e., double counting the same sighting several times, only one record per sighting was considered (the first location recorded for each sighting). Although not an absolute measure, ER allows us to compare our data within our study period. Encounter Rate varies between 0 and 1, in which 0 is when there were no sightings of sei whales and 1 when they were observed in all the trips.

2.3.4. Travelling direction

Sei whales have been observed passing by the Azores every year. For each sighting, the distance, time, velocity and azimuth (i.e., direction angle) were calculated with Excel based on the information of the location and the time registered for each sighting. However, only the sighting for which the initial and ending point were available and consecutive (i.e., with no other GPS records between them) were used. These four parameters for each sighting were mapped with QGIS. Travelling direction was plotted using arrows, in which the size was proportional to the velocity and the angle to the azimuth (or travelling direction). Main travelling direction was estimated per season/month to check if it agrees with the expected migration route.

Since we aimed to analyse the travelling direction, only sightings in which the whales presented travelling behaviour were used, because in that situation they should be moving in a certain direction instead of searching for food when foraging or in undirected moves as milling.

Direction of all the whales was designated as one of the eight principal compass points (north, northeast, east, southeast, south, southwest, west and northwest). The percentage of whales travelling for each quadrant was calculated, paying attention to the main quadrant for each period compared (month or season). Then, the Montecarlo simulation was applied to test the hypothesis of whales randomly travelling or moving in a defined direction for the selected period. We produced 1000 simulations, and for each one, a random sample of observations of the same size as our "real sample" (which is the real number of sei whale sightings considered) was selected. The percentage of whales moving to the quadrant of the main direction was calculated for this random subset and then compared with our real value.

2.3.5. Photo-identification

On each trip, whenever was possible, photos of the individuals were taken. These new photos were downloaded daily and stored properly for photo-identification purposes, according to date and photographer. A back-up of these raw data was always kept.

To start the photo-identification process, good quality photos were chosen (avoiding blurry, unfocused, wrong angled, etc.). Photos of the dorsal fin were separated in right side and left side. These photos were the main ones used for identification of individuals. However, when there was some difficulty to identify individuals based on the dorsal fin, we looked also at other body parts, as they could help on the identification, for example marks on the body. All photos were cropped in order to have one dorsal fin per image, but also keep the rest of the body when available and deleting excess water or boats on it (Figure 2.1).

Figure 2.1- Example of photo-identification of a sei whale (*Balaenoptera borealis*): individuals with fins with unique shapes and marks.

To process the raw photos, we started selecting the best photos of each individual per day, i.e., the ones in which the shape and marks were more visible and easier to distinguish. Individuals were then compared with the already identified ones in the catalogue to look for re-sightings. If the individual has been already identified in the catalogue, a re-sighting was noted. If not, a new individual was added to the catalogue with the following code: Number-of-individual_Species_YearMonthDay.Side-of-fin_Photographer.Island (e.g., 01Bb_22052019_L_LGG_SM).

The catalogue contains the best photos of each individual (left and right dorsal fin, and any other particular one if needed, when available). A folder was created for each individual named with the corresponding code and containing the best photos of the different resighting dates, in order to keep the track of the evolution of the animal.

Three excel files supported the photo catalogue: an excel with all the data, other with the whale's information and other with the photo source information. The first one contained all the sighting information of sei whales recorded on board. The second contained the information of the individuals identified. One record per individual per day, including all the associated sighting information of that individual (at the beginning of the sighting), plus dates of re-sighting if the animal has been identified on several occasions. Thus, we have the most complete context for each sighting of each individual easily accessible. Lastly, the excel with the photo source helped to track the photo effort we have. Each day with sei whale photos, there was information about how many there were, where they were stored, the photographer, quality of the photos, number of individuals on those sightings and the correspondent individuals identified.

2.3.6. Residence time

For each individual identified, we looked for re-sightings over our study period. The residence time was defined as the minimum time an individual remained in the same area (Baracho-Neto et al., 2012). Therefore, it was calculated for each identified individual looking for re-sightings in consecutive days or frequently sighted within a short period of time (i.e., from a few days to a few weeks), in order to set the minimum period of permanence in our study area.

2.3.7. Habitat preferences

2.3.7.1. Environmental variables

Generalized Additive Models (GAMs) were used to understand the effect of the static and dynamic environmental variables on sei whales' distribution around São Miguel waters. The static variables included depth, slope and distance to shore; and the dynamic variables included SST, SST gradient, chlorophyll-*a* concentration and the Eddy Kinetic Energy (EKE) calculated from altimetry data, which characterizes the mesoscale phenomena as eddies and fronts. These variables were chosen according to the ecological meaning for the sei whale's occurrence, based on cetacean bibliography (e.g., Skov et al., 2008; González García, 2019; Pérez-Jorge et al., 2019; Houghton et al., 2020).

The bathymetry of the study area was obtained from EMODNET (https://emodnet.ec.europa.eu/) and processed with QGIS (version 3.10.10- A Coruña). It was derived from bathymetry surveys (e.g., echosoundings and multibeam surveys) and satellite-derived bathymetry to cover the gaps. It presented a resolution of ¼ of an arc minute. The slope was obtained from the bathymetry layer using the terrain analysis tools of QGIS. The slope in degrees for each sighting point was acquired.

Distance from the shore was calculated also with QGIS, calculating the distance from the sighting point to the nearest point on the coast in kilometres, in which the coastline file was retrieved by the Instituto Hidrográfico de Portugal.

Dynamic environmental variables were selected according to their availability for the entire study area in the entire study period. For the SST, we selected the product Operational SST and Sea Ice Analysis (hereafter referred as OSTIA), which was produced at the Met Office and provided by the Group for High Resolution Sea Surface Temperature. It was obtained from the Copernicus Marine Environment Monitoring Service (CMEMS; marine.copernicus.eu). It produced L4 products (gap-free data), obtained by combining complementary satellite and/or *in situ* observations and using interpolation methods to fill data gaps (Meneghesso et al., 2020). It had a gridded resolution of 0.05x0.05 degrees and a correlation length scale of 1 to 100 km (Donlon et al., 2012). It had a variety of temporal resolution available, as daily, weekly, and monthly. The daily data was extracted. It included data from microwave and infrared satellite instruments, both with a high spatial resolution, but also from in-situ data from drifting buoys. *In situ* data is important to adjust the bias error associated with satellite retrieval algorithms, since infrared satellite is highly impacted by cloud and aerosol contamination and the microwaves satellites by precipitation and land contamination (Donlon et al., 2012). The use of these two types of data, satellite and *in situ* data, allows to create a daily, globally and model-free analyses of the foundation SST, meaning the SST free from the diurnal variations (Good et al., 2020). Furthermore, SST gradient was calculated as by the difference of SST between grid points in latitudinal and longitudinal direction.

On the other hand, the chlorophyll-*a*, considered a proxy of primary production, was extracted from GlobColor (http://globcolour.info) as L3 products, with a spatial gridded resolution of 4km and a daily resolution. We chose to use merged satellite products, which included Meris, Modis, VIIRS or/and SeaWiFS, according to the study time period. Merged satellite data joined data from multiple sensors, forming a unified ocean colour time series. The individual ocean colour missions normally present gaps caused, for example, by the clouds or sensor error. Thus, the merging of the sensors increases the coverage by the association of patchy daily coverage of each sensor, creating a better global daily coverage of the world's oceans on shorter time scales. It also presents improved data products with lower uncertainties (Maritorena & Siegel, 2005; Maritorena et al., 2010).

Determination of chlorophyll from the satellites' data, is done with semi-analytical algorithms to retrieve the values. These algorithms involved optimization of the bio-optical parameters (as chlorophyll-*a* concentration) in an approximate solution of the radiative transfer equation to match the modelled reflectance with the reflectance assessed by the satellite (Clay et al., 2019). There are two methods available, the GSM (Garver–Siegel Maritorena) and the AVW (Weighted Average method). For our study, both methods provided similar % of blank values, therefore, based on the literature, GSM model was chosen. It has a higher accuracy because it decouples the contribution of the optically active components (e.g., phytoplankton, non-algal particles and coloured dissolved organic carbon), therefore decoding the phytoplankton signal from yellow substances (Clay et al., 2019), which is of particular importance in oceanic waters like the ones of our study area.

To study the sub mesoscale and mesoscale dynamic phenomena, as fronts and eddies, the Eddy Kinetic Energy was calculated from altimetry data. The altimetry data was extracted from two products downloaded from Copernicus Marine Environment Monitoring Service (CMEMS; marine.copernicus.eu), one with data from 2008 to 2019 and the other with data of 2020, since there was no product covering the entire study period. Both products were L4 products, with a horizontal spatial resolution of 1/12º (~8km) and 50 vertical levels. Both products were based on ocean models with data assimilation. Horizontal and vertical components of the geostrophic velocity anomalies [3D dynamic variables (U, V): Eastward Ocean current velocity and Northward Ocean current velocity] were obtained as Delayed Time from all satellites in both products.

The first product, called "GLOBAL_REANALYSIS_PHY_001_030" – GLORYS12V1 (Global Ocean Reanalysis and Simulation; Drévillon et al., 2008) – was a global ocean eddy-resolving reanalysis. This reanalysis used the 'Nucleus for European Modelling of the Ocean' ocean model, and the data assimilation was acquired from AVISO using a reduced-order Kalman filter, with a 3D-Var scheme for bias correction of temperature and salinity. The second product, called "GLOBAL_ANALYSIS_FORECAST_PHY_001_024", was provided by The Operational Mercator Global Ocean Aanalysis and Forecast System. It aims to provide analyses and forecasts of the physical state of the ocean from surface to bottom (Drévillon et al., 2008).

From both altimetry data products, Eddy Kinetic Energy (EKE) was derived by the following formula: $½[(u-u_{mean})^2+(v-v_{mean})^2]$, in which the u_{mean} and v_{mean} represents the temporal means of each velocity parameter over each year of the study period (González García et al., 2018). The yearly average was chosen to remove the interannual velocity fluctuations in the calculations of the EKE, since the location and intensity of the branches of the North Atlantic Current and the Azores Current were reported to have interannual variability (Penduff et al., 2004).

Dynamic variables were extracted for each sighting location with R (version 4.0.5). We used the environmental daily data to calculate the seven days average, by averaging the variable value of the day of the sighting and the three days before and after it (± 3 days from the sighting date). The choice of using weekly data was to reduce the contamination of clouds from finer time resolutions, since it is a region normally cloudy leading to data loss and probably to a lower accuracy of the model. We did not choose coarser resolutions, as monthly, because Azores is a highly dynamic area, and we aimed to capture short-time variability of the oceanographic (habitat) conditions and the short-term -and or smaller-oceanographic events. We finally obtained a dataset with depth, slope, distance to the coast, SST, SST gradient, chlorophyll-*a* concentration and yearly EKE for each sighting.

2.3.7.2. Generalized additive models (GAM)

To study the habitat preferences, Generalized Additive Models (GAMs) were fitted in R studio (version 4.0.5) using gam function from the mgcv package (Wood, 2011). This package offers the ability to produce generalized additive modelling functions using penalized regression splines to estimate the smoothed parameters (Wood, 2006). A binomial distribution (presence/absence) was used with a logit link function. Sei whale sightings were used as presence data. Since we did not have data on real absences, those were obtained as pseudo-absences, using the presence of other cetaceans recorded under the same sampling effort, period and area, therefore, sharing the same bias (e.g., Esteban et al., 2013; González García et al., 2018). This option has shown a better performance than presence only or random pseudo-absences (Elith & Leatherwick, 2007; Phillips et al., 2009). Three different models were applied: (1) considering all sightings obtained during the study period (2008-2020); (2) considering sightings from 2008 to 2014; (3) considering sightings from 2015 to 2020. Models 2 and 3 were carried on in order to compare our results with a previous study done with the same dataset (González García, 2019), in order to compare differences along the study period and in the use of variables.

The explanatory variables to include in the full model were tested for correlation. According to Pearson correlation, we aimed to exclude the variables with a correlation equal or higher than 0.8 (López-Baucells et al., 2017; González García et al., 2018). We also checked for correlation based on the VIF (Variance Inflation Factor), aiming to exclude the variables with values higher than 5, which indicate multi-collinearity (González García et al., 2018; Lezama-Ochoa et al., 2020). None of the variables were considered highly correlated.

To obtain the best-fitted model, we followed a backward selection process, starting with a full model with all the variables and excluding the less significative one each time, according to its higher p-value. In the final model, only variables with a p-value lower than 0.01 were retained. According to the goodness of fit, if the removal of the variable provided a lower AIC (Akaike Information Criterion) the last model was retained. This process stopped when the removal of the variables did not lower the AIC value plus all variables were considered significant.

In our model, we set the following parameters: gamma= 1.4 to handle better with overdispersion of the data, and k (number of knots or splines)= 4, to prevent the overfitting of the model (Wood, 2006).

A temporal k-fold cross-validation was applied using as sampling period a year. From all the years of our data (13 years), all years except one were used for model training; and the remaining year was used for model validation. The model was trained and repeated until it tests all folds. Then, the pROC (Receiving Operating Characteristic Plot) package in R was used, since it allows to compute the performance of the predictions, by analysing the area under the curve (AUC) (Drévillon et al., 2008). The AUC for each model was obtained for each fold (year) to compare its performance each year. The average AUC and its standard deviation were obtained, which indicates the model performance. An AUC higher than 0.5 indicated that the model performs better than a random selection, an AUC of 1 indicated perfect agreement on the validation.

2.4. Results

2.4.1. Temporal distribution

Between 2008 and 2020, in São Miguel, sei whales were sighted every year, with 313 sightings, in which 42 of the records were register in 2010 and only eight in 2009, and 169 of them presented travelling behaviour.

It is possible to observe that all the sei whales’ sightings in the study period were mostly registered in spring and summer, from April to July, with 78.22% of the sightings (12.41% in April, 23.00% in May, 28.12% in June and 14.70% in July). Most of the sightings with calves were during spring and summer. The last sighting of each year corresponded usually to single adults. The period with highest concentration of sei whales’ sightings each year seem to delay slightly for later in the season (Figure 2.2). The year 2020 was kept out from the study of temporal distribution due to the pandemic, which made the trips impossible to occur between mid-March and end of June.

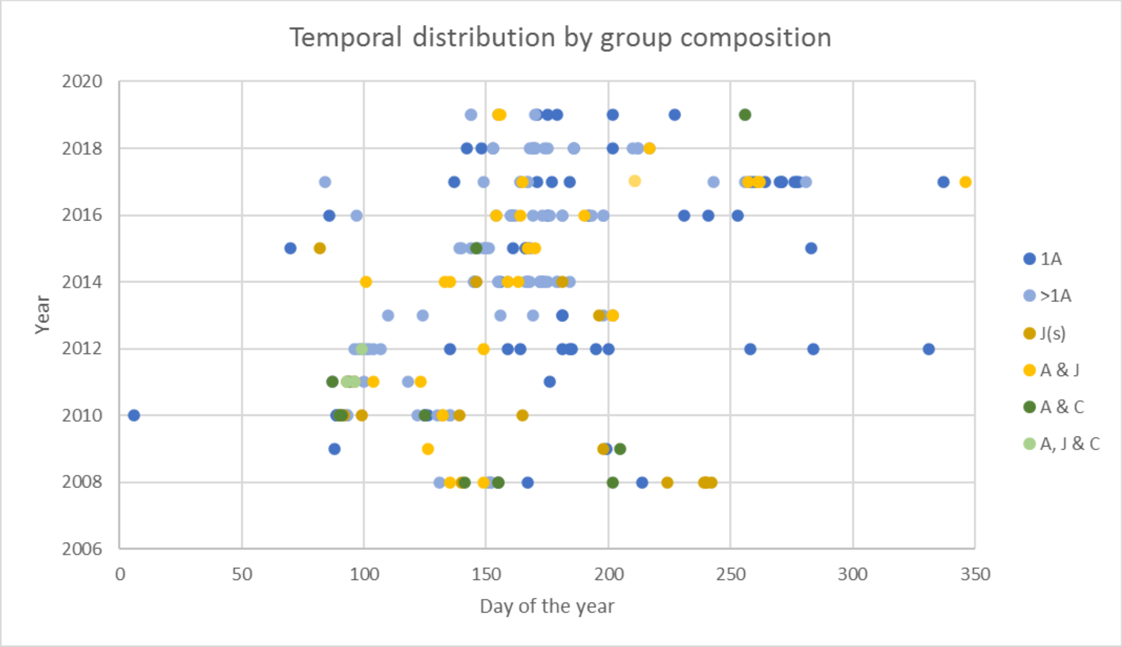

Figure 2.2- Temporal distribution of the sei whales (*Balaenoptera borealis*) between 2008 and 2020, in São Miguel, Azores, divided by group composition: 1A- one adult; >1A- more than one adult; J(s)- juvenile(es); A & J- Adult(s) and juvenile(es); A & C- Adult(s) and calve(s); A, J & C- Adult(s), juvenile(es)and calve(s).

Monthly Encounter Rates (ER) ranged from 0 to 0.75, with the highest values usually registered in May-June (mean of 0.13, range from 0 to 0.43). However, there are three peaks in April that stand out, in 2010, 2011 and 2012 and another one around July in 2020 (Figure 2.3). The mean monthly ER value was 0.09 sightings per trip, in which the highest was of 0.75, in July of 2020, with 15 sighted sei whales' sightings recorded.

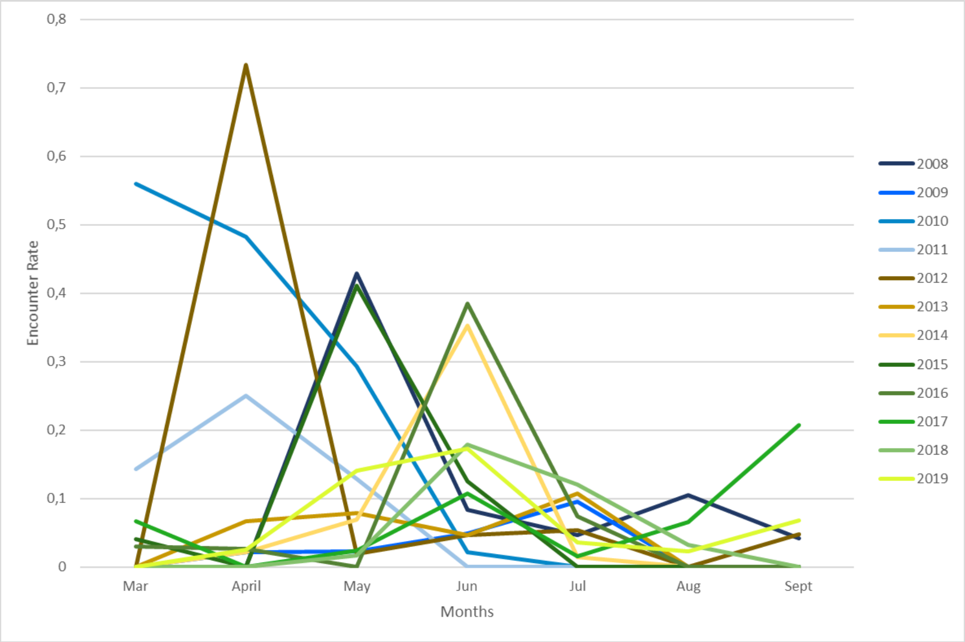

Figure 2.3- Monthly Encounter Rate of sei whales (*Balaenoptera borealis*), from March to September, between 2008 and 2020, in São Miguel, Azores.

2.4.2. Travelling direction

A northwest tendency was observed for all the sei whales' sightings registered in spring and summer, from March to July. In August and September, the travelling direction changed with no clear main direction but more directed southward (Figure 2.4; Appendix I). From October to February, there were not enough sightings to study this parameter. The mean travelling direction obtained for the sei whale sightings recorded between March and July was of 315º (NW), accounting the fourth quadrant (270-360º) for 71,88% of the sightings recorded in that period (n = 128 sightings) (Figure 2.5). The Montecarlo simulation was applied to the sei whales recorded within the same time period with 1000 iterations, obtaining a probability lower than 1/1000 of a random sample of n = 128 (equal to the number of sei whale sightings recorded) moving in the fourth quadrant, meaning that the real direction registered for the sei whales was not random.

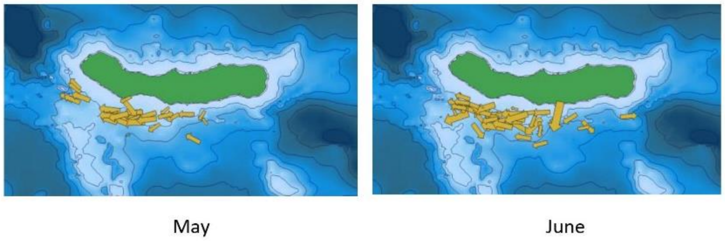

Figure 2.4- Example of travelling direction of all sei whales (*Balaenoptera borealis*) sighted between 2008 and 2020, in São Miguel, Azores, during May and June, in which the size of the arrow corresponds to the velocity of the individual.

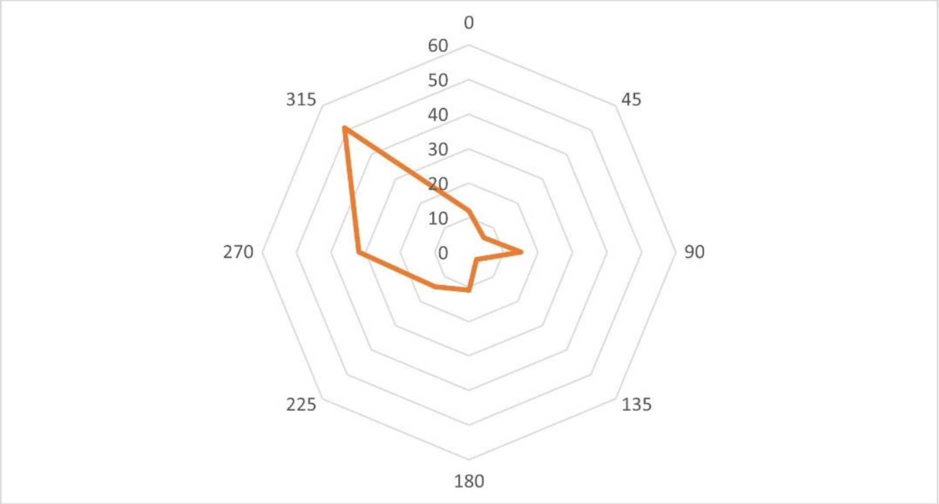

Figure 2.5- Travelling direction of all sei whales (*Balaenoptera borealis*) sighted during spring and summer, from march to July, between 2008 to 2020, in São Miguel, Azores.

2.4.3. Photo-id

From 2592 photos available between–2008 and 2020, 2126 photos had sufficient quality for photo-identification. Eighty-seven individuals of sei whales were identified in the waters around São Miguel. It was not possible to identify individuals in the year of 2009 and from 2011 to 2014, mostly due to the not enough quality of the photos available. In 2008, we only identified three, but in 2019, 25 individuals were identified. Most of the whales identified during the study period (47.13%) were seen during spring, 43.68% in summer, 9.20% during autumn and none in winter (Figure 2.6).

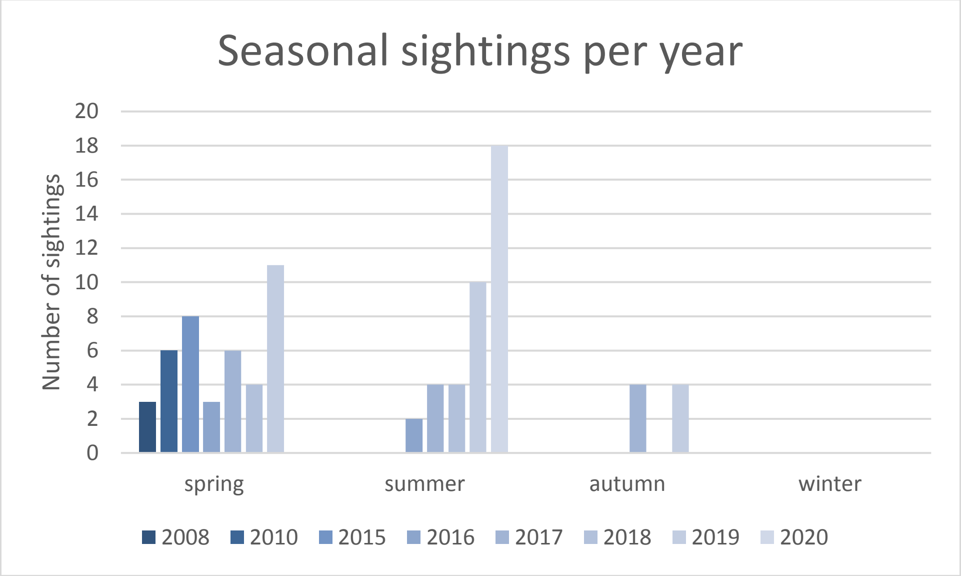

Figure 2.6- Number of sei whales (*Balaenoptera borealis*) identified per season and year, between 2008 and 2020, in São Miguel, Azores.

Most of the photo-identified sei whales (89.66%) only have photos of one side of the fin: 47 have just the left side and 31 the right side. Only nine individuals (10.34%) have both, the left and right side.

2.4.4. Residence time

The majority of the identified sei whales (96.55%) were not photographically recaptured. Only three individuals presented re-sightings, all within the same year, without any resightings between years. The individual number 69, first sighted on 17th of October 2019, was observed three times after that date, on 20th of October, 22nd of October and 17th of November 2019, indicating a residence time around São Miguel of at least one month. In the year 2020, other two individuals were sighted more than once. The individual number 81, who was first sighted on 24th of July 2020 and observed four times after that date, on 29th of July, 2sd of August, 3rd of August and 4th of August 2020, with a residence time of at least 11 days. The other individual (number 82) presented a residence time of at least seven days, being first sighted on 24th of July 2020, and then on 28th and 31st of July 2020.

2.4.5. Habitat preferences

The best model containing sightings of all years presented the lowest deviance (7.68), and the lowest (although reasonably good) AUC (0,65). It retained SST, chlorophyll-*a*, depth, slope and SST gradient variables, showing an increased habitat suitability when SST is lower than 20 ºC, SST gradient lower than 0.0005 ºC/km, chlorophyll-a higher than 0.70 mg/m^3 and when the depth is higher than 500 m (Appendix II).

Comparing first and second part of the study period yielded similar statistic performance (deviance of 16% and 13,3%, and AUC of 0,7 and 0,72 respectively), but different results regarding variable selection (Table 1). Both models retained the SST and SST gradient, however, smoothers obtained were quite different among them (Figure 2.7). Before 2014, sei whales showed a preference for colder areas, less than 20 ºC; but in the model after 2014, habitat suitability is higher between 18 and 20 ºC, with temperatures lower than 18 ºC not being favoured. According to the SST gradient, on the first model, although with wider confidence intervals, suitable values were lower than 0.00014 ºC/km with a slightly higher preference for gradients around 0.0001 ºC/km. The model after 2014 favoured values lower than 0.00005 ºC/km. Regarding the other variables, the model before 2014 retained chlorophyll-*a*, representing more suitable habitats where levels of chlorophyll-*a* were higher than 0,05 mg/m^3 with higher preference for values around 1.5 mg/m^3, and depth, preferring depths between 500 and 1500 m (Figure 2.8). The model after 2014 did not retained chlorophyll-*a* nor depth, but distance to coast was considered significant, where waters between 8 and 25 km from the coast seemed more suitable for sei whales (Figure 2.9).

Table 1- Results of the three GAMs for sei whale (*Balaenoptera borealis*) occurrence in São Miguel, Azores: model 1 including all sightings of the study period (2008-2020), model 2 with the sightings from 2008 to 2014 and model 3 with the sightings from 2015 to 2020. AUC: Area under the curve; sd: standard deviation; SST: sea surface temperature; Chl-a: chlorophyll-a.

Models	**Significant Variables**	**Deviance Explained (%)**	**AUC (Mean ± SD)**
1) Sightings 2008-2020	SST, Chl-*a*, depth, slope, SST grad	7.68	0.65 ± 0.09
2) Sightings 2008-2014	SST, SST grad, Chl-*a*, depth	16	0.70 ± 0.14
3) Sightings 2015-2020	SST, SST grad, distance to coast	13.3	0.72 ± 0.14

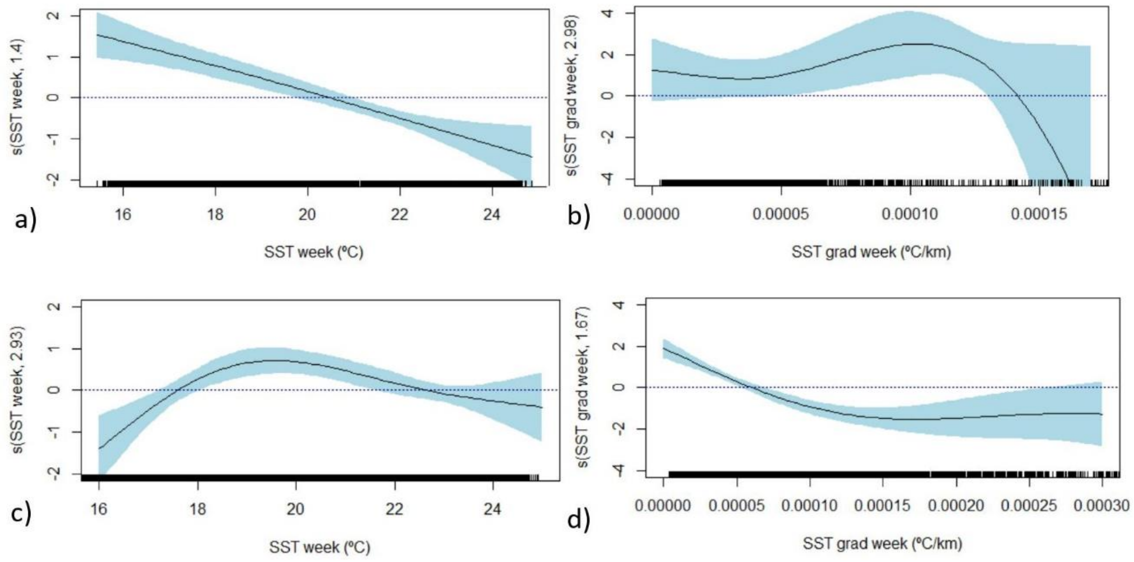

Figure 2.7- Smoothers of the SST and SST gradient variable in the GAM (Generalized Additive Models) of sei whale (*Balaenoptera borealis*) occurrence, in São Miguel, Azores, for the model 2 -2008-2014- (2.8.a and c) and model 3 -2015-2020- (2.8.b and d). Tick marks in the x-axis indicate the distribution of the observations (both with presences and absences). Shaded areas represent 95% of CI (confidence interval). The degrees of freedom are presented in parenthesis on the y-axis.

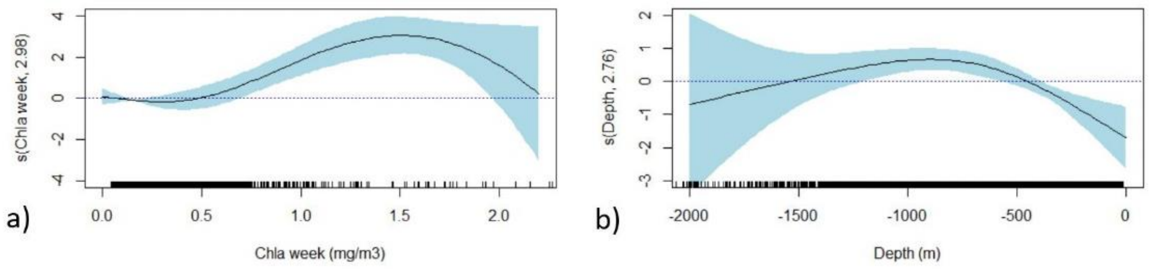

Figure 2.8- Smoothers of the Chlorophyll-a (a) and depth (b) in the GAM (Generalized Additive Models) model 2 (2008-2014) for sei whale (*Balaenoptera borealis*) occurrence, in São Miguel, Azores. Tick marks in the x-axis indicate the distribution of the observations (both with presences and absences). Shaded areas represent 95% of CI (confidence interval). The degrees of freedom are presented in parenthesis on the y-axis.

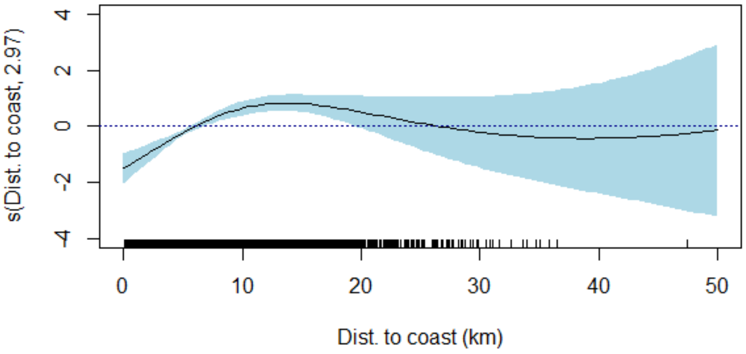

Figure 2.9 - Smoother of distance to coast in the GAM (Generalized Additive Models) model 3 (2014-2020) for sei whale (*Balaenoptera borealis*) occurrence, in São Miguel, Azores. Tick marks in the x-axis indicate the distribution of the observations (both with presences and absences). Shaded areas represent 95% of CI (confidence interval). The degrees of freedom are presented in parenthesis on the y-axis.

2.5. Discussion

This study offers new insights about the distribution, movement patterns and habitat preferences of a migratory species, sei whale (*Balaenoptera borealis*), in São Miguel, Azores, over the course of the last 13 years (2008-2020).

We must keep in mind that it is based on opportunistic data, with both disadvantages and advantages. For instance, the collection of data depends on the number whale watching trips run, influenced by the environmental conditions (visibility to detect the cetaceans from land and sea state) and presence of tourists. However, as a regular basis, trips' time schedule and duration, as well as data collection methods, were maintained or minimally changed over the study period. The species behaviour, as their swimming velocity and time spent at the surface, affects the probability of sighting the individuals, and therefore, sightings with more elusive behaviour or less chances of observation (such as beaked whales) are less favoured because of commercial reasons. Generally, the lack of absolute effort supposes a limitation, but in this case, we minimized it calculating an encounter rate to allow comparisons within the study period, and using as pseudo-absences the sightings of the non-target species in the models. Nonetheless, opportunistic data, particularly in this case, present important advantages, since they offer a long-term database year-round and collects scientific data on a daily basis with regular and intense spatial cover (Gero & Whitehead, 2006; Alves et al., 2018; González García et al., 2018).

2.5.1. Temporal distribution

Most of the sightings in Azores were in spring and summer, with rare records in autumn, as also observed by Silva et al. (2014). Along the years, it seemed that the sei whales were passing through Azores later in the season, which could be related to the track of resources or climate change, linked to changes in the distribution of the preys in high latitudes, as the feeding grounds. With the increase of the temperature, and therefore the reduction of the sea-ice coverage, the spring blooms have appeared earlier and longer in some of the expected feeding grounds, such as in Disko Bay (Laidre & Heide-Jørgensen,2012). Plus, in the feeding ground of Gulf of Maine, the range of the prey and fish stocks have been changing, which may lead to seasonal shifts in the whale's presence (Davis et al., 2020).

Our results point out that groups with calves are sighted off São Miguel earlier in the year, particularly before 2011. In contrast, Mizroch & Breiwick (1984) said that the migration to the feeding grounds is first taken by pregnant females, then by the other adults and lastly by the immatures. Besides, there were no records of calves during autumn, which can be related to the fact that females reproduce in the low latitudes during winter and then move north with their calves, that are dependent of them, passing through Azores in spring. Then, when returning to breeding areas in the south, the calves may be more independent of the mother and swim apart from her, since the wean is up to six to eight months (Norris, 1966). The number of individuals noted per sighting were usually the ones observed, meaning that other whale that could be some distance apart (e.g., enough to us to don't see it, but enough for them to be in touch and belong to the same group) might not be considered. This leads to potentially be mistaken with a juvenile, since biologists onboard registering data might not distinguish sizes accurately, especially if they are not together (and therefore not comparable between them). Besides, the life stage is not always possible to be register onboard.

2.5.2. Travelling direction

Sei whales are migrant species, taking seasonal migration between breeding areas in the tropics, during the winter, and feeding areas in the sub poles, during summer. Our results clearly showed a main travelling direction of this species during spring, supporting the idea that at least some sei whales pass through Azores in direction to northwest, to their feeding grounds such as the Labrador Sea, as observed in telemetry studies by Olsen et al. (2009). Unfortunately, we could not verify a defined direction on its autumn migration since there were few sightings in São Miguel in that season. However, expectations are to be directed south-southeast, to their breeding areas whose location is still uncertain, and as suggested by the only sei whale tagged in the Azores in autumn, who showed a southeast direction to Madeira before the tag was lost (Prieto et al., 2014).

2.5.3. Photo-id

From 2008 to 2020, in São Miguel, 87 sei whales were identified from the 313 sightings registered. This could be related to the difficulty on the field of taking good photos valid for photo-identification. This is a species which usually moves fast, often sighted with an erratic diving behaviour where expectations about surfacing location are not accurate, and thus, not easily capture by the cameras. Additionally, quality of photos might be hampered also due to bad sea conditions (Boyd et al., 2010). Analysing the photos for identification of the individuals, has also some challenges. For example, this species can be confused and misidentified with the fin whale or Bryde´s whale (Steiner et al., 2008), which both can be sighted in the study area. However, misidentification has been drastically minimized over the years with qualified and experienced observers (staff) onboard, better quality cameras and photos good enough at least to confirm the species, focusing on unique characteristics such as 1 ridge on the head instead of three like Bryde’s whale, or grey right lower jaw instead of white as fin whales. Furthermore, doubtful identifications were not considered for the analyses. The availability and quality of the photos and the marks of the individuals have a great influence on the identification process. In the first years, there were less individuals identified, without any whales identified in the year of 2009 and between 2011 and 2014, due to the bad quality of the photos. Most of them are blurred, in a bad angle or with the reflectance of the sun. In the last years, specially 2019 and 2020, there were cameras with better quality and more photographers on board, thus allowing identification of a higher number of individuals (48.27% in 2019 and 2020). Some individuals were easy to identify due to clear marks (e.g., Bb11) or rare shapes (e.g., Bb20), while other have a similar fin and body shape and required more attention to details, sometimes not only of the dorsal fin, but also from other parts of the body to be correctly identified (e.g., Bb07 & Bb57). Also, left and right sides of the dorsal fin of the same individual were only matched when they were clearly the same, and they were considered as different individuals when there were no marks or if in doubt.

Our results, compared with catalogues obtained from the whaling data, presented a low number of individuals identified, as is the case of the IWC database of vessels in the Angolan exclusive economic zone waters, in which 793 sei whales were identified between 1971 and 1975. On the other hand, for a similar study period, our results have more individuals identified (87) just in one island (São Miguel) and by one company (Futurismo Azores Adventures) than the MONICET platform, which collects sighting data from whale watching companies since 2009 from the archipelago of Azores, and have 59 sei whales identified by August 2021. With further work and comparison with other catalogues, it would be expected to find matches between the whales sighted in Azores and the ones in the Labrador Sea, since it is considered one important feeding ground suggesting a migratory corridor between these two regions for this species (Prieto et al., 2014).

2.5.4. Residence time

The fact of detecting only re-sightings of three individuals, indicates that we normally see different individuals passing in the South of São Miguel, i.e., that sei whales are spending short times around the island. Thus, it supports the hypothesis that this species is passing by the waters of São Miguel and can be using the island as navigation cue in their migration, as suggested by Prieto (2017). Besides, we did not see matches between years, which can lead to think that this species does not go in the same route every year. However, these low number of matches could be related to an uneven photographic effort over the years, plus not all photos available have sufficient quality to identify the individuals, therefore missing some identifications. Visser et al. (2011), only observed one resighting of this species in the central group of the Azores, with a residence time of 17 days. We also observed a low number of resightings in São Miguel (Azores) with a residence of 11, 17 days and one month. In order to have a higher insight of the residence time of sei whales in Azores, a higher photographic effort with photo-identification purposes would be of great help, identifying a higher proportion of the individuals sighted, and increasing chances to find resightings over time.

2.5.5. Habitat preferences

The Generalized Additive Models allowed us to understand the habitat preferences of the sei whales in São Miguel. These models have the great advantage of being able to deal with non-linear data and with non-normal distributions, which makes possible to use presence/absence (or pseudo-absence) data as the response variable. With the use of the sightings of other cetaceans recorded under the same sampling effort, time and area, we reduced the bias of these models. There are other advantages, as easy interpretation or high flexibility and regularization that reduces the overfitting (Lehmann, 1998; Ravindra et al., 2019). The model 1 presented a lower AUC than the model 2 and 3. This could be related with sei whales prefering different environmental conditions along the study period, since there is evidence of inter-annual variability in predicted distribution made in the North Atlantic, and seems to present a northward expansion in the distribution along the years, related to shifts on their prey distribution due to the climate change (Houghton et al., 2020).

Model 3 showed a preference for higher temperatures than model 2. It was observed a rise of 0.1 to 0.5 ºC/decade of the SST in the North Atlantic in the past century and it is expected to continue (Peck & Pinnegar, 2019). Plus, Siemer et al. (2021) observed an increase of 2.7 ºC in Azores in the last century. This increase seems to be affecting prey distribution, and therefore, their predators, as the sei whales. For example, one of the sei whale prey, the capelin (*M. villosus*) has been observed to shift its distribution during its larval and adult phase, by changes in the feeding areas, spawning locations or in migrations, due to variation on the temperature, impacting the food web (Rose, 2005). Northward shifts of the cetaceans' ranges of distribution have been predicted due to warming of the waters, which can have negative consequences for the species conservation status (MacLeod, 2009). The climate change vulnerability for some species of cetacean have been also assessed, represented by changes in the migration, generation length, site fidelity, habitat specificity and home range (Sousa et al., 2021).

Sei whales sighted off São Miguel from 2008 to 2020, seem also to change their preference of SST gradient to lower gradients. Stronger gradients are related with the presence of stronger or more defined fronts and filaments, and therefore with prey aggregation or increased of primary production. Thus, in the model 2 (2008-2014), the preference for higher SST gradient was consistent with the retention of the chlorophyll-*a* variable on the model, on the contrary of the model 3 that did not retain the chlorophyll-a, not being associated with high SST gradients. Skov et al. (2008), confirms the preference of this species for strong flow gradients, at depths less than 100 m in the Mid-Atlantic Ridge (north of Azores), where whales are suspected to be feeding.

Chlorophyll-*a* was considered an important variable in sei whales' distribution only before 2014. Chlorophyll-*a* is usually used as a proxy of primary production, and therefore, to trigger zooplankton development, i.e., one of the potential prey for sei whales. Sightings of sei whales with feeding behaviour have been confirmed in São Miguel, including lunging and the swimming on the side eating krill (González García,2019) and presence of faeces (Ojeda et al., 2019). In our model 2 (2008-2014), sei whales preferred high concentrations of chlorophyll-*a* which can be linked to the phytoplankton bloom that occurs each spring. The diet of sei whales is mostly based on calanoid species (*C. finmarchicus*) but can also include euphausiids (Prieto et al., 2012; Pérez-Jorge et al., 2019; Houghton et al., 2020), all of them in low levels of the trophic chain, i.e., more related with primary production. Opposing to Prieto et al. (2014) which indicated that this species did not forage in areas south of 48ºN since the primary production variables were not retain in their Ecological Niche Modelling final results, our results suggested that sei whales were feeding in Azores, reflected by the model 2 (2008-2014), and also supported by several observations of feeding whales during the rest of the study period, although this behaviour is less frequent than for other baleen whales (González García, 2019). Still, consideration of the time lag between the phytoplankton bloom and the presence of the whales is of interest, indicated to be between 12 to 17 weeks, since sei whales need advanced development stages of the krill to feed

(Visser et al., 2011; González García, 2019).

After 2014, chlorophyll-*a* was not selected in the model. Chlorophyll-*a* patterns might have been related to the temperature of the waters. Cold waters are normally related to high productivity, and oceanographic events such as eddies or fronts usually act as aggregation systems for it. After 2014, the whales were registered in warmer waters. As they were seen later in the year in São Miguel, there is the possibility that when they arrived to the island, the delayed effect of the spring bloom was already weaker, and therefore the concentration of whales' prey could be also lower.

In our study, sei whales were distributed in a wide range of depth, because the diverse bathymetry around São Miguel. However, they showed a higher preference for waters between 500 and 1200 m deep. Pérez-Jorge et al. (2019) observed an association of sei whales to waters deeper than 1500 m, in whales tracked from Azores to Labrador Sea.

Pérez-Jorge et al. (2019), found a preference of off-shore waters observing sei whale migration through the mid-North Atlantic, including waters from Azores to Greenland. As our study focused on São Miguel Island, the area covered is relatively close to the shore due to the commercial nature of the whale watching data, therefore "coastal waters" predominate. It was possible that waters near the coast were more productive, both due to the interaction of the oceanographic features with the bathymetry surrounding the island, and also because of the interaction of island topography and wind, which may trigger coastal upwelling (González García, 2019), therefore creating suitable conditions for this species closer to the shore. However, in the model where distance to the coast was significant, the chlorophyll-*a* was not, which can mean that this variable may be related to other oceanographic features, or that a delay between maximum chlorophyll-*a* and whale prey availability is needed.

It is important to notice that the data used here were obtained from whale watching, with fewer data during the winter, since the number of boat trips (effort) was lower. Nonetheless, the peak of sightings of this species is between spring and late summer (agreeing with Prieto et al., 2014; Visser et al., 2011; González García, 2019; Romagosa et al., 2020), not necessarily linked to the highest number of trips, showing that effort bias was somehow limited.

For future research and since our study is focused on environmental variables linked to the local productivity, it would be important to include other variables as the ones linked to their migration (e.g., latitude and longitude if considering larger areas, and magnetic components). It would also be useful to model the habitat preferences according to the season since Azores oceanographic conditions present a variability throughout the year. Plus, to get a more robust understanding of sei whale habitat preferences and distribution, predictive models can supplement our results. Here we provide a thorough understanding of sei whale occurrence in São Miguel, Azores. With this information, we can infer how the species might react to future changes in the marine environment and to anthropogenic pressure, therefore it is essential to support conservation and management plans for this endangered ocean migrant.

2.6. Conclusion

This study leaded to a better understanding of the distribution, movement patterns and habitat preferences of sei whale (*Balaenoptera borealis*), in São Miguel, Azores. This species seems to be delaying its passing in the waters of Azores along the years, which might be related to the track of resources related to the climate change. It presents a main travelling direction to northwest during spring, supporting the idea that they are migrating to higher latitudes, to feeding grounds. From the 87 individuals identified, only three were resighted showing a short time of permanence in these waters, confirming the idea that sei whales may be using the island as navigation cue in their migration. According to their habitat preferences, sei whales seems to prefer different environmental conditions along time, observed clear on the SST and SST gradient variables, which can be explained by a northward expansion due to the climate change.

2.7. Acknowledgements

I want to thank to Futurismo Azores Adventures to provide me with the possibility to do this study, and for all the data taken on board together with the photos. Plus, also a great thank you to all of the colleagues who helped with their knowledge to improve this study.

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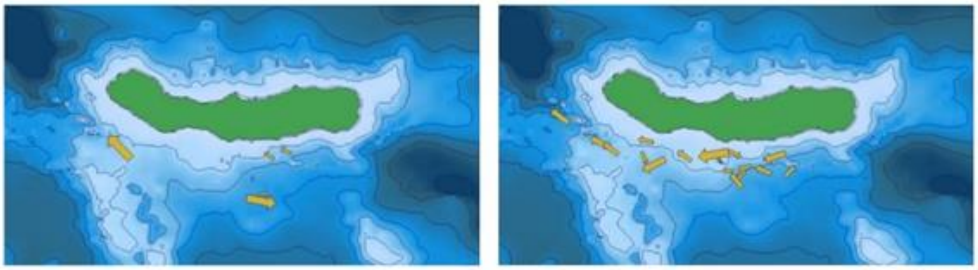
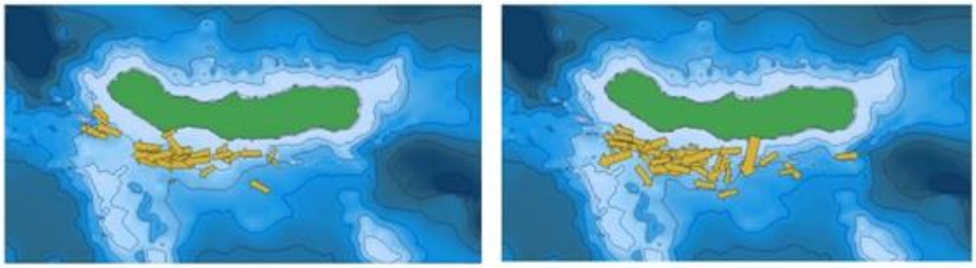
Appendix I- Travelling direction of the sei whales (*Balaenoptera borealis*) sighted between 2008 and 2020, in São Miguel, Azores



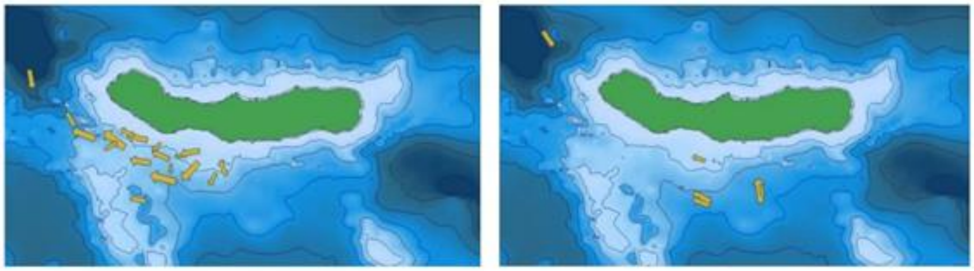
March

April



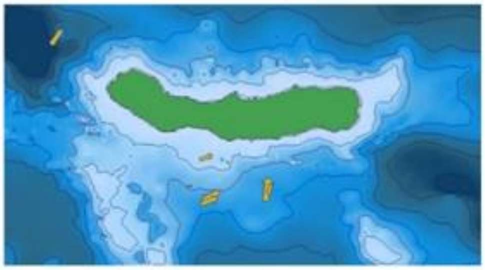
May

June



July

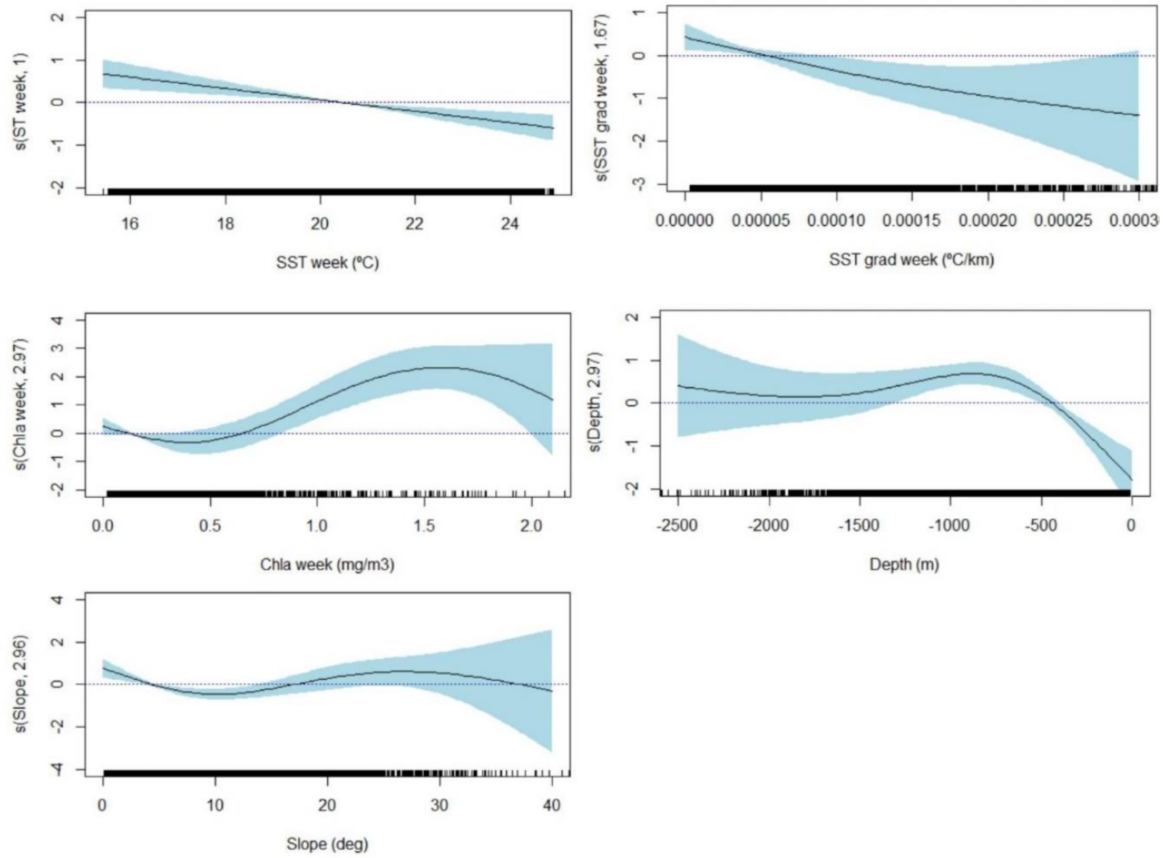
August



September

Appendix I- Travelling direction of all sei whales (*Balaenoptera borealis*) sighted between 2008 and 2020, in São Miguel, Azores, during May and June, in which the size of the arrow corresponds to the velocity of the individual.

Appendix II- Smothers of the variables in the GAM (Generalized Additive Models) of sei whale (*Balaenoptera borealis*) of the model 1 (2008-2020)



Appendix II- Smoothers of the SST (sea surface temperature), SST gradient, Chlorophyll-a, depth and slope in the GAM (Generalized Additive Models) model 1 (2008-2020) for sei whale (Balaenoptera borealis) occurrence, in São Miguel, Azores. Tick marks in the x-axis indicate the distribution of the observations (both with presences and absences). Shaded areas represent 95% of CI (confidence interval). The degrees of freedom are presented in parenthesis on the y-axis.