Mafalda dos Santos Albuquerque

Sei whale feeding and transiting behaviour in the Azores

UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2023

Mafalda dos Santos Albuquerque

Sei whale feeding and transiting behaviour in the Azores

Mestrado em Biologia Marinha

Supervisor

Dr. Catarina Vinagre (University of Algarve)

Co-supervisor

Dr. Gisela Dionísio (MARE-Universidade de Lisboa & AtlanticNaturalist.org)

UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2023

Declaração de autoria de trabalho

Sei whale feeding and transiting behaviour in the Azores.

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

Assinado por: Mafalda dos Santos Albuquerque
Identificação: BI15058915
Data: 2023-09-25 às 17:18:35

Abstract

Sei whales (*Balaenoptera borealis)* of the North Atlantic were brought to near extinction by twentieth-century industrial whaling. Currently, this species is classified as Endangered, and it is one the baleen whales more poorly understood. This baleen whale uses the Azores region during their annual latitudinal migrations towards the northern areas, but little is known yet to know the importance of this region to their migration success. Therefore, the present study is a contribution to update the information about the species' habitat use and social ecology in the Azores, including its seasonality, bathymetry, group size, population structure and behaviour, using data from 2009 to 2022. Additionally, feeding behaviour is described in detail based on the large feeding aggregation, registered from August to November of 2022, near Faial and Pico Islands. For the analysis, opportunistic data, collected during whale-watching surveys is used and photo-identification of the individuals observed in the aggregation event too. In total, four islands' data is analysed and compared, with support of statistical tests. The results show that sei whales are changing the time of their passage in the Azores to late summer/autumn and using this area to feed and not only to pass and rest, as previous reported. The feeding aggregation gives a new idea about the importance of the Azores to *Balaenoptera borealis*, as it might be becoming an important feeding ground during its migration to northern areas. With this new insight on the species ecology, local conservation measures are revised and proposed, so the navigation of vessels and whale-watching in the feeding zones do not have major impacts on the behaviour and feeding of the animals.

Keywords

Balaenoptera borealis, Faial, aggregation feeding event, habitat use, social ecology

Resumo

A baleia sardinheira, *Balaenoptera borealis*, é uma espécie da ordem Cetacea, subordem Mysticeti e família Balaenopteridae. Pertence ao grupo chamado rorquais ou baleias de barbas e tem uma distribuição muito pouco conhecida, uma vez que é muitas vezes confundida com a baleia de Bryde e pelo facto de que o seu padrão é imprevisível, pois estes animais podem ficar por algo tempo numa área e desaparecerem sem previsão. Sabe-se que as baleias sardinheiras tendem a estar mais presentes em zonas de latitude média que as outras baleias de barbas, mas a espécie é considerada cosmopolita, podendo estar presente no mar aberto, em zonas temperadas, subtropicais e subpolares, em ambos os hemisférios e em todos os oceanos. As baleias de barbas são conhecidas por realizarem migrações sazonais de zonas de alta latitude no verão, com elevada produtividade onde se alimentam, para zonas de baixa latitude no inverno, para a reprodução. Relativamente à alimentação, esta espécie destaca-se pela sua adaptação morfológica que a permite alternar entre estratégias de alimentação, principalmente entre os chamados "lunging", comum no grupo das baleias de barbas e o "skimming", que é a estratégia alimentar mais comum dos Balenídeos. Esta última é mais usada para a captura de copépodes e pequenas presas e o lunging para outras presas tais como, peixe, cefalópodes e krill.

Relativamente às suas populações, esta espécie sofreu um declínio durante a caça à baleia nos séculos 19 e 20, principalmente no hemisfério sul, mas também no Atlântico e Pacífico Norte, nos anos 50, 60 e 70, para a extração de óleo e carne. Desde 1985, a baleia sardinheira é protegida pela Comissão Baleeira Internacional, o que sessou a sua caça intensiva e levou a uma recuperação gradual das populações. No entanto, esta espécie é também afetada pelas alterações climáticas, pelo ruído antropogénico, colisões de navios e emaranhamento em artes de pesca, estando listada como Ameaçada, na Lista Vermelha de Espécies Ameaçadas da IUCN.

De acordo com a Comissão Baleeira Internacional, a baleia sardinheira é uma espécie politípica, sendo distinguida em duas subespécies: *Balaenoptera borealis borealis* Lesson, 1828, considerada a baleia sardinheira do Hemisfério Norte e *Balaenoptera borealis schlegellii* Flower, 1865, a baleia sardinheira do Hemisfério Sul. No Atlântico Norte, a baleia sardinheira é observada por toda a área, tendo a tendência de seguir o padrão de migração em que passa por Cabo Verde e Madeira, atravessa os Açores e segue para o Mar do Labrador, perto da Gronelândia, onde fica a maior parte dos meses do verão. Relativamente ao arquipélago dos

Açores, tem sido considerado uma paragem nesta rota migratória, onde as baleias são observadas, na maioria de abril a junho, a descansar e algumas vezes a alimentarem-se. Esta zona destaca-se pelas suas características a nível de batimetria, temperatura da superfície da água e produtividade, que tornam os Açores uma das áreas do mundo com maior biodiversidade. No entanto, ainda pouco se sabe acerca da importância deste arquipélago no sucesso migratório das baleias de barbas, incluindo a baleia sardinheira. Para além disto, esta espécie é uma das baleias de barbas de que temos menos conhecimento, nomeadamente em relação à sua migração e distribuição, sendo importante rever e perceber os seus padrões e os fatores que mais influenciam o seu movimento, para ser possível criar medidas de conservação adequadas à sua proteção.

Sendo assim, neste projeto, pretendeu-se atualizar a informação da ocorrência da baleia sardinheira nos Açores, nomeadamente do uso do habitat e ecologia social. Foi também analisado o evento de agregação desta espécie, que ocorreu entre agosto e novembro de 2022, em redor das ilhas do Faial e Pico, onde se analisa com mais detalhe o comportamento alimentar da espécie. Para tal, foram usados dados oportunísticos recolhidos durante as viagens de observação de cetáceos, para o estudo de vários parâmetros: sazonalidade, preferência de batimetria, tamanho dos grupos, estrutura da população e comportamento. Para tornar a análise mais robusta, foram também usados dados do projeto POPA, recolhidos através de transetos numa embarcação de pesca comercial. Posteriormente, foi feita uma comparação entre quatro ilhas dos Açores: Faial, Pico, São Miguel e Terceira, e toda a análise foi acompanhada por testes estatísticos. Para se poder comparar o evento de agregação com o os restantes períodos, em que baleias sardinheiras foram observadas, os dados foram divididos em dois períodos: de 1998 a julho de 2022 e de agosto a novembro de 2022. Para o último período, foi também realizada a foto-identificação dos indivíduos e criado o catálogo com os mesmos.

Entre 1998 e 2022, as baleias sardinheiras tenderam a ser observadas cada vez mais tarde, estendendo a sua passagem pelos Açores para o verão e início do outono, principalmente nas ilhas do Faial e do Pico. Em termos de batimetria, esta espécie apresentou um padrão oportunístico, não mostrando preferência por profundidades específicas. Relativamente ao tamanho de grupos, em concordância com estudos anteriores, esta espécie é maioritariamente observada ou sozinha ou em pares e a presença de crias ou juvenis não parece variar muito entre ilhas nem apresentar um padrão, mesmo considerando algumas falhas de precisão no registo destes dados. Quanto ao comportamento, foi criada uma sugestão de etograma para o estudo deste parâmetro da baleia sardinheira e, mais uma vez, de acordo com estudos anteriores, estas baleias de barbas passaram pelos Açores, sobretudo em trânsito.

Relativamente ao evento de agregação, de agosto a novembro de 2022, estes animais foram observados a profundidades muito inferiores, com já alguns avistamentos com grupos maiores (mais de 10 animais próximos do barco), comum nas zonas de agregação para alimentação já estudadas. Foi também observada uma maior percentagem de crias e juvenis durante este período, o que vai de encontro ao facto de a sua passagem nos Açores estar a ser cada vez mais tardia e prolongada, antes de seguirem para o Mar do Labrador. Adicionalmente, foram identificados 79 indivíduos e um deles foi avistado durante algumas semanas na mesma zona, comprovando também o possível prolongamento de passagem no arquipélago. Ainda neste evento, contrariamente ao observado antes, o comportamento mais frequente foi alimentação, com a observação de diferentes estratégias alimentares, incluindo o lunging e skimming. Nos mesmos avistamentos, foi também possível identificar três espécies de presas, o carapau, *Trachurus trachurus,* o trombeteiro, *Macroramphosus scolopax,* e o mini-saia, *Capros aper.*
Visto que o comportamento mais observado foi a alimentação, crê-se que esta agregação se deveu então a uma aglomeração de presas na zona, o que atraiu os animais durante o seu percurso migratório para o norte. De acordo com estudos anteriores, estas aglomerações devem-se a processos oceanográficos, nomeadamente mistura de correntes no grupo central do arquipélago, que pode levar a uma subida da nutriclina e confinamento do sistema de remoinhos e frentes, rico biologicamente. A maior abundância de presas pode dever-se também à influência da temperatura na abundância do fitoplâncton, o que pode tornar-se mais frequente no futuro. Sendo assim, é importante continuar a monitorizar esta espécie de baleia de barbas e a sua passagem nos Açores e permanecer com a recolha de dados durante as expedições de observação de cetáceos.
Este estudo é uma primeira abordagem e junta diferentes métodos para se poder perceber melhor se o ideal é o seu uso em simultâneo ou se cada um deverá ser melhorado. Os resultados indicam que um método eficaz é a recolha sistemática de dados por parte da equipa de biólogos das marítimo-turísticas, recolhendo campos previamente definidos, como é o caso do iNaturalist e MONICET e, se se garantir a formação da equipa para que a qualidade da recolha de dados seja melhorada, pode ser possível unir a ciência com estas plataformas com dados mais fiáveis e a custo zero. De qualquer das formas, os resultados do presente estudo contribuem para uma visão atualizada da importância dos Açores para a baleia sardinheira e indicam que esta espécie está a mudar a sua passagem pelos Açores, sendo mais observada pelo fim do verão e início do outono. Com esta nova perspetiva sobre a baleia sardinheira nos Açores, criou-se um código de conduta para a circulação de embarcações em zonas de alimentação, de modo a contribuir para a conservação da espécie e destes eventos de agregação.

Para futuros estudos, sugere-se o uso de métodos aéreos para uma melhor observação e análise do comportamento dos animais, uma análise de um período maior na foto-identificação, uso de tags para uma melhor compreensão dos padrões migratórios da espécie e análise de variáveis ambientais, tais como a temperatura e clorofila, a fim de perceber quais as principais causas da acumulação de presas na zona da agregação.

Palavras-chave

Balaenoptera borealis, Faial, evento de agregação alimentar, uso do habitat, ecologia social

Acknowledgements of the thesis

After a long journey, Gisela and José Nuno deserve a big thanks for your patience, support, help. You gave me a great opportunity and without your ambition and passion, this wouldn't be possible. I will always be grateful for all I am learning with you and for being so supportive and kind to me.

I also want to thanks to my university's supervisor, Catarina Vinagre, for being a great professor and for the help and guidance during this thesis.

I am very grateful to be part of the team of "Naturalist, Science and Tourism", that teaches me a lot every day, with special thanks to Tiago for the guidance when I first came to Faial, in October of 2022. A big thanks also to Jairo and Maria, that made this team even better. To Nádia, Luana and Bia, for the great months we had in Faial together, for the gossip, movie and dinner sessions that made this experience much better. Luana, you are the sweetest friend, and I will only read your book if you read my thesis. Nádia, you deserve a statue for having all the patience during this season and making me laugh so much. Inês, you came on the last part of this journey, but you also contributed with your calm presence and for being an amazing friend that can deal with me and Nádia's bad days.

A big hug to Thomas, for helping me on the last strength and being chill and special, as always.

A big thanks to my housemates, especially Alvi, Sophie, Ruth and Gaby, you are the best housemates ever!

I want to send a big hug to my best friends, Bia, Inês, Jay, Manuel, and Miguel. I miss you a lot and you definitely have to come to Faial. Thank you for all the amazing moments and memories!

From Faial to Algarve, I want to thank to Rui Peres dos Santos for accepting me in the Lighthouse project and teaching me so much about cetaceans. A big thanks to Tânia, for always being there on the next door and giving me the "bear hugs". Thank you also to my group of friends in Faro, especially to Raquel, Vincent, Rui, Patrícia, Maria and Samuel for the great moments and friendship.

Finally, I would like to mention the most important people in my life, my parents, Francisco and Elisabete and my sister, Mónica. You are the best I could ever have and the long-distance and time will completely fade away in the moment I hug you. Thank you, parents, for all the support and love you gave me and to my sister, for all the connection we have and help you gave me through all this time. A big thanks too to Nuno, Rodrigo and Su for being always there and being part of my family! Also, a thanks to Tia Ana, Joaninha and Nênê for supporting me.

To Avó Salete and Avó Amélia a big hug and kiss, I miss you a lot. And dedication to Avô Abel, I did it!

Contents

List of figures

List of tables

List of abbreviations, acronyms, and symbols

B.borealis – *Balaenoptera borealis*

BBO - *Balaenoptera borealis*

GEBCO - General Bathymetric Chart of the Oceans

GPS - Global Positioning System

ID – Identification

IUCN - International Union for Conservation of Nature

IWC - International Whaling Commission

SST - Sea Surface Temperature

VHF - Very high frequency

Chapter 1 - General Introduction

1. The study of Cetaceans

    1.1. Order Cetacea

The order Cetacea includes all animals known as whales, dolphins, and porpoises and it is currently composed by 89 species (Jefferson et al., 2015). This order is divided in three sub-orders: the extinct Archaeoceti, and two extant, the Odontoceti and Mysticetei (Fordyce, R. Ewan, 2001). The Odontoceti includes the toothed whales and dolphins, in which ten families are included and all animals have teeth and one blowhole. In contrast, the Mysticeti are the baleen whales, with keratin baleen plates and two blowholes, in which four families are included: right whales, pygmy right whale, grey whale and the rorquals (Shirihai & Jarrett, 2006).

Cetaceans occur around the globe, in oceans, rivers and lakes. Some species are considered cosmopolitan, and others can be limited to one hemisphere or ocean or even to only a specific region. Certain species, as the baleen whales, have their migratory capacities well developed and so, they travel several nautical miles from feeding cold regions, during the summer, to breeding temperature regions, at low latitudes (Shirihai & Jarrett, 2006). The toothed whales can also have a seasonal migration but more reduced and frequently just between inshore and offshore areas. While the toothed whales have the melon organ in their head that allows them to communicate and hunt through echolocation, the mysticetes do not (Lanzetti et al., 2022). These last ones tend to stay in small groups, while some toothed whales can be in large and social groups (Shirihai & Jarrett, 2006).

    1.2. The importance of cetaceans in Ecology

Before, cetaceans were only considered for commercialization of their meat and oil, but the importance of cetaceans in the ecosystems started to get more attention soon as the whaling period stop and due to the increasing measures of wildlife protection. These animals are great contributors to the ocean productivity, as the great migrators' pumping, iron-rich feces, fertilize the water and enhance the primary production (Lockyer, 1976). Additionally, the biomass of these animals has great values, contributing as a stable repository for carbon dioxide and, after death, their bodies are one of the several contributions of biodiversity and sequestration of carbon in the ocean floor (Lockyer, 1976).

It has been suggested that cetaceans present top-down effects in the ocean, as they are consumers at most trophic levels, and with their big body sizes, abundance and migrations they are dominant predators (Bowen, 1997).

1.3. Studying cetaceans with opportunistic data

With the curiosity about the importance of cetacean in the ecosystems, studying the populations' evolution after the whaling and their conservation needs are now an interest to many researchers and so, several methods have been developed.

Whale-watching has also been combined with data collection and so, boat surveys are a non-systematic manner to study the spatial distribution, temporal patterns in abundance, and behaviour, by collecting opportunistic data (Vinding et al., 2015). This method allows the collection of many data during long periods of time and have less spatial and temporal constraints than the dedicated surveys. As this activity has been increasing in the last years, the more geographic coverage increases the collection of scientific information (Vinding et al., 2015). Thus, each encounter with an animal can contribute to several details about the species, such as seasonality, bathymetry, abundance, population structure and behaviour.

For the population structure and residency, photo-identification is widely used as individuals can be identified over time through photos of their flukes, dorsal fins, or specific body marks. With this method, it is possible to monitor where specific individuals are observed in different seasons and, by comparing catalogues from different regions, researchers are able to get to know the migratory paths, connections and habitat preferences to feed, rest and breed (Davies et al., 2001).

For studies in behavioural ecology, an ethogram is one the most important tools, as it includes a list of already defined behaviours of the species that, when used as a basis, makes the data more consistent to then be analysed (Bird, 2019). Additionally, when the data is being collected from boats, the viewpoint that is used can difficult the observation of the real behaviour, since it is only possible to observe the animal at the surface. Nevertheless, there are some strategies to improve the method, such as using the focal follow or recording videos with drones (Bird, 2019).

2. Sei whale

2.1. Taxonomy

Sei whales are included in the order Cetacea, suborder Mysticeti and family Balaenopteridae, and are called the rorqual whales (Jefferson et al., 2015). Currently, this species is considered polytypic, meaning two subspecies can be considered, although they are not widely distinguished: *Balaenoptera borealis borealis* Lesson, 1828, which refers to the Northern hemisphere sei whale and *Balaenoptera borealis schlegellii* Flower, 1865, including the sei whales from the Southern hemisphere (Shirihai & Jarrett, 2006).
This rorqual species is one of the most poorly understood species of all baleen whales (Jefferson et al., 2015).

2.2. Biology

Sei whale calves are born with a length between approximately 4.5 and 4.8 meters and the adult size ranges between 12 and 21 meters, although females tend to be larger than the males, as it is common with other baleen whales (Shirihai & Jarrett, 2006). Thus, females size ranges between 13.4 and 21 meters and males measure from 12.8 to 18.6 meters. A large adult can weight up to 30 tons while a newborn around 0.65 tons (Shirihai & Jarrett, 2006; Jefferson et al., 2015). Juveniles sexually mature when they are 6-12 years and reach 13 m length and one calf is born every two to three years after a gestation of 13 months (Shirihai & Jarrett, 2006).
Their coloration is mostly grey or dark grey except for a white area near the belly. Round scars that can occur in the back are usually from the cookie-cutter sharks or lamprey bites (Prieto da Silva, 2014; Jefferson et al., 2015). This species has usually a tall and falcate dorsal fin, with a steep angle with the back of at least 45º and a pointed and narrow rostrum with a single prominent ridge in the middle (Jefferson et al., 2015). This ridge is one of the main ways to distinguish this species from the Bryde's whale, which has three ridges instead of one (Shirihai & Jarrett, 2006). There is some confusion between these two species, and this has been one of

the factors that difficult the study of their ecology. Additionally, sei whales tend to show a downturned tip, which may also be a good characteristic to distinguish them from Bryde's, fin and Omura's whales (Jefferson et al., 2015). A scientific illustration of *B.borealis* with some of the main morphological characteristics is represented in figure 1.1.

Figure 1. 1 - Scientific illustration of the sei whale. (NOAA Fisheries, 2023)

This species has on average from 340 to 350 dark plates on each side, measuring between 75 to 80 cm, and being narrower than in other whales (Jefferson et al., 2015). Sometimes it can have white plates close to the tip of the rostrum and these animals can produce a columnar blow of at least three meters (Shirihai & Jarrett, 2006).

Balaenoptera borealis is frequently seen alone or in groups of two to five individuals, but little is known about how they socialize. They can swim fast, with a speed of 25 km per hour and do not show the fluke or arch the back before the dive. However, they usually leave "footprints", which are circles on the surface that these whales create by moving the fluke underwater (Jefferson et al., 2015). When transiting slowly, they show the dorsal fin and the blowhole, simultaneously (Jefferson et al., 2015). These animals can live up to seventy years and they can dive from five to twenty minutes, although they do not tend to go deeper than 300 m (Shirihai & Jarrett, 2006; Jefferson et al., 2015).

2.3. Distribution and habitat preferences

Sei whale's distribution is not well known since this species can be confused with Bryde's whales and it has an unpredictable pattern as they can be present for a long time in a region and then disappear (Jefferson et al., 2015). Nevertheless, it is known that these whales are more limited to the mid-latitude zones than the other rorqual whales but they are considered cosmopolitan, occurring in open ocean, especially in temperate, subtropical, and subpolar waters, in both hemispheres and on the major three oceans (Prieto da Silva, 2014).

2.4. Migration

Baleen whales are known to have seasonal migrations, from summer feeding areas, in high-latitude regions, to winter low-latitude zones for breeding and calving (Stern, 2009). The sei whales usually have these seasonal migrations but it tends to be less extensive than other large whales (Jefferson et al., 2015). In the North Atlantic, Pérez-Jorge et al. (2020) suggests that some sei whales have a defined migratory corridor and they travel to Northwest in direction to the Labrador Sea and pass in Azores during this path (Pérez-Jorge et al., 2020).

2.5. Feeding behaviour

Sei whales eat on average 900 kg of food daily and its diet is dependent on the ocean basin and prey groups characteristics (Prieto da Silva, 2014). This species is considered ecologically flexible since they can switch between feeding strategies. They perform several lunges when below the surface, as the others rorquals, but they can also forage by skim-feeding, at the surface, similar to how balaenids feed (Segre et al., 2021). While lunging, they catch fish, cephalopods, and krill and, when skimming, they feed on copepods and other small prey (Goldbogen et al., 2007; Jefferson et al., 2015.).

Previous research, Werth et al. (2018) and Segre et al. (2021), found that sei whales have the ability to switch between feeding strategies (e.g. skimming, lunging) is mainly due to their morphological adaptations, in which they have longer baleen plates with bigger gaps between them, and finer fringes with denser mats (Werth et al., 2018; Segre et al., 2021). In terms of evolution, sei whales diverged from Bryde's whale (*Balaenoptera edeni*), three million years ago and the Bryde's whales feed mainly by lungings (Segre et al., 2021). Nevertheless, it is not known if Bryde's Whale has the same ability to produce different feeding strategies since it does not have the same morphological adaptation (the longer baleen plates) as the sei whale (Werth et al., 2018; Segre et al., 2021). Therefore, it has been concluded that the skim-feeding and the favourable morphology have derived from the ancestral lunge-feeding mode and converged with the continuous feeding behaviour, characteristic from the balaenids (Segre et al., 2021). Additionally, it has been hypothesized that *B. borealis* evolved this intermediate flexibility in feeding strategies to escape from the competition with bigger baleen whales (Segre et al., 2021). Thus, they evolved to be generalists, having the ability to capture a high variety of prey, including copepods, euphausiids, amphipods, decapods, cephalopods, and fish (Prieto da Silva, 2014).

2.6. Conservation status and threats

This species population was decreased in the 19^{th} and 20^{th} century due to commercial whaling, especially between the 1950's to 1970's in Southern Hemisphere, but also in North Pacific and North Atlantic. Approximately three hundred thousand individuals were captured for their oil and meat (Jefferson et al., 2015;.). Since the 1985, *Balaenoptera borealis* is a protected species by the International Whaling Commission and the current main threats of this species are vessel strikes and entanglement in fishing gear, but they are also affected by the climate change and ocean noise According to the IUCN Red List, this species is listed as endangered, as the world population has around 50 000 mature individuals and it keeps increasing (The IUCN Red List of Threatened Species, 2018).

3. Study Area

Azores is an archipelago with an extension of 8,051,544 km2, including the Exclusive Economic Zone (EEZ), and composed by nice volcanic islands located in the central North Atlantic Ocean (Visser et al., 2011; Peran et al., 2016). Between 28° 00′ N – 49° 00′ N, and 17° 00′ W – 41° 00′ W, this is where the three tectonic plates (African, Eurasian and North American) meet, having a high volcanic activity (Quartau et al., 2012; Peran et al., 2016;

Borges et al., 2020). Thus, the islands constitute a volcanic plateau with 20-60 million years and are divided in three groups: the eastern group of São Miguel and Santa Maria, the central group of Faial, Pico, Graciosa, São Jorge and Terceira and the western group of Corvo and Flores (Borges et al., 2020). The Mid-Atlantic Ridge separates the western group from the others and these three groups are parted by sea channels with 1000-2000 m deep, although the channel between Faial and Pico has some zones where the depth does not exceed 50 m (Quartau et al., 2012; Borges et al., 2020).

Additionally, the Azorean seafloor is composed by several peaks and seamounts, that work as feeding zones, by attracting pelagic prey (Morato et al., 2008). Thus, some marine predators, such as some tuna species, common dolphins and Cory's shearwater, have been associated with seamounts with shallow summits, where they tend to be more abundant (Morato et al., 2008). Because of this diverse ocean floor morphology, Azores is an area with great biodiversity (Morato et al., 2008).

Furthermore, with influence of the Gulf Stream, by the transportation of warm water and air masses and high-pressure systems, this archipelago is characterized by its distinct oceanic climate, with high humidity and precipitation levels and low temperature variation (Borges et al., 2020). Thus, having good conditions for a great productivity, Azores has been defined as one great potential foraging area, being one of the places in the world with higher cetaceans' biodiversity (Visser et al., 2011; Afonso et al., 2020). Many migratory baleen whale species pass by the Azores during their migration, to mainly feed and rest, and then they continue their journey to the north (Afonso et al., 2020).

4. Sei whales in Azores

4.1. Habitat use

Sei whales were first registered in the Azores in 1989 and they tend to visit this region during spring, while migrating (Prieto da Silva, 2014). Previous research, Gomes Pereira (2008) and Prieto da Silva (2014), showed that encounters have occurred between early spring and late summer with peaks in April and May, from periods with lower sea surface temperature (16ºC) to periods with higher (above 23ºC). Additionally, some acoustic studies have shown a high abundance in spring and autumn (Leal, 2021).

Satellite telemetry records are lacking for the North Atlantic and Azores and only one study was made until now with a reduced number of Sei Whales being tag (n=6). This study showed movements of this species between the Labrador Sea and the Azores, which might indicate that both migratory stops should be connected, at least for this reduced number of animals (Prieto da Silva, 2014). This result also give us some highlights on the complexity of latitudinal and longitudinal large baleen whales movements, concretely Sei Whales (Prieto da Silva, 2014; Leal, 2021).

Records of sei whales feeding in the Azores are rare and most authors refer this archipelago as a travelling stop during their migration (Prieto da Silva, 2014; Romagosa et al., 2020). Other studies have concluded that the availability of prey has influence on the time window of the whales, directly connected to the onset of North Atlantic phytoplankton blooms, but to sei whales it is not the case, in which it has been suggested that the Azores does not function as a feeding ground for sei whales (Visser et al., 2011; Pérez-Jorge et al., 2020).

4.2. Aggregation events

Until today, no aggregation events have been registered in the Azores archipelago, North Atlantic. However, there are some reports of similar events in the Falkland Islands and North Pacific. Since 2021, Falkland Islands have been considered the only Key Biodiversity Area for sei whales and a hotspot for recovery of their populations (Weir et al., 2021; *Whale Aggregation Discovered in Falkland Islands Waters,* 2021). There was a research during five years that showed that these whales appear in the coastal waters of this location, during the summer and autumn, using it as feeding grounds. The results show that they tend to return every year to feed, especially on crustaceans. From photoidentification, it was possible to identify five hundred animals (*Whale Aggregation Discovered in Falkland Islands Waters*, 2021).

The other aggregation event was reported near Vancouver Island (British Columbia), in the North Pacific, also in 2021 (*Sei What?! Researchers Spot a Large Group of Critically Endangered Sei Whales off the Coast of British Columbia. | WildWhales*, 2021). This was also considered unique since little is known about this population and only 10 sightings of sei whales were documented in this region since the 1960s.

Additionally, the Charlie Gibbs Fracture Zone has been considered a foraging hotspot since there are reports of large feeding aggregations of sei whales (Waring et al., 2008).

5. Theme justification

Little is known about *Balaenoptera borealis* in the Azores and since it is one of the places in the world with the highest cetacean biodiversity, it is important to have more knowledge about the species that occur here. Being one of the spots in which this species passes by, during the migration to the north, this archipelago may be important in the journey and its conditions, such as prey abundance, presence of other species or environmental variables, may be decisive for the success of their migration. Therefore, it is needed to study the habitat use of sei whale in the Azores, so it is possible to evaluate the importance of this archipelago on the survival of the species. Thus, some ecological parameters must be studied, such as population structure, groups size, seasonality, and behaviour. Then, it will be possible to create conservation measures that contribute to the survival and protection of this endangered species.

6. Objectives

The aims of this study were filling the gaps: (1) infer about the sei whale's habitat use in Azores archipelago, by investigating the seasonality, depths of occurrence and behaviour of this species; (2) increase the knowledge on the population ecology, by analysing groups size, population structure (presence and percentage of calves), population size and occurrence patterns in the Azores (by using photo-identification and updating the Azores catalogue of the sei whale); (3) description of a rare feeding aggregation event observed in Faial and Pico islands; and (4) creation of local conservation measures, as a code of conduct, based on the new insight of the species ecology.

References

Afonso, P., Fontes, J., Giacomello, E., Magalhães, M. C., Martins, H. R., Morato, T., Neves, V., Prieto, R., Santos, R. S., Silva, M. A., & Vandeperre, F. (2020). The Azores: A Mid-Atlantic Hotspot for Marine Megafauna Research and Conservation. *Frontiers in Marine Science*, *6*, 826. https://doi.org/10.3389/FMARS.2019.00826/BIBTEX

Bird, C. (2019). *Classifying cetacean behavior – Geospatial Ecology of Marine Megafauna Laboratory*. https://blogs.oregonstate.edu/gemmlab/2019/11/18/classifying-cetacean-behavior/

Borges, P. A. V., Amorim, I. R., & Gabriel, R. (2020). Azores. *Encyclopedia of Islands*, 70–75. https://doi.org/10.1525/9780520943728-019

Bowen, W. D. (1997). Role of marine mammals in aquatic ecosystems. *Marine Ecology Progress Series*, *158*(1), 267–274. https://doi.org/10.3354/meps158267

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C., & Vincent, M. (2001). Marine monitoring handbook. *Joint Nature Conservation Committee*, *March*, 405.

Fordyce, R. Ewan, and C. de M. (2001). Evolutionary history of cetaceans: a review. In *Secondary adaptation of tetrapods to life in water* (Issue October, pp. 169–233).

Goldbogen, J. A., Pyenson, N. D., & Shadwick, R. E. (2007). Big gulps require high drag for fin whale lunge feeding. *Marine Ecology Progress Series, 349*. https://doi.org/10.3354/meps07066

Jefferson, T. A., Webber, M. A., & Pitman, R. L. (2015). *Marine mammals of the world: a comprehensive guide to their identification* (2nd ed.). Academic Press. https://doi.org/https://doi.org/10.1016/C2012-0-06919-0

Lanzetti, A., Chrouch, N., Portela Miguez, R., Fernandez, V., & Goswami, A. (2022). Developing echolocation: distinctive patterns in the ontogeny of the tympanoperiotic complex in baleen and toothed whales (Cetacea). *Biological Journal of the Linnean Society, 135*, 394–406. https://academic.oup.com/biolinnean/article/135/2/394/6485081

Leal, M. (2021). *Sei whales (Balaenoptera borealis): Photo identification and habitat preferences of a migrant ocean traveller in São Miguel, Azores*.

Lockyer, C. (1976). Body weights of some species of large whales. *J. Cons. Int. Explor. Mer*, *36*(3), 259–273. https://academic.oup.com/icesjms/article/36/3/259/639247

Morato, T., Machete, M., Kitchingman, A., Tempera, F., Lai, S., Varkey, M. G., Dâmaso, C., Santos, M., Prieto, R., & Santos, R. S. (2008). Abundance of seamounts in the Azores and their effect on aggregating visiting species. *Environmental Science*. http://www.popaobserver.org

Peran, A. D., Pham, C. K., Amorim, P., Cardigos, F., Tempera, F., & Morato, T. (2016). Seafloor Characteristics in the Azores Region (North Atlantic). *Frontiers in Marine Science | Www.Frontiersin.Org, 3*, 204. https://doi.org/10.3389/fmars.2016.00204

Pérez-Jorge, S., Tobeña, M., Prieto, R., Vandeperre, F., Calmettes, B., Lehodey, P., & Silva, M. A. (2020). Environmental drivers of large-scale movements of baleen whales in the mid-North Atlantic Ocean. *Diversity and Distributions*, *26*(6), 683–698. https://doi.org/10.1111/ddi.13038

Prieto da Silva, R. (2014). *Sei whale (Balaenoptera borealis) Ecology and Management in the North Atlantic*. Universidade dos Açores.

Quartau, R., Tempera, F., Mitchell, N. C., Pinheiro, L. M., Duarte, H., Brito, P. O., Bates, C. R., & Monteiro, J. H. (2012). Morphology of the Faial Island shelf (Azores): The interplay between volcanic, erosional, depositional, tectonic and mass-wasting processes. *Geochemistry, Geophysics, Geosystems*, *13*(4), 1–30. https://doi.org/10.1029/2011GC003987

Romagosa, M., Baumgartner, M., Cascão, I., Lammers, M. O., Marques, T. A., Santos, R. S., & Silva, M. A. (2020). Baleen whale acoustic presence and behaviour at a Mid-Atlantic migratory habitat, the Azores Archipelago. *Scientific Reports*, *10*(1), 1–11. https://doi.org/10.1038/s41598-020-63117-1

Segre, P. S., Weir, C. R., Stanworth, A., Cartwright, S., Friedlaender, A. S., & Goldbogen, J. A. (2021). *Biomechanically distinct filter-feeding behaviors distinguish sei whales as a functional intermediate and ecologically flexible species*. https://doi.org/10.1242/jeb.238873

Sei What?! Researchers spot a large group of critically endangered sei whales off the coast of British Columbia. | WildWhales. (2021). https://wildwhales.org/2021/07/12/sei-what-researchers-spot-a-large-group-of-critically-endangered-sei-whales-off-the-coast-of-british-columbia/

Shirihai, H., & Jarrett, B. (2006). *Whales, Dolphins and Seals: A Field Guide to the Marine Mammals of the World*. Bloomsbury Wildlife.

Stern, S. J. (2009). Migration and Movement Patterns. *Encyclopedia of Marine Mammals*, 726–730. https://doi.org/10.1016/B978-0-12-373553-9.00168-1

The IUCN Red List of Threatened Species. (2018). *Balaenoptera borealis (Sei Whale)*. https://www.iucnredlist.org/species/2475/130482064

Vinding, K., Bester, M., Kirkman, S. P., Chivell, W., & Elwen, S. H. (2015). The use of data from a platform of opportunity (whale watching) to study coastal cetaceans on the southwest coast of South Africa. *Tourism in Marine Environments*, *11*(1), 33–54. https://doi.org/10.3727/154427315X14398263718439

Visser, F., Hartman, K. L., Pierce, G. J., Valavanis, V. D., & Huisman, J. (2011). Timing of migratory baleen whales at the azores in relation to the north atlantic spring bloom. *Marine Ecology Progress Series*, *440*(October), 267–279. https://doi.org/10.3354/meps09349

Waring, G. T., Nøttestad +, L., Olsen +, E., Skov, H., & Vikingsson, G. (2008). Distribution and density estimates of cetaceans along the mid-Atlantic Ridge during summer 2004. *J. CETACEAN RES. MANAGE*, *10*(2), 137–146.

Weir, C. R., Taylor, M., Jelbes, P. A. Q., Stanworth, A., & Hammond, P. S. (2021). Distribution and abundance of sei whales off the west coast of the Falkland Islands. *Marine Mammal Science*, *37*(3), 919–933. https://doi.org/10.1111/MMS.12784

Werth, A. J., Potvin, J., Shadwick, R. E., Jensen, M. M., Cade, D. E., & Goldbogen, J. A. (2018). Filtration area scaling and evolution in mysticetes: trophic niche partitioning and the curious cases of sei and pygmy right whales. *Biological Journal of the Linnean*

Society, *125*(2), 264–279. https://doi.org/10.1093/BIOLINNEAN/BLY121

Whale aggregation discovered in Falkland Islands Waters. (2021). https://www.keybiodiversityareas.org/kba-news/whale-aggregation-discovered-in-falkland-islands-waters-now-made-a-kba

Chapter 2 - Sei whale feeding and transiting behaviour in the Azores

Abstract

Sei whales (*Balaenoptera borealis)* of the North Atlantic were brought to near extinction by twentieth-century industrial whaling. Currently, this species is classified as Endangered, and it is one the baleen whales more poorly understood. This baleen whale uses the Azores region during their annual latitudinal migrations towards the northern areas, but little is known yet to know the importance of this region to their migration success. Therefore, the present study is a contribution to update the information about the species' habitat use and social ecology in the Azores, including its seasonality, bathymetry, group size, population structure and behaviour, using data from 2009 to 2022. Additionally, feeding behaviour is described in detail based on the large feeding aggregation, registered from August to November of 2022, near Faial and Pico Islands. For the analysis, opportunistic data, collected during whale-watching surveys is used and photo-identification of the individuals observed in the aggregation event too. In total, four islands' data is analysed and compared, with support of statistical tests. The results show that sei whales are changing the time of their passage in the Azores to late summer/autumn and using this area to feed and not only to pass and rest, as previous reported. The feeding aggregation gives a new idea about the importance of the Azores to *Balaenoptera borealis*, as it might be becoming an important feeding ground during its migration to northern areas. With this new insight on the species ecology, local conservation measures are revised and proposed, so the navigation of vessels and whale-watching in the feeding zones do not have major impacts on the behaviour and feeding of the animals.

Keywords

Balaenoptera borealis, Faial, aggregation feeding event, habitat use, social ecology

2.1. Introduction

Sei whales, *Balaenoptera borealis,* is a species from the order Cetacea, suborder Mysticeti and family Balaenopteridae, which can be called rorqual whales (Jefferson et al., 2015). This species is can reach 21 meters, and being a rorqual whale, the females tend to be bigger than the males (Shirihai & Jarrett, 2006). The juveniles get sexually matured when they are 6-12 years and reach 13 m length and one calf is born every two to three years after a gestation of 13 months (Shirihai & Jarrett, 2006).

The sei whale has a tall and falcate dorsal fin, with a steep angle with the back of at least 45º and a pointed and narrow rostrum with a single prominent ridge in the middle (Jefferson et al., 2015). This ridge is one of the main ways to distinguish this species from the Bryde's whale, which has three ridges instead of one (Shirihai & Jarrett, 2006). Additionally, sei whales tend to show a downturned tip, which may also be a good characteristic to distinguish them from Bryde's, fin and Omura's whales (Jefferson et al., 2015).

B. borealis has, on average, from 340 to 350 dark plates on each side, measuring between 75 to 80 cm, and being narrower than in other whales (Jefferson et al., 2015). Sometimes it can have white plates close to the tip of the rostrum and these animals can produce a columnar blow of three meters (Shirihai & Jarrett, 2006). Additionally, they have longer baleen plates with bigger gaps between them, and finer fringes with denser mats, which is a morphological adaptation that allowed this species to evolved differently from the other rorqual whales (Werth et al., 2018; Segre et al., 2021). Thus, sei whales can lung-feeding, below the surface, as commonly seen in rorqual whales, but they can switch to skim-feeding, at the surface, which is a feeding strategy observed in the balaenids (Segre et al., 2021). With this capacity, sei whales eat on average 900 kg of food daily, and the diet is dependent on the ocean basin and prey groups characteristics (Prieto da Silva, 2014). This species is considered ecologically flexible since they can switch between feeding strategies and will feed on fish, cephalopods, and krill, while lunging, and on copepods and other small prey, while skimming (Goldbogen et al., 2007; Jefferson et al., 2015).

Nevertheless, this rorqual species is one of the most poorly understood species of all baleen whales, including its distribution and migration patterns (Jefferson et al., 2015). Although with lack of information, sei whale is considered cosmopolitan and is known for its seasonal migrations, from summer feeding areas, in high-latitude regions, to winter low-latitude zones for breeding and calving (Stern, 2009; Jefferson et al., 2015) . After the decreasing population with the 19th and 20th century commercial whaling, since 1985, *B.borealis* is a protected species by the International Whaling Commission and the current main threats are vessel strikes and entanglement in fishing gear, but they are also affected by the climate change and ocean noise (Jefferson et al., 2015). According to the IUCN Red List, this species is listed as endangered, and the world population has around 50 000 mature individuals and it keeps increasing (The IUCN Red List of Threatened Species, 2018).

As mentioned above, sei whales in the North Atlantic tend to switch between winter low-latitude zones and summer high-latitude zones and it has been concluded that some sei whales have shown a defined migratory corridor and they travel to Northwest in direction to the Labrador Sea and pass in Azores during this path (Pérez-Jorge et al., 2020). This archipelago is composed by nice volcanic islands located in the central North Atlantic Ocean (Visser et al., 2011; Peran et al., 2016). Between 28° 00′ N – 49° 00′ N, and 17° 00′ W – 41° 00′ W, this is where the three tectonic plates (African, Eurasian and North American) meet, having a high volcanic activity (Quartau et al., 2012; Peran et al., 2016; Borges et al., 2020). Thus, the islands constitute a volcanic plateau with 20-60 million years and are divided in three groups: the eastern group of São Miguel and Santa Maria, the central group of Faial, Pico, Graciosa, São Jorge and Terceira and the western group of Corvo and Flores (Borges et al., 2020). The Mid-Atlantic Ridge separates the western group from the others and these three groups are parted by sea channels with 1000-2000 m deep, although the channel between Faial and Pico has some zones where the depth does not exceed 50 m (Quartau et al., 2012; Borges et al., 2020). The Azores has an irregular seafloor and is influenced by several oceanic processes, such as Gulf Stream, which attracts pelagic prey and some marine predators, including cetaceans (Morato et al., 2008). Being characterized by its distinct oceanic climate, with high humidity and precipitation levels and low temperature variation, the Azores has good conditions for a great productivity (Borges et al., 2020). Thus, is has defined as one great potential foraging area, being one of the places in the world with higher cetaceans' biodiversity (Visser et al., 2011; Afonso et al., 2020). Many migratory baleen whale species pass by the Azores during their migration, to mainly feed and rest, and then they continue their journey to the north (Afonso et al., 2020).

As previously reported, sei whales tend to pass in the Azores during their migration to the Labrador Sea, being observed mainly in April and May (Prieto da Silva, 2014). These animals are mainly seen in transit and rarely feeding and so, the Azores has been described more as a travelling stop than as a feeding ground (Prieto da Silva, 2014; Romagosa et al., 2020). Additionally, no feeding aggregation event has been reported in this archipelago but in other regions, there are some sightings of great abundance of sei whales feeding in nor considered foraging hotspots, as the Charlie Gibbs Fracture Zone, Falkland Islands and Vancouver Islands (Waring et al., 2008; *Sei What?! Researchers Spot a Large Group of Critically Endangered Sei Whales off the Coast of British Columbia. | WildWhales*, 2021; *Whale Aggregation Discovered in Falkland Islands Waters*, 2021).

Little is known about *Balaenoptera borealis* in the Azores and since it is one of the places in the world with the highest cetacean biodiversity, it is important to have more knowledge about the species that occur here. Being one of the spots in which this species passes by, during the migration to the north, this archipelago may be important in the journey and its conditions, such as prey abundance, presence of other species or environmental variables, may be decisive for the success of their migration. Therefore, it is needed to study the habitat use of sei whale in the Azores, so it is possible to evaluate the importance of this archipelago on the survival of the species. Thus, some ecological parameters must be studied, such as population structure, groups size, seasonality, and behaviour. Thus, it will be possible to create conservation measures that contribute to the survival and protection of this endangered species.

The aims of this study were filling the gaps: (1) infer about the sei whale's habitat use in Azores archipelago, by investigating the seasonality, depths of occurrence and behaviour of this species; (2) increase the knowledge on the population ecology, by analysing groups size, population structure (presence and percentage of calves), population size and occurrence patterns in the Azores (by using photo-identification and updating the Azores catalogue of the sei whale); (3) description of a rare feeding aggregation event observed in Faial and Pico islands; and (4) creation of local conservation measures, as a code of conduct, based on the new insight of the species ecology.

2.2. Materials and Methods

2.2.1. Study area

The Azores archipelago is part of the Macaronesia region in the North Atlantic, which includes Canaries, Madeira, and Cape Verde archipelago (Borges et al., 2020). Between 28° 00′ N – 48° 00′ N, and 17° 00′ W – 41° 00′W, this archipelago crosses the Mid-Atlantic Ridge and has an extension of 8,051,544 km^2, including the Exclusive Economic Zone (EEZ) (Peran et al., 2016). The Azores is composed by nine volcanic islands, divided in three groups: the west, with Corvo and Flores, the central with Faial, Pico, São Jorge, Terceira and Graciosa, and the eastern group with São Miguel and Santa Maria, as seen on figure 2.1 (Borges et al., 2020). The groups are separated by a complex ocean topography and waters that can be deeper than 2000 m, which make this region highly diverse in marine habitats, from shallow waters and a narrow continental shelf to deep waters (Pérez, 2003; González García et al., 2018).

The sea surface temperature in this region can go from 15ºC in the winter to 25ºC in the summer. The archipelago is mainly influenced by the cold branch of the Gulf Stream, the flowing south-eastward North Atlantic Current (NAC), between 45ºN and 48ºN, and the Azores Front/Current System (AF/AC), which passes in the south of the archipelago and is characterized by the strong salinity and temperature cross-gradients (Pérez, 2003; Sala et al., 2016; González García et al., 2018). These currents interaction is represented on figure 2.2 and it favours the aggregation of marine species in this region.

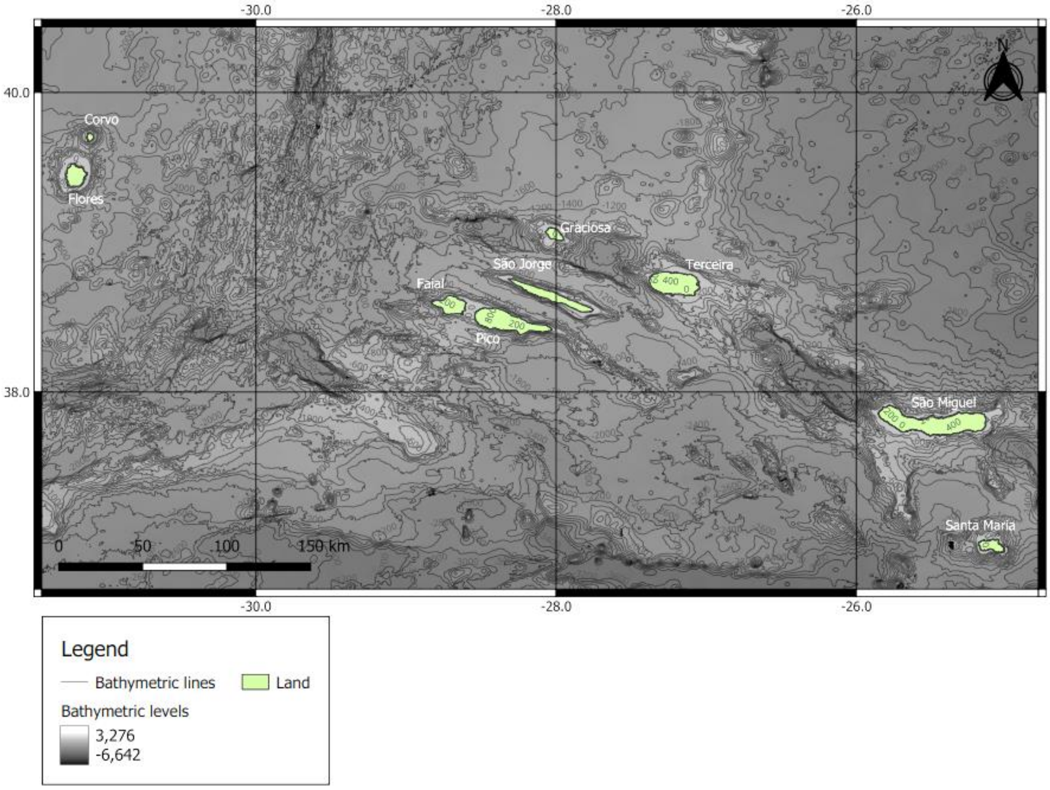

Figure 2. 1 - Study Area: Azores archipelago with its nine islands, bathymetry data and depth contours each 200 m.

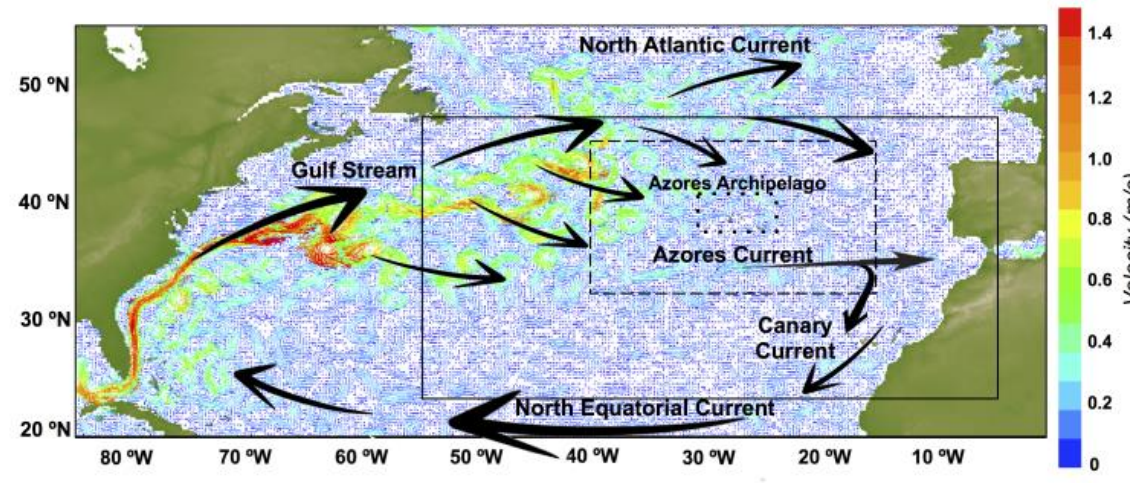

Figure 2. 2 - Currents interaction around the Azores archipelago. It is represented the Gulf Stream, the North Atlantic Current, the Azores Current, the Canary Current, and the North Equatorial Current. The dotted square limits the Azores archipelago. (Sala et al, 2016)

2.2.2. Data collection and analysis

2.2.2.1. Boat surveys

For this study, three different data sources were used: Naturalist, Science and Tourism, MONICET and POPA.

For all objectives, the main dataset is composed by opportunistic data collected from 2016 to 2022, by Naturalist, Science and Tourism, based in Faial Island. Additionally, the MONICET opportunistic data, used for the first and second objectives, was collected from 2009 to 2022 by several whale-watching companies from different islands in the Azores.

For each whale-watching surveys, spotters in specific locations in the islands, with professional binoculars (for instance, Steiner M1580 15x80mm) start searching for cetaceans about an hour before the boat's departure and share the location of the animals with the team that is on board, via VHF radio. Usually, they continue the observation of those animals until the boat reaches them and so, they know in advance where the animals are, and the boat can go directly to their locations. The cetaceans' sightings always follow the code of conduct for touristic whale-watching (Decreto Legislativo Regional Nº 10/2003/A de 22 de Março). Nevertheless, many sightings are spontaneous, as some animals may approach the boat, or some can be firstly observed by the team on the boat.

Once with the animals, marine biologists on board register several parameters, including species, date and time of the sighting, GPS location, number of individuals (adults and calves), observed behaviours (before and after), prey (only for feeding behaviour and if identified), animals' speed and travelling direction and presence of other species and other boats. All this data is registered on paper datasheets while on board or, in the case of Naturalist Research team data, it is directly registered in the app iNaturalist, in the Project "Baleias e Golfinhos – Portugal – Turismo de Conservação", where the same parameters are present. Permits and Research licenses are attributed to each specific whale watching company in each island and a specific Research licence attributed to Naturalist, Science and Tourism.

As complementary for the first and second objectives, POPA data, collected between 1998 and 2022, was analysed. This regional fisheries observation programme collects scientific data on board of commercial fisheries vessels in which the team is composed of observers with previous specific formation and the equipment includes GPS, binoculars, camera, and computers. The vessels can measure from 14 to 30 meters length with crews of 10 to 18 members and the fishing season tends to be from May to October of each year. The observers have the goal to collect continuous data about the target species (tunas) and all species that interact with this fishing activity (cetaceans, seabirds, and sea turtles). All data is registered on board in the official forms, created and later analysed by the POPA's scientific organization.

Thus, for the first and second objectives of this study, a total of 5174 encounters with sei whales were analysed, and 178 encounters for the third and fourth objectives, about the aggregation event.

2.2.2.2. Collected Parameters and analysis

For this study, the dataset was divided in two periods: between 1998 and July of 2022, to study the sei whale's habitat use and social ecology in the Azores, and from August to November of 2022, for the aggregation event.

Since the objectives of the present study include the analysis of the habitat use, social ecology and aggregation feeding event of the sei whale in the Azores, several parameters collected during the boat surveys were used: seasonality, bathymetry, group size, population structure and behaviour. Thus, all parameters were analysed for both study periods and then compared between them.

For the data analysis, all datasets were analysed using Microsoft Excel (for Microsoft 365 MSO, version 2304 Build 16.0.16327.20200, 64-bit) for the data preparation and tables, RStudio (version 4.3.0, 2023-04-21 ucrt) for graphs and statistical analysis (using the standard p-value of 0.05) and QGIS (version 3.28.4-Firenze) for map creation and extraction of bathymetric values, with the projection WGS84 Geographic Coordinate System. The coordinates were all converted to decimal degrees (DD).

Regarding the duplicates, the datasets were selected a priori and one company data per island was considered: Naturalist for Faial, and then from MONICET data, AquaAzores registrations were used for Pico and Picos de Aventura for Terceira and for São Miguel Islands. Nevertheless, there is a lack of data, especially in Faial, Terceira, and Pico islands, in 2016, and in Terceira, from 2020 to 2022

2.2.2.2.1 Seasonality and Bathymetry

For the seasonality and bathymetry, the presence of sei whales was registered with the coordinates of the location of the sighting in each boat survey, from each island dataset.

To analyse the seasonality of the sei whale in the Azores, it was created a presence table with the four-island data of sei whale, each one with a different colour on the month were the sei whale was present in the boat surveys. Additionally, a map with all encounters from the first studied period was created, in which the data from the four islands and POPA's data were included.

For the bathymetry, the data from Naturalist, MONICET and POPA were inserted in QGIS to map the spatial distribution of the sei whale's encounters. The GPS coordinates, collected during the boat surveys, were firstly converted to the same format, and plotted along the bathymetry, acquired from the General Bathymetric Chart of the Oceans (*GEBCO Gridded Bathymetry Data*, n.d.). Afterwards, to study the depth range of the sei whale, the average encounter depths, from 1998 to July of 2022, from four islands and different datasets, were extracted and analysed through a mean and standard deviation plot and the differences' significancy was evaluated with the non-parametric tests Kruskal-Wallis and its post-hoc pairwise comparison. Later, the aggregation event's encounters were also all represented on a map and then this data was compared with the data from the period before the event (1998-July of 2022). This comparison was represented on a mean and standard deviation plot and on a table with the correspondent values of average depth and standard deviation. Furthermore, an appropriate statistical test was performed to check the differences' significancy between the average depths of the different datasets.

2.2.2.2.2 Group size and population structure

While observing sei whales, the team on board, and after 5 minutes of in situ observations, counted the number of individuals visible until a quarter of mile from the boat in all directions. This parameter has been nominated group size.

For the average group size, the data was analysed with a mean and standard deviation plot and appropriate statistical tests were performed to evaluate the significancy of the differences between islands. Furthermore, the group size was divided in four classes: one individual, from two to five individuals, from six to ten and more than ten individuals, close to the boat. Then, from the total sei whale encounters, it was calculated the percentage of encounters with each group size class, for the four islands.

Additionally, to infer about the size of the population and its structure, population structure was also inspected such as the presence of adults, juveniles, or calves. Thus, the percentage of encounters with calves or juveniles was calculated, and then it was created a map in which the encounters with absence of calves or juveniles were distinguished from the encounters with their presence. Furthermore, an appropriate statistical test was performed to analyse the differences' significancy between the percentages of encounters with calves or juveniles of each dataset.

Additionally, the results from both periods were compared and the non-parametric tests Kruskal-Wallis and its post-hoc pairwise comparison were performed to check the differences' significancy.

2.2.2.2.3 Behaviour

From our best knowledge until now, there is a lack of knowledge regarding the behaviour on Sei whales and no ethograms were created for this species. With is in mind, an ethogram was created specifically for this species and to standardize the animals' behaviours based on recent studies conducted for other baleen whales (Torres et al., 2018). The ethogram is present at the results section (table 2.4) with support of images (figures 2.7 and 2.8) to better represent some specific behaviours, never recorded in the Azores.

To study the frequency of each observed behaviour, histograms were used to compare the data between islands and between two periods: from January to July and December, between 2009 and 2022 and from August to November, between 2009 and 2022 (not including the aggregation event in the Faial Island). Then, statistical tests were performed to analyse the differences' significancy.

For the analysis of feeding strategies, the average depths of the foraging-feeding encounters were analysed with a mean and standard deviation plot and the non-parametric tests Kruskal-Wallis and its post-hoc pairwise comparison were performed to compare the results from the two studied periods. Specifically for the aggregation event, the percentage of observation of each feeding strategy was analysed through a histogram and the Kruskal-Wallis statistical test.

2.2.2.2.4 Prey source

During the aggregation event boat surveys and while observing sei whales feeding, prey species were registered by *in situ* visual inspection or while analysing the videos or photography data set of the sightings. When identified, the prey species are also registered on the datasheet. Then, the percentage of observation of each prey species was calculated and compared with a histogram and the Kruskal-Wallis statistical test.

2.2.2.2.5 Photo identification

While on board, several photographs of the animals were taken, including both sides of the dorsal fins and the body, as some animals may be distinguished by their different coloration pattern and rostrum. The photographs were taken during the boat surveys, by the marine biologists on board with a camera Canon EOS 77D.

Later, at Naturalist base, all photos were downloaded and edited to then be used for the catalogue. The process starts by choosing the good quality photos, meaning they should not be blurry, unfocused and need to have an angle close to 90º to the fin, as observed on figure 2.3. Afterwards, the photos were divided on left and right side, 2x1 cropped using Microsoft Photos 2023.10030.27002.0 and named with a specific code, Company.Date.Region.ImageName, as in the following example: nt.20220723.azor.IMG_9515.jpg.

Figure 2. 3 - Example of a photo used for photo-identification of the sei whale, where is it possible to observe a dorsal fin with specific marks. (Naturalist, 2022)

A total of 715 photos from August of 2021 to October of 2022 were used to make the catalogue of Faial and Pico regions. Firstly, photos of dorsal fins with more distinguishable marks and shapes were selected and the individuals were identified. Then, the rest of the photos were compared with the already identified animals to look for re-sightings. If there was no re-sighting, a new individual would be added to the catalogue. Therefore, the catalogue is composed by left and right sides of each individual when the match was possible.

The photo-identification was supported by one Excel file, where many parameters of each photo were registered, as observed on Appendix I, figure IA.1. Although the main feature to identify the individual is the dorsal fin, in the cases where there were more difficulties, some body marks were also analysed.

2.2.2.2.6 Local conservation measures - Code of conduct

To suggest new conservation measures for the navigation near the feeding zones, the velocities of the animals, when they are transiting and feeding, were analysed. Furthermore, a code of conduct for touristic whale watching in the feeding zones was created with basis on the obtained results.

2.3. Results

2.3.1. Habitat use and Social Ecology in the Azores

2.3.2.1. Seasonality

From the data collected, and as represented on figure 2.4, it is possible to observe all sei whales' sightings from 1998 to 2022, excluding the encounters during the aggregation event (from August to November of 2022, in Faial). These registrations are from the four studied islands: Faial, Pico, São Miguel, and Terceira. There were several sei whales' encounters in the south of Pico (149) and São Miguel (133) and POPA's data, collected with a different method, has registrations practically across the entire archipelago (with a total of 372 sei whales' encounters).

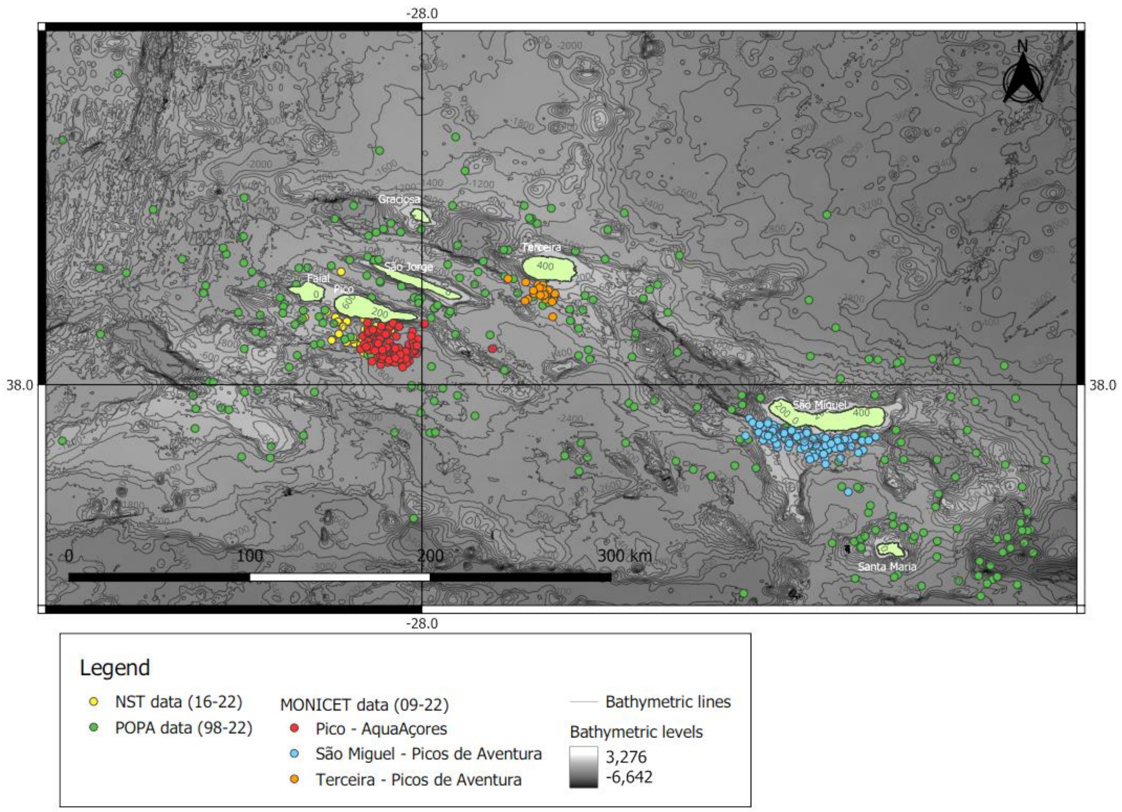

Figure 2. 4 - Map with sei whale encounters from 1998 to July of 2022. Sightings in Faial are on yellow, in Pico on red, in Terceira are on orange and in São Miguel on blue. POPA sightings are represented by the green dots.

The seasonality of sei whale in the Azores was analysed through a presence table, represented on table 2.1. It is possible to observe that in the Azores the sei whale was mostly spotted from April to October and on the last two years, the observations increased in Faial Island and decreased in São Miguel Island. Few data exist for Pico and Terceira Islands.

Table 2. 1 – Opportunistic observation of *Balaenoptera borealis* from boat surveys' registrations in 4 islands of the Azores archipelago. Each island has a different colour at the table. Faial (blue colour), Pico (green colour), Terceira (yellow colour), and São Miguel Island (orange colour), from 2016 to 2022. ND means there is no data from that island on that date.

<table>
<tr><th>2016</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pico</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td></tr>
<tr><td>Terceira</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>2017</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td></td><td style="background:#9DC3E6"></td><td></td><td></td><td></td></tr>
<tr><td>Pico</td><td></td><td></td><td></td><td></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td></td><td style="background:#A9D18E"></td><td></td><td></td></tr>
<tr><td>Terceira</td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#FFD966"></td><td style="background:#FFD966"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td style="background:#F4B183"></td><td></td><td style="background:#F4B183"></td><td></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td></td></tr>
<tr><th>2018</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td></td><td></td><td></td></tr>
<tr><td>Pico</td><td></td><td></td><td></td><td></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Terceira</td><td></td><td></td><td></td><td></td><td></td><td style="background:#FFD966"></td><td style="background:#FFD966"></td><td style="background:#FFD966"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>2019</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pico</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#A9D18E"></td><td></td><td></td></tr>
<tr><td>Terceira</td><td></td><td></td><td></td><td style="background:#FFD966"></td><td style="background:#FFD966"></td><td></td><td></td><td></td><td style="background:#FFD966"></td><td></td><td></td><td></td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td></td><td></td><td></td><td style="background:#F4B183"></td><td></td><td></td></tr>
<tr><th>2020</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td></td><td></td><td></td></tr>
<tr><td>Pico</td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td></td><td></td><td></td></tr>
<tr><td>Terceira</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#F4B183"></td><td></td><td></td><td></td><td></td></tr>
<tr><th>2021</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td></td></tr>
<tr><td>Pico</td><td></td><td></td><td></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td style="background:#A9D18E"></td><td></td><td></td></tr>
<tr><td>Terceira</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>2022</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Faial</td><td></td><td></td><td></td><td></td><td style="background:#9DC3E6"></td><td></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td style="background:#9DC3E6"></td><td></td></tr>
<tr><td>Pico</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Terceira</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td></tr>
<tr><td>São Miguel</td><td></td><td></td><td></td><td></td><td style="background:#F4B183"></td><td></td><td style="background:#F4B183"></td><td style="background:#F4B183"></td><td></td><td></td><td></td><td></td></tr>
</table>

2.3.2.2. Bathymetry

After the calculation of the depth of occurrence of each encounter, through the created maps, the values were analysed and compared as showed below, on figure 2.5, where all sei whale sightings, from the four studied islands and from 1998 to July of 2022 were considered. Regarding the data obtained using POPA dataset, they have more variability from the mean, and, on average, the encounters were on deeper zones (average encounter depth of 2385 m) while in the maritime-touristic encounters, the range is smaller, and the average depth is 1058 m. The total dataset, includes both previous datasets and is a suggestion of what could represent the general depth range of the sei whale in the Azores, but statistical tests must prove there is no significant differences between A and B. Since the requisites to perform a parametric test were not met, a Kruskal-Wallis was used, and it proved that the differences on the average depth between the datasets are statistically significant (p-value $< 2^{e-16}$). Furthermore, with a post-hoc pairwise comparison using Wilcoxon rank sum test, it was possible to ensure that all datasets are statistically different among them (p-value $_{B\ vs\ A\ +\ B\ vs\ C}$ < 2e-16, p-value $_{C\ vs\ A}$ = $1.4e^{-11}$).

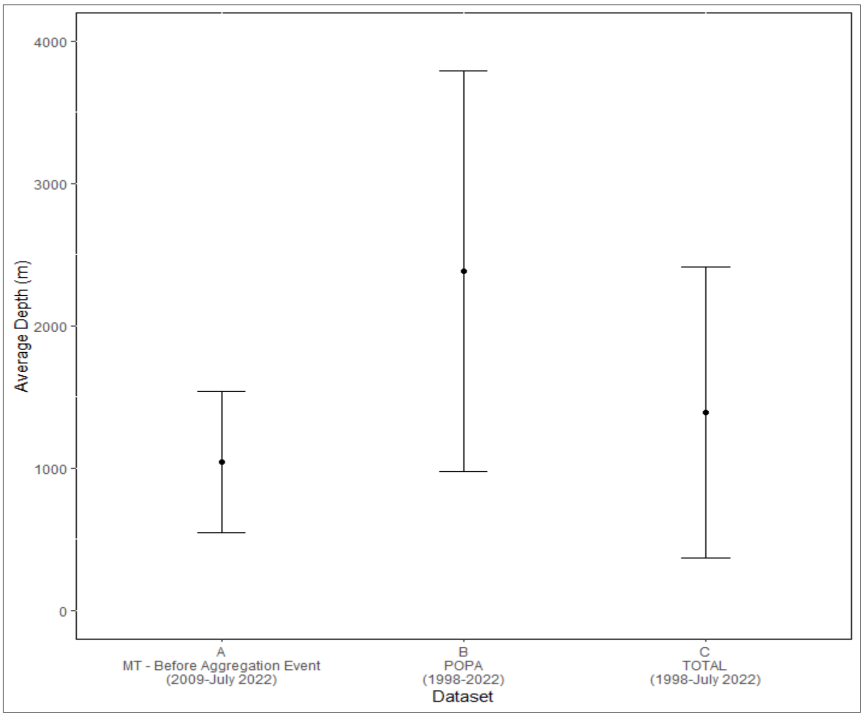

Figure 2. 5 - Mean plot representing the mean and standard deviation of the encounters' bathymetric values. The data was separated in four groups: **A** - Data collected in four islands, by the touristic boats, before the aggregation event, **B** – Data collected in POPA's fishing vessel, and **C** – All data collected from the touristic boats and POPA's fishing vessel, before the aggregation event (A+B).

2.3.2.3. Group size

Regarding the group size and according to the figure 2.6, it is possible to observe that the average size of the observed groups from each dataset between island is not significantly different. Nevertheless, the mean is higher in São Miguel Island (1.82 individuals) and lower in Terceira Island (1.45 individuals). Without the requisites to perform a parametric test, it was obtained the p-value 0.03148 with a Kruskal-Wallis test. This means that the average group size may not be all the same, but with a post-hoc pairwise comparison using Wilcoxon rank sum test, no p-value was lower than alpha and so, differences on the group size are not statistically significant between islands.

Additionally, and as observed on table 2.2, most of the sightings were with only one individual (57.81% in Faial, 58.78% in Pico and 70% in Terceira), except for São Miguel Island, where in 57.89% of a total of 133 encounters, the species was observed in groups between two and five individuals.

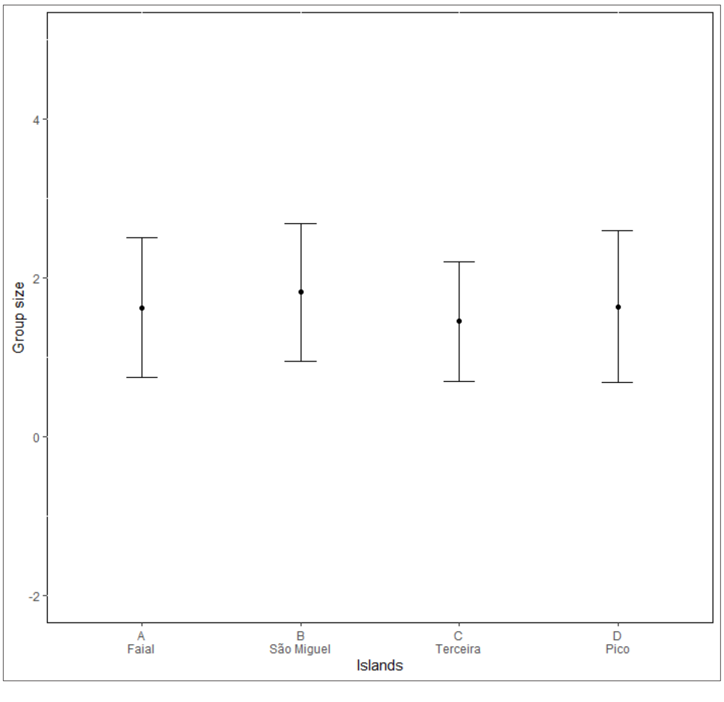

Figure 2. 6 - Mean plot representing the mean and standard deviation of the size of the observed groups in the encounters with sei whale, from 2009 to July of 2022. The data was separated in the four studied islands: A-Faial, B-São Miguel, C-Terceira, D-Pico. Faial data does not include the aggregation event registrations.

Table 2. 2 – Group sizes of *B.borealis* from the encounters from 1998 to 2022.

Islands	Total nr of encounters	Percentage of observation of group size class (From 2009 to July of 2022)			
		1	2-5	6-10	>10
Faial*	64	57.81%	42.19%	0.00%	0.00%
Pico	148	58.78%	40.54%	0.68%	0.00%
Terceira	20	70.00%	30.00%	0.00%	0.00%
São Miguel	133	42.11%	57.89%	0.00%	0.00%

*Faial's data does not include the aggregation event registrations.

2.3.2.4. Population structure

In terms of population structure, it was analysed the presence for juveniles and or calves by the percentage of encounters from the four studied islands: Faial, Pico, Terceira, and São Miguel and from POPA data. On figure 2.7, all encounters with presence of calves or juveniles are represented and on table 2.3 there are the corresponding percentage of those encounters. As observed, more calves or juveniles have been registered in POPA expeditions, with 7.00% of the encounters with calves or juveniles, Faial Island, and São Miguel Island with 4.23% and 3.76% of these encounters respectively. Since the requisites for a parametric test were not met, a Kruskal-Wallis test was performed, in which it was shown that there are statistically significant differences between the percentage of encounters with calves or juveniles between datasets (p-value= 0.001955). Furthermore, with a post-hoc pairwise comparison using Wilcoxon rank sum test, it was possible to see that the significant differences are between POPA and Pico, Terceira, and Faial values and then between São Miguel and Terceira values (p-values represented on table IA.2).

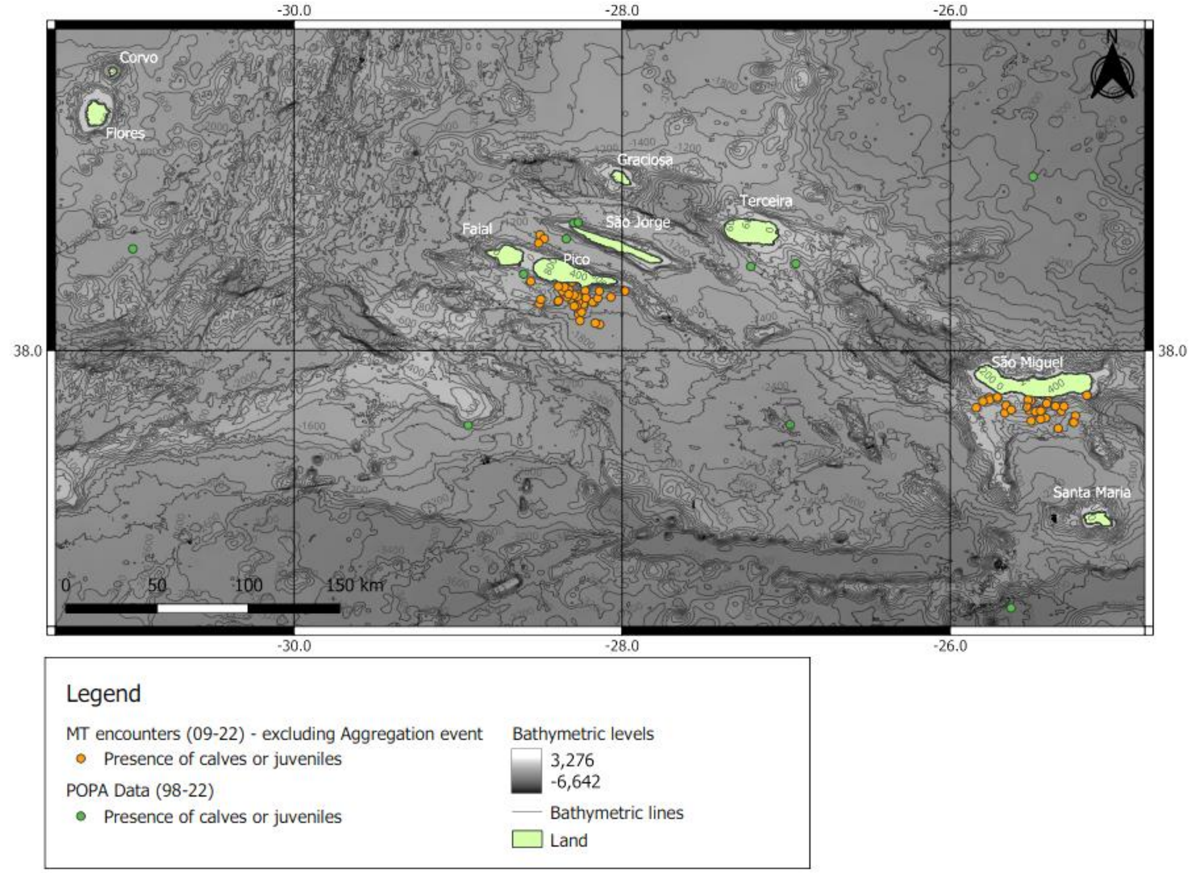

Figure 2. 7 - Map with the encounters with calves or juveniles. Red dots represent the maritime-touristic encounters in the four studied islands, from 2009 to 2022. In Faial data, the aggregation event data were excluded. The green dots represent the POPA encounters with presence of calves or juveniles, from 1998 to 2022.

Table 2. 3 - Percentage of encounters with presence of calves or juveniles, from 1998 to 2022.

Datasets	% Of encounters with calves or juveniles (1998-2022)
Faial	4.23%*
Pico	2.68%
Terceira	0.00%
São Miguel	3.76%
POPA	7.00%

*Faial's data does not include the aggregation event registrations.

2.3.2.5. Behaviour

Below on table 2.4, an ethogram is proposed, with basis on the general baleen whales' behaviour and on other studies, such as one where an ethogram was defined for the gray whale (Torres et al., 2018). The present table was created to collect the data for this project and to be used in the future.

For the feeding strategies, the terms were described with basis on several studies and books about the rorqual whales' feeding behaviour and then, a nomenclature was defined. Thus, sei whales can switch between two main feeding strategies: Skimming, a continuous slow filtering ram-feeding, at the surface, in which whales strain food through their bristles in the baleen plates, as observed on figure 2.8 (Segre et al., 2021). Then, there is the Lunging, an intermittent feeding, in which they gulp a large mouthful of food from a bait ball and in some cases they do it horizontally at the surface, represented on figure 2.9 (Goldbogen et al., 2012; Keen, 2017; Segre et al., 2021; van der Hoop et al., 2019). This last strategy starts with a body acceleration, followed by a wide opening of the mandibles and expansion of the buccal cavity, so a great volume of water is engulfed (represented on figures 2.9C and 2.9D) and then it is expelled through the baleen plates, while the prey are retained in the buccal cavity (Goldbogen et al., 2007). In this strategy, the filtration tends to take longer and has higher energetic costs than in the skim-feeding (Acevedo-Gutiérrez et al., 2002; Goldbogen et al., 2007; Keen, 2017; Segre et al., 2021). Additionally, some behaviours are more difficult to be distinguished or well-known so, new terms were defined: Multiple skimming, when several skim movements are performed, Vertical, which can be a skimming or a vertical lunging and Skimming followed by Lunging, when the animal performs a skim movement followed by a lunging and engulfment.

Table 2. 4 - Ethogram created for the encounters with sei whales. The different feeding strategies were described according to our observations and based on some previous studies, such as Torres et al. (2018).

Behaviour	Definition
Slow Transit - TS	The animal is swimming without changing direction, with regular surfacing intervals, at a slow speed (<3knots).
Average Transit - TA	The animal is travelling at an average speed (3-5 knots).
Fast Transit - TF	The animal is swimming without changing direction, with regular surfacing intervals, at a fast speed (> 6knots).
Foraging - FO	There is not a regular direction, and the whales stay in a general area. Surfacing intervals may be irregular and can occur with a high arch terminal dive so they have a more vertical body angle. It may also be observed defecation, sharking (vertical profile of half the fluke above the water surface) and bubble blasts (underwater release of air that rises to surface and forms a circle/puka).
Feeding - F	The whales show the different strategies to catch the prey. It can be possible to observe the bait balls and prey remainings at the surface. Possible strategies: SK – Skimming 1x; L – Lunging (lateral); V - Skimming/Vertical Lunging; MSK – Multiple Skimming; SK+L – Skimming and Lunging; UN - Unknown.
Social - SO	Interactions with a conspecific, that can be a tactile action, mother/calf nursing, or coordinate surface activity (e.g., racing and splashing).
Rest - R	Whale remains in the same location, lying at or just below the surface, showing no action or a minimal fluking, to promote movement. Surfacings are generally slow and at regular intervals.
Unknown - UN	No known or classifiable behaviour patterns are observed.

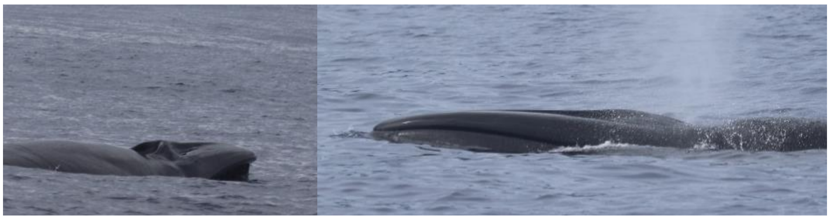

Figure 2. 8 - Sei whales performing skim-feeding. (Naturalist, 2022)

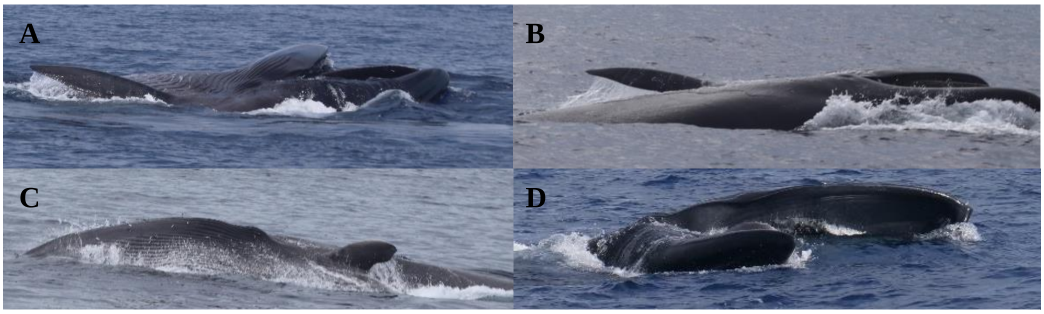

Figure 2. 9 - Sei whales performing lunge-feeding. On figures C and D, it is observed an engulfment, one of the steps on this feeding strategy. (Naturalist, 2022)

For the behaviour analysis, two comparisons were made: all registered behaviours from January to July and December, between 2009 and 2022 and all registered behaviours from August to November, between 2009 and 2022 (not including the aggregation event in the Faial Island) and this analysis can be seen on figure 2.10. As observed, the most common behaviour is transiting followed by foraging-feeding, on the four islands. The non-parametric test Kruskal-Wallis and the post-hoc pairwise comparisons using Wilcoxon rank sum test were performed and from January to July and December, the significant differences occur in registrations in São Miguel and Faial Islands. In São Miguel, the frequencies of transiting are statistically significantly higher than the frequencies of foraging-feeding, socializing, and resting (p-value $_{TvsFO+F}$= 0.00193, p-value $_{TvsR/SO}$= 0.00053). In Faial, the percentage of observation of transiting is significantly higher than foraging-feeding and the resting behaviours' frequencies (p-value $_{TvsFO+F/R}$= 0.0085). Furthermore, statistical tests were also made to compare each island data by behaviour, and there are no statistically significant differences on its percentage of observation among islands (p-value > 0.05).

Additionally, from August to November, the frequency of transiting and foraging-feeding are significantly higher than the frequency of socializing, in São Miguel Island data (p-value $_{SOvsT/FO+F}$=0.015). On the other islands and for each behaviour, compared by islands, there are no significant differences (p-value >0.05).

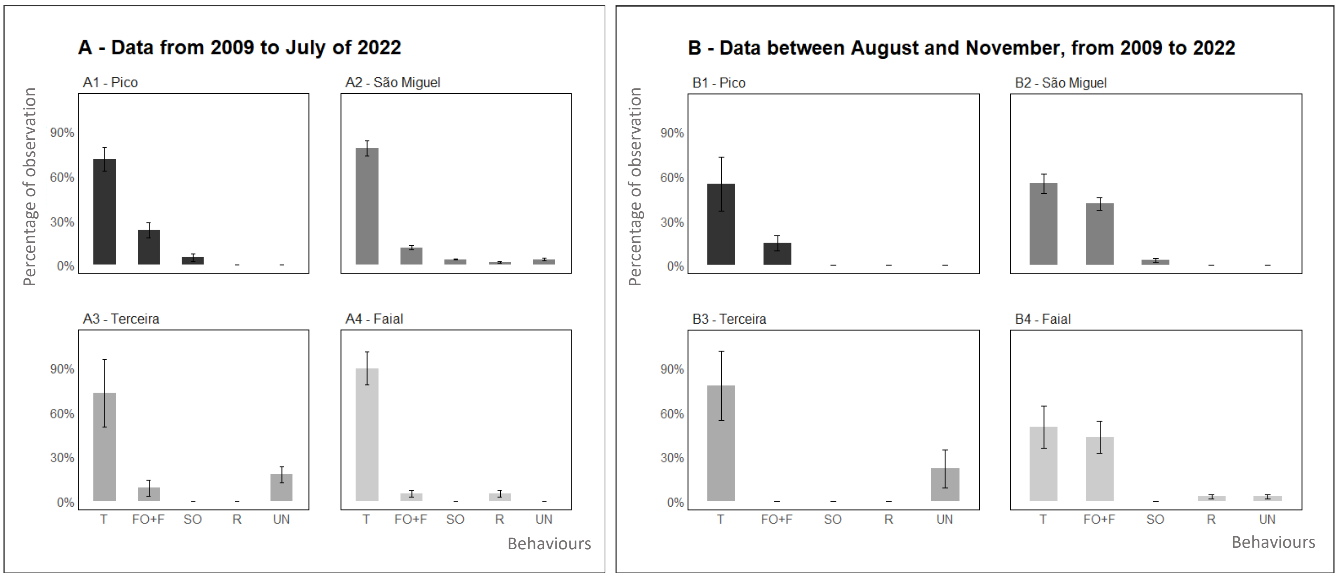

Figure 2. 10 - Bar plots representing the percentage of observation and the associated error bars of the sei whales' behaviours observed during the boat surveys. T refers to Transiting, FO+F to Foraging and Feeding, SO to Socializing, R to Resting and UN to Unknown. The data was in two time periods: **A** – data from 2009 to July of 2022 and **B** – data from 2009 to 2022, only from August to November. Per each figure, the data was also divided by the fours studied islands: **A1** and **B1** - Pico, **A2** and **B2** - São Miguel, **A3** and **B3** - Terceira, and **A4** and **B4** - Faial).

2.3.2. Aggregation Event

2.3.2.1. Bathymetry

From the data collected during the aggregation event, from August to November of 2022, the 178 encounters were represented on a map, as seen in figure 2.11.

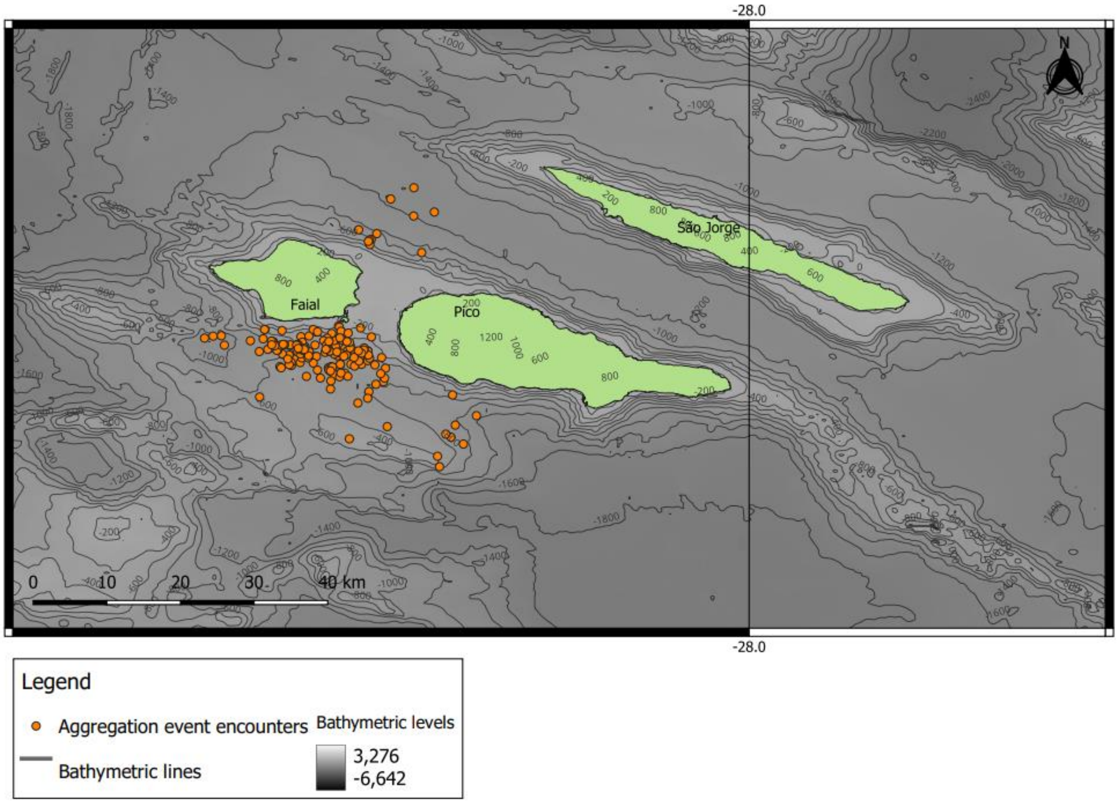

Figure 2. 11 - Map with the orange dots representing sei whale encounters between August and November of 2022, near Faial and Pico Islands

Afterwards, the average encounters depth was analysed, as represented on figure 2.12, where it is possible to observe that the collected data during the aggregation event is less variable and from the mean and the average is lower than on the other studied period and datasets (714.68m, as observed on table 2.5), while the average encounter depth of POPA's data, 2384.54 m is the highest and more variable from the mean. Since the normality assumptions were not met, a non-parametric test was performed to evaluate if there were statistically significant differences between the values. The Kruskal-Wallis test showed that there are significant differences between the datasets (p-value<$2.2e^{-16}$). Additionally, the post-hoc pairwise comparison using Wilcoxon rank sum test proved that all datasets have statistically differences and so, the average encounter depth during the aggregation event is significantly different from the average encounter depth from the other datasets (p-value < 0.05, as represented on the figure Appendix I, Figure IA.3).

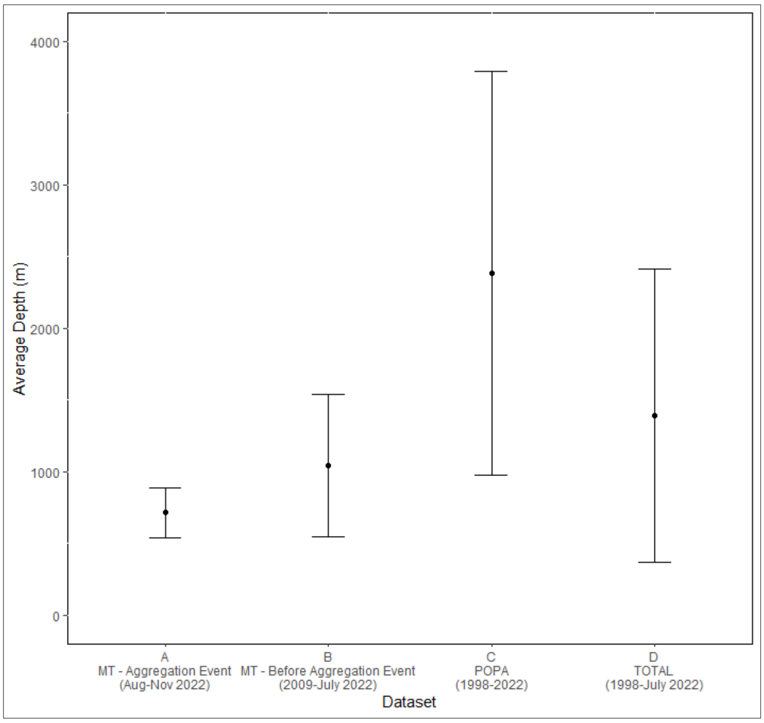

Figure 2. 12 - Mean plot representing the mean and standard deviation of the encounters' bathymetric values. The data was separated in four groups: **A** - Data collected by the tourism boats during the aggregation event, **B** – Data collected by the touristic boats before the aggregation event, **C** – Data collected in POPA's fishing vessel, and **D** – All data collected from the touristic boats and POPA's fishing vessel, before the aggregation event.

Table 2. 5 - Average encounters' depth and the respective standard deviations of data collected by maritime-touristic companies and by POPA. The TOTAL dataset represents all data together besides the aggregation event registrations.

Dataset	Average Depth (m)	Standard Deviation
MT - Aggregation Event (Aug-Nov 2022)	714.6798	173.7737
MT - Before Aggregation Event (2009-July 2022)	1041.6796	498.6862
POPA (1998-2022)	2384.5445	1407.6127
TOTAL (1998-July 2022)	1390.317	1021.923

2.3.2.2. Group Size

The average group size was also calculated for the encounters during the aggregation event and as observed on figure 2.13, this value is higher and the data is more variable from the mean, when compared with the data before this event. Additionally, with no requisites to perform a parametric test, the Kruskal-Wallis was used, and it was obtained a p-value of 0.008986, and the post-hoc pairwise comparison using Wilcoxon rank sum test proved that no p-value is smaller than alpha and so, the average group size during the aggregation event is not significantly different from the average group size before the event. Nevertheless, during the aggregation event, from 186 encounters with sei whales and as observed on table 2.6, in the majority one or two individuals were present (47.85% both), but in 3.23% and 1.08% of the encounters, there were from six to ten individuals and above ten, respectively.

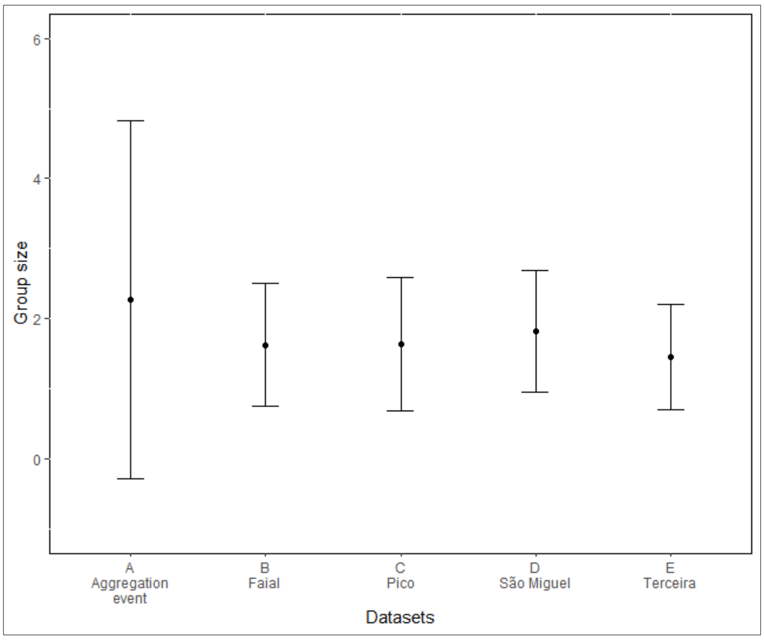

Figure 2. 13 - Mean plot representing the mean and standard deviation of the encounters' observed group size. The data was separated in four groups: **A** - Data collected by the tourism boats during the aggregation event, **B** – Data collected by the touristic boats before the aggregation event, **C** – Data collected in POPA's fishing vessel, and **D** – All data collected from the touristic boats and POPA's fishing vessel, before the aggregation event.

Table 2. 6 - Total number of encounters from the different datasets (Faial during the aggregation event, Faial before the event, Pico, Terceira, and São Miguel); Percentage of observation of each group size class: 1, 2-5, 6-10, >10.

Datasets	**Total nr of encounters**	**Percentage of observation of group size class**			
		1	**2-5**	**6-10**	**>10**
Faial (Aggregation event)	186	47.85%	47.85%	3.23%	1.08%
Faial	64	57.81%	42.19%	0.00%	0.00%
Pico	148	58.78%	40.54%	0.68%	0.00%
Terceira	20	70.00%	30.00%	0.00%	0.00%
São Miguel	133	42.11%	57.89%	0.00%	0.00%

2.3.2.3. Population structure

From the bathymetric data collected during the aggregation event, it was possible to compare the average encounter depth, and here, the data is divided in two groups: encounters with presence of calves or juveniles and encounters without calves or juveniles, as it is possible to see on figure 2.14. On figure 2.15, it is represented the average depth of the same encounters. Afterwards, the statistical test Kruskal-Wallis was performed, and it was obtained a p-value of 0.4585, meaning there are no significant differences in the average encounter depth between encounters with and without calves or juveniles.

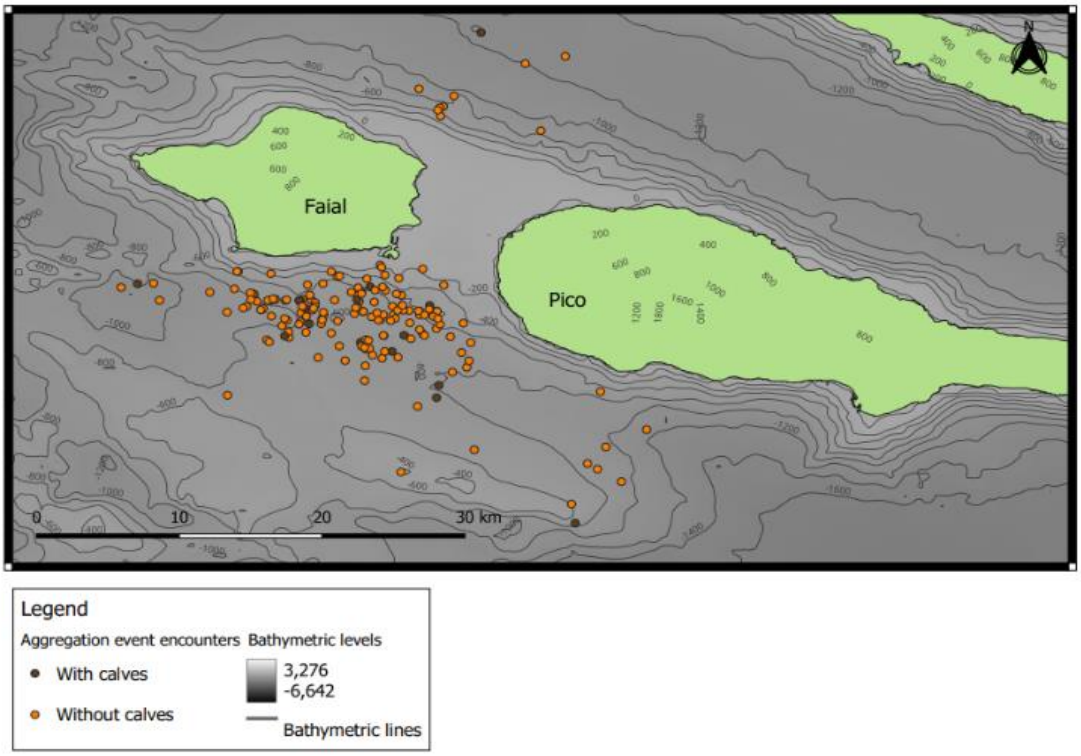

Figure 2. 14 - Map with the encounters with calves or juveniles and the encounters without, during the aggregation event. The orange dots represent the registrations without calves and the brown dots represent the encounters with calves.

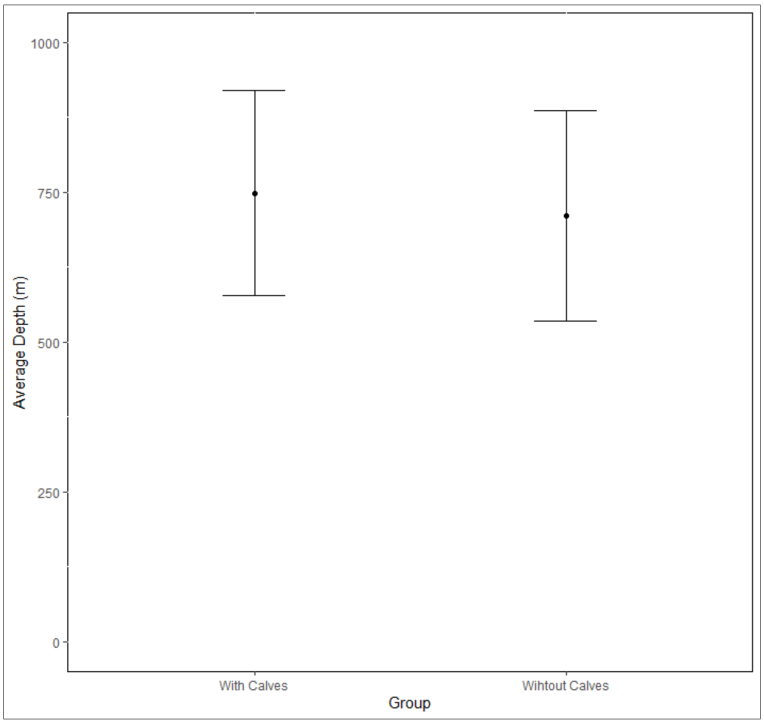

Figure 2. 15 - Mean plot representing the mean and standard deviation of the average encounters' bathymetric values. The data was separated in two groups: **With Calves** - Encounters with presence of calves or juveniles and **Without calves** – encounters without the presence of calves or juveniles.

Afterwards, all calves and juvenile data from the different studied periods and datasets were compared, represented on figure 2.16. As observed in the table 2.7, from 2016 to July of 2022, near Faial Island, calves or juveniles were observed in 4.23% of the encounters with sei whales. During the feeding aggregation event, from August to November of 2022, they were observed in 10.31% of the encounters. From 2009 to 2022, in Terceira Island, no calves or juveniles were registered in the encounters with sei whales and in Pico Island they were present in 2.68% of the encounters, only before the aggregation period. Finally, from 2009 to 2022, in São Miguel Island, calves or juveniles were registered in 3.13% of the encounters with sei whales, and in 20% of the encounters during the aggregation period. For the POPA data, 7% of the encounters, before the aggregation event, had the presence of calves or juveniles. Without the requisites for a parametric test, A Kruskal-Wallis test was performed in which the p-value of 0.001955 proves that there are significant differences between the percentages of encounters with calves or juveniles, from the different datasets. Furthermore, the post-hoc pairwise comparison using Wilcoxon rank sum test shows that some p-values are smaller than alpha and so, the significant differences are between POPA's data and Pico, Terceira, and Faial's data and then between Terceira and São Miguel's data.

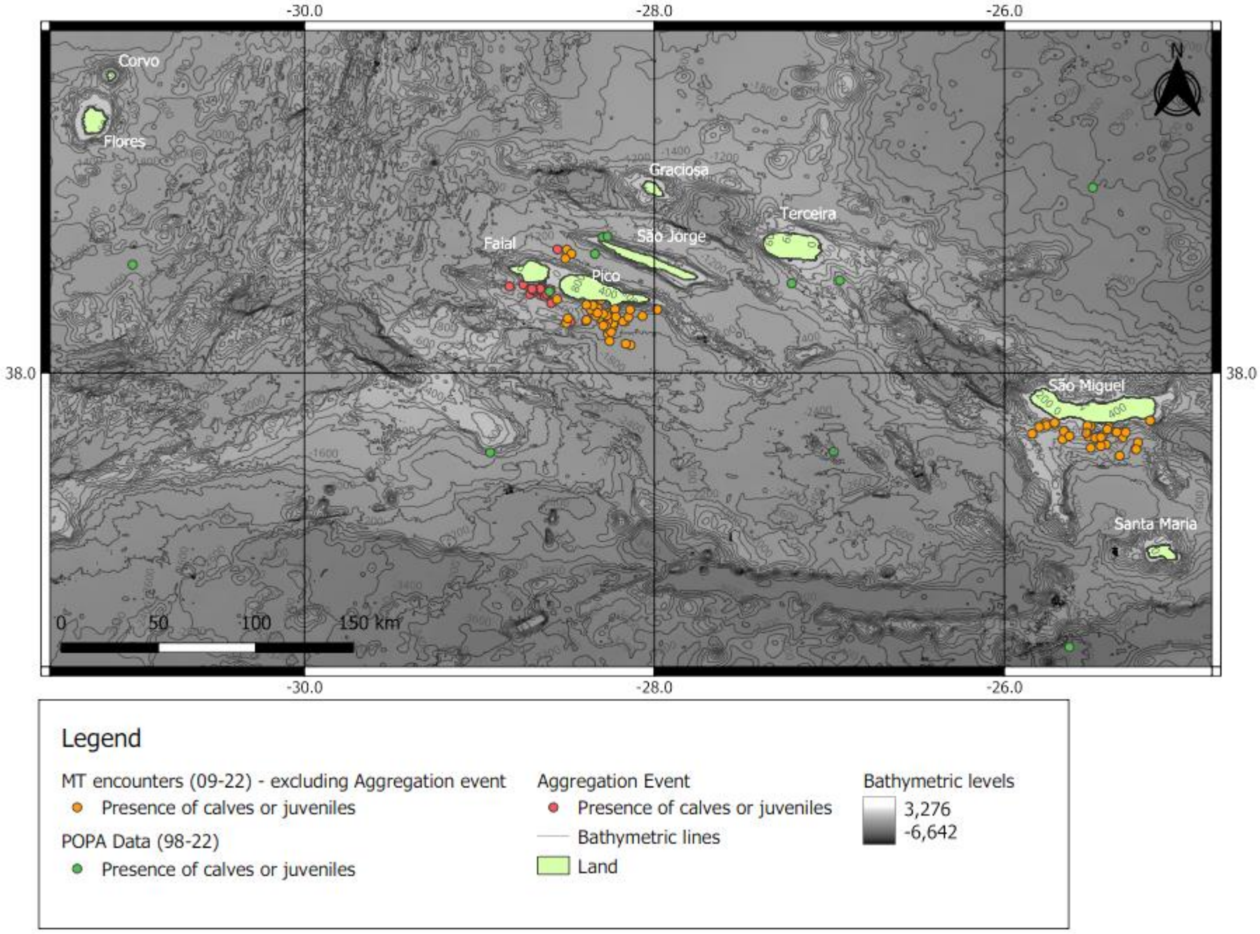

Figure 2. 16 - Map with the encounters with calves or juveniles. The orange and green dots represent the registrations until July of 2022 and the red dots represent the registrations during the aggregation event.

Table 2. 7 - Percentage of encounters with presence of calves and juveniles, before and during the aggregation event. The data was divided in the five studied datasets: Faial, Pico, Terceira, São Miguel and POPA.

% Of encounters with calves or juveniles		
Datasets	**Before the event**	**Aggregation Event (Aug-Nov 22)**
Faial	4.23%	10.31%
Pico	2.68%	0.00%
Terceira	0.00%	0.00%
São Miguel	3.76%	20.00%
POPA	7.00%	0.00%

2.3.2.4. Behaviour

To analyse the differences in foraging-feeding behaviour, before and during the aggregation event, the average encounters' depth, while sei whales were foraging, was calculated, with the respective standard deviation, as seen on figure 2.17. The Kruskal-Wallis test was performed and there are statistically significant differences between the encounter depth where sei whales forage before and during the event (p-value = $4.208e^{-15}$).

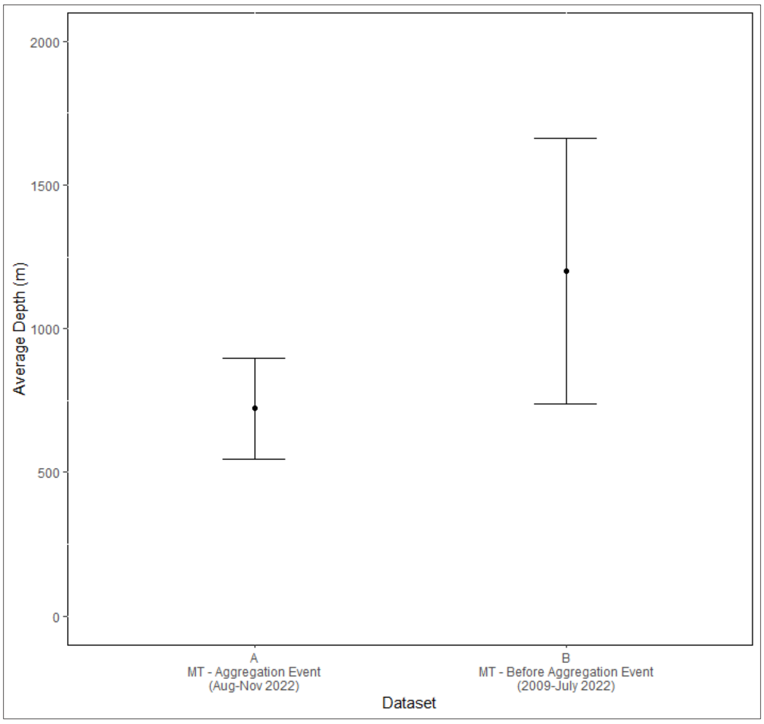

Figure 2. 17 - Mean plot representing the mean and standard deviation of the encounters' depth of occurrence, when sei whales were foraging. The data was separated in two groups: **A** - Data collected by the tourism boats during the aggregation event, and **B** – Data collected by the touristic boats before the aggregation event.

During the feeding aggregation event, the most observed behaviour was foraging-feeding (50.8%), followed by transiting (44.0%), as observed on figure 2.18. Since the requisites for a parametric test were not met, a Kruskal-Wallis test was performed. With a p-value of 0.002, being smaller than alpha, there are statistically significant differences between the frequency of the observed behaviours. Consequently, with a post-hoc pairwise comparison using Wilcoxon rank sum test, it was possible to see that the statistically significant differences are between foraging-feeding and resting and socializing (p-value $_{FO+F\ vs\ R/SO}$=0.043), between transiting and resting and socializing (p-value $_{T\ vs\ R/SO}$=0.043). Between foraging-feeding and transiting behaviours, the frequencies of occurrence are not significantly different.

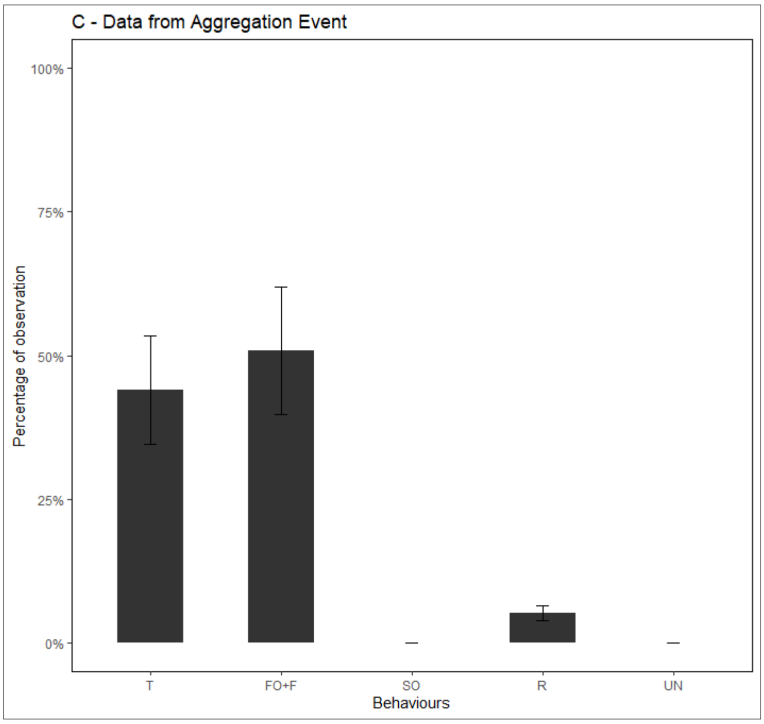

Figure 2. 18 - Frequency of observation of the different sei whale's behaviours, during the aggregation event. T refers to Transiting, FO+F to Foraging and Feeding, SO to Socializing, R to Resting and UN to Unknown.

During the event, sei whales preformed different feeding strategies that were also analysed, as observed on figure 2.19, being the Lunging the more frequent strategy (32.95%), followed by Skimming (18.18%). Without the requisites for a parametric test, the non-parametric test Kruskal Wallis was performed and there are no statistically significant differences between the percentage of observations of the different strategies (p-value = 0.5483).

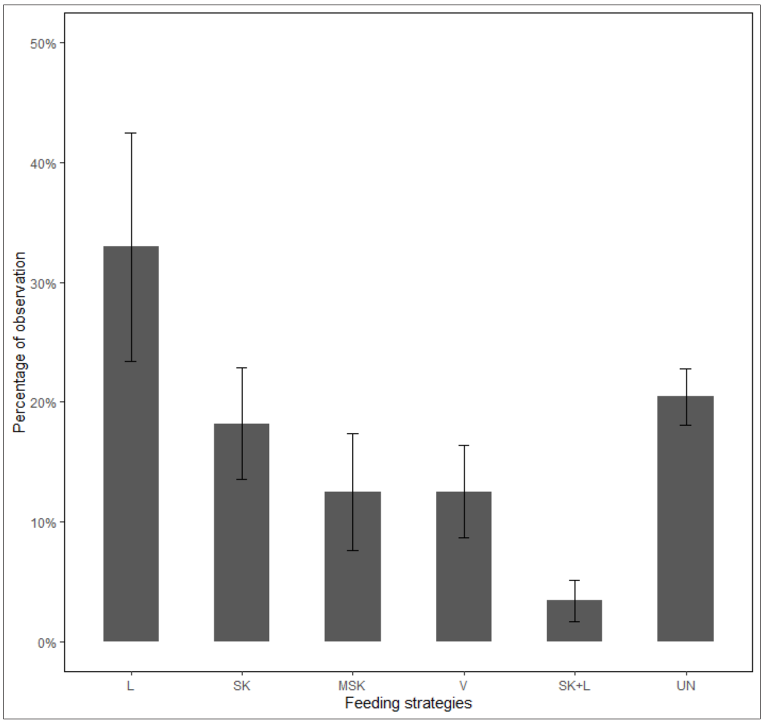

Figure 2. 19 - Percentage of observation of the different sei whale's feeding strategies, during the aggregation event. L refers to Lunging, SK to Skimming, MSK to Multiple Skimming, V to Skim/Vertical Lunging, SK+L to a Skimming with a Lunging and UN to unknown strategy.

2.3.2.5. Prey source

During these sightings, in 21 surveys, it was possible to identify the prey and so, their percentages of observation were analysed. The most observed species was *Macroramphosus scolopax*, present in 48% of the observations, also known as longspine snipefish, as observed on figure 2.20. This species is followed by the *Capros aper*, present in 33% of the observations and then there is *Trachurus trachurus*, present in only 19% of the events. With lack of the parametric test requisites, a Kruskal-Wallis test was performed and there are no significant differences between the percentage of observation of these three species (p-value=0.8905).

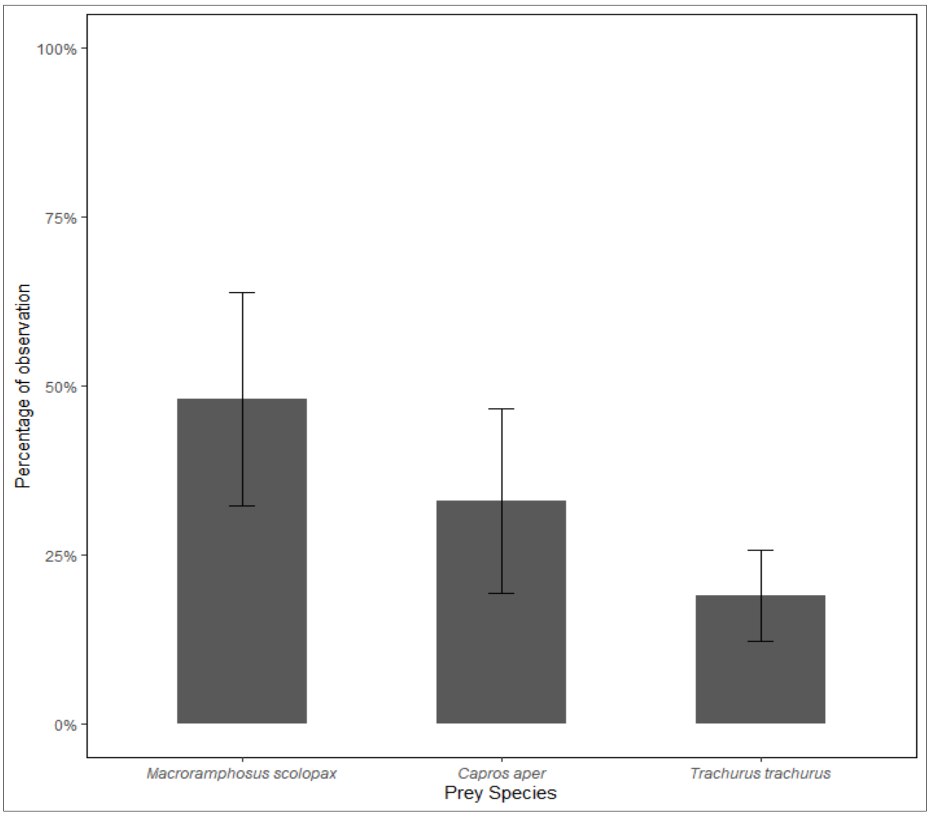

Figure 2. 20 - Percentage of observation of the different sei whale's prey species.

2.3.2.6. Photo Identification

With high certainty it was possible to identify 79 different individuals that were in the Azores during the aggregation event and the individual BB32 was seen in two different days, in 27th of August and 1st of September. No matches were found between the individuals from this event and the ones that passed by on the previous summer, in 2021.

2.3.2.7. Local conservation measures - Code of conduct

On table 2.8, it is presented the analysis of the velocity of the sei whale when in transiting and feeding. It shows that the average velocity while feeding is 3.04 knots and in transiting is 3.75 knots. Since the main behaviour observed on the studied event was feeding, in which the whales' activity is more sensible than being in transit, specific measures should be included in the code of conduct for whale watching, during feeding in the Azores. Therefore, there is a suggestion of a code of conduct for these events, represented on figure 2.21.

Table 2. 8 - Analysis of the recorded speed of sei whales while transiting and feeding.

Behaviour	Speed (knots)		
	Average	Minimum	Maximum
Transiting	3.75 ± 1.93	2.00	11.00
Feeding	3.04 ± 1.07	2.00	5.00

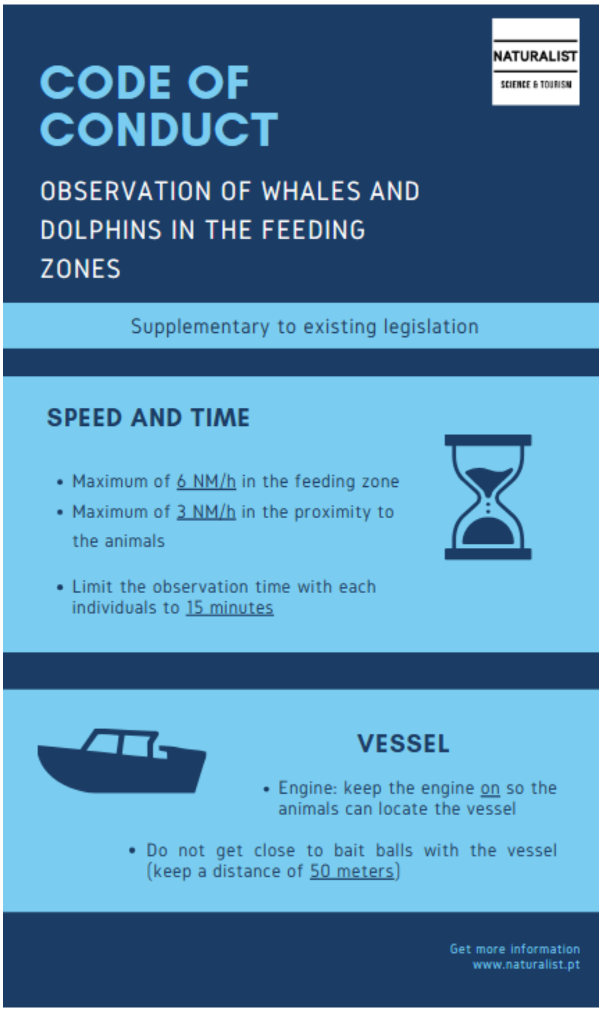

Figure 2. 21 - Suggestion of code of conduct for the whale-watching in feeding zones (Portuguese version is on the appendix, represented on figure IA.4).

2.4. Discussion

This study offers updated insights into the habitat use and social ecology of the sei whale in the Azores, filling a gap in the understanding of sei whale's aggregation events, by describing for the first time a feeding aggregation event in the Azores archipelago. It is provided information on the seasonality, bathymetry, group size, population structure and behaviour of this species in four islands in the Azores, through the combination of several opportunistic and transect data. Several datasets were used for this study on *Balaenoptera borealis*, ranging from 1998 to 2022, in which two different studied periods were investigated: from 1998 to July of 2022 and from August to November of 2022, when the aggregation event was recorded.

The present study can contribute to conservation measures as new information about the sei whale in the Azores was obtained and a new event described, where more appropriate and specific measures should be taken. However, while interpreting the results of the present study, it should be bear in mind some caveats that can affect them. Firstly, the analysis is based on opportunistic data, collected during whale watching boat surveys. This method has its advantages and limitations. The main limitation is the time spent with cetaceans being dependent on the surveys' duration and the presence of tourists and the fact that these surveys are dependent on the weather conditions (sea state and visibility), which have impact on the land spotters, skippers, and biologists to spot, identify and count the individuals. Nevertheless, the surveys' duration and time schedule and the data collection methods were kept constant, as much as possible during the studied period. Additionally, the animals' behaviour, as the velocity, direction, and surface time, has impact on the probability of sighting them and so, encounters with less changes of observation and more elusive behaviours are less favoured due to commercial reasons. However, opportunistic data, at least for this study, showed some advantages, as it was possible to have several surveys per day during several months, having a long-term database and to have a high spatial cover, presented by this touristic activity.

All encounters with sei whales, excepting the ones during the aggregation event (figure 2.4), were observed in great abundance mainly in the south regions of the studied islands. It is important to consider that those regions are the whale-watching areas and does not mean no sei whale is present all around the islands. Thus, POPA data was added and it turns this analysis more robust, as in this project the data is collected for a regional fisheries observation programme, having a high spatial range (*Como Trabalhamos – POPA*, n.d.). Therefore, sei whales are present around all archipelago, being observed near the coast but also offshore.

For the seasonality, a presence table of the sei whales was used to analyse the data from each island, along all studied years and months, although there is a lack of data, especially in Faial, Terceira, and Pico islands, in 2016, and in Terceira, from 2020 to 2022. According to this table (table 2.1), the seasonality of this species in São Miguel tended to be in concordance with previous studies, as sei whales were more observed from April do June (Visser et al., 2011; Pérez-Jorge et al., 2020). In Faial and Pico Islands, this species was observed during the summer, and in Faial, also in late summer/autumn, which is not in agreement with Pérez-Jorge et al. (2020) and Zahn et al. (2022), where sei whales were commonly seen from March to July and the rare sightings after August were associated to an unusual food availability during this time (Pérez-Jorge et al., 2020; Zahn et al., 2022). On the same previous work , the sei whales were also observed in October of 2020 and it led to the assumption that the levels of available food were exceptionally good in that autumn (Zahn et al., 2022). By observing the results of the present study, as already mentioned, since 2020 the sei whale has been observed for longer time and in late summer/autumn, especially in Faial and Pico, which could be possibly also justified by the changing of the food availability levels and so by the presence of high quantities of prey, also observed *in situ* through this period during the several expeditions made (21 surveys in which was possible to observe and identify the great amount of prey).

Moreover, the bathymetry preferences of the sei whale were analysed and, as shown on the figure 2.5, different platforms of data collection had different results, as POPA data showed an average encounter depth of 2385 meters, while the maritime-touristic data had 1058 meters of average encounter depth. Since the results have statistically significant differences, a total dataset that join all platforms, represented by the dataset C on figure 2.5, cannot be used as the general depth preference of the sei whale in the Azores. Therefore, these results show that *Balaenoptera borealis* is an opportunistic species without a preferable depth, having an encounter depth range that tends to go from 200 meters to 3500 meters. Thus, collecting data by different methods is the correct approach to study this species as the different results from different platforms help to have a more realistic knowledge about these whales. As previous bibliography as mentioned, sei whales are commonly observed alone or in groups from two to five individuals (Shirihai & Jarrett, 2006; Jefferson et al., 2015). According to the present study results about the group size, the average group size does not vary along the different islands and most of the encounters were with one individual and then some with groups from two to five individuals (figure 2.6 and table 2.2). Thus, the present results are in concordance with previous information about the species, with a highlight to São Miguel, where sei whales tended to be observed in groups from two to five individuals then on the other islands, with exception for the aggregation event recorded in Faial, that will be discussed below.

When analysing the population structure of the observed sei whales (table 2.3), it is possible to infer that POPA data had the higher percentage of encounters with calves and juveniles, followed by Faial and São Miguel Islands. Looking to Terceira Island results, no encounter had the registration of calves and juveniles. Since the sei whale's information in the Azores does not vary too much along the different islands and, as observed on figure 2.7, POPA data had some encounters with younger whales near this island, it is not possible to affirm that no younger whale was present in this island. These results can be explained by the consistency and methodology used by the observers in each island, as some might not be registering the presence of calves and juveniles.

Other analysed parameter about this species is the behaviour, and it started by the creation of an ethogram for the sei whale, and to the best of our knowledge and according to the bibliography available there was none created until now. Ethograms are crucial tools to study the cetaceans, and concretely whales' behaviour, since support the accuracy of the description and registration of the observed behaviours. For this parameter, it was made a comparison between two different periods: from 2009 to July of 2022 and from August to November, between 2009 and 2022, excluding the Faial Island data from 2022 (aggregation event). According to our results (Figure 2.10), the main behaviour adopted by sei whales is transiting, followed by foraging-feeding, and there is no significant variation between the different islands and different periods. In concordance to what has been previously concluded, the sei whale tends to pass by the Azores during its migration until the Labrador Sea and this species uses the Azorean archipelago as a quick stop, being rare observing its feeding behaviour (Prieto da Silva, 2014; Romagosa et al., 2020). Therefore, with the data analysed here it is possible to infer an agreement with previous studies on this species, in which sei whales use the Azores as a fuel station, at least if they maintain the migrations patterns and no other factors contribute to change these annual migrations (e.g. food availability). Nevertheless, it is also important to refer that during their migrations, and in case of any external factor, such as high quantities of prey (e.g. small pelagic species, as *Macroramphosus scolopax*), small and specific areas create the ideal conditions for these animals to stay during some days or even weeks.

In what regards to the aggregation event reported between August and November of 2022, there was a high number of encounters with sei whales, near Faial and Pico Islands (Figure 2.11). This result goes in concordance with the one on the previous topic, in which it was observed that in the last years sei whales have been more observed in the Azores in the late summer/autumn, contrarily from what was common on other years and on previous studies (Prieto da Silva, 2014; Pérez-Jorge et al., 2020).

For this period, the bathymetry was also analysed, and the results show that the average encounter depth during this aggregation event is 714.68 meters, much lower than the random data collected by POPA's observers, in which the average encounter depth was 2384.54 meters and lower than the average encounter depth on the previous studied period (1041.68 meters) (table 2.5). Thus, *Balaenoptera borealis* is a species with a wide depth range. The depths of species occurrence are statistically different between different datasets, which confirms that this is an opportunistic species. The fact that this study incorporated several methodologies and type of data was important to understand the variations and depth range of the sei whale occurrence. Additionally, during the event, there was the accumulation of whales in lower depth zones, and the foraging-feeding behaviour was, on average, registered in lower depth zones (figure 2.17), when compared to the encounter depth from the previous period (from 1998 to July of 2022). Although the possible environmental variables that may have influenced this were not analysed, it might be due to several oceanographic processes, and a microscale phenomenon observed only at Faial and Pico Island. It is known that the central group of this archipelago is the wider in area and number of islands, having a greater oceanic imprint and so, it has a greater capacity to mix the incoming flow, causing the shallowing of the nutricline and trapping the system of eddies and fronts, which is biologically enriched (Caldeira & Reis, 2017). Thus, these processes and the consequent higher levels of sea surface chlorophyll could explain why the aggregation of these whales occurred in the central group, near Faial and Pico Islands, in less deep zones.

During this period (aggregation event), the encounters with groups from two to five individuals increased from an average percentage of observation of 42.66% to 47.85% (table 2.6), and there were some with groups with more than ten individuals. Previous studies have stated that observing sei whales in groups with more than five individuals is rare and these specific sightings are from feeding grounds, where more whales aggregate, as it has occurred in Falkland Islands (Shirihai & Jarrett, 2006; Weir et al., 2021; *Sei Whale Tracking - Falklands Conservation*, n.d.).

During the specific period of the aggregation was possible to observe that there were more encounters with calves or juveniles than on the previous period recorded, on Faial and São Miguel Islands. This data could be explained by the possible lack of method that exist between different operators (MONICET data) and the consistent methodology applied on the data collected by the research team in Faial during the aggregation event. The data collected in each island is taken by different observers increasing errors since different methodologies and approaches are used. Consequently, for this study no comparisons were made between data from different islands, and only between Faial Island 's data, for the two studied periods (before and during the aggregation event. From the observed results, we can see that the maritime-touristic companies collect fundamental data to study and monitor cetaceans' species and with the correct methodology, the data and results are more trustful.

In what regards to behaviour, and specifically during this event, sei whales presented foraging-feeding behaviour in 50.8% of the observations, followed by transiting with 44.0%. Therefore, this event was called a feeding aggregation event. As referred, this species has the capacity to capture prey, while altering between feeding strategies, and this was observed during this event, being the lunging, and secondly the skimming, the most frequent (32.95% and 18.18% respectively, figure 2.19). Hence, these observations confirm the great capacity this species has to switch between feeding modes, which can be adapted to the annual variations they face and different scenarios, as the different size and density of prey. The results obtained are in concordance with previous works that argue that sei whales use intermediate states between continuous and intermittent filter feeding, as skim-feeding is associated with small prey and the lunge-feeding to prey that are larger or with greater density (Brodie & Vikingsson, 2009; Segre et al., 2021). Additionally, it was inferred that they evolved this ability to compete with other rorqual species that may be more efficient and bigger (Segre et al., 2021). As already mentioned, on average sei whales are seen alone or in groups from two to five individuals and during the feeding event, some groups were composed by more than five whales. Thus, it is important to understand how whales aggregate and it could possibly be through communication between them. Previous studies regarding baleen whales' acoustic, it was inferred that sei whales might produce songs as their vocalisations showed some patterning in their sequences (Tremblay et al., 2019) and there is a bi-seasonal pattern of calling activity in spring and autumn, which is in agreement with the migration of this species through the Azores (Romagosa et al., 2020). Although these referred vocalisations do not seem to be associated to a feeding context, as the calling rates tend to be reduced while the whales are feeding and higher with social activity (Baumgartner & Fratantoni, 2008), they may serve as downsweep contact calls with a song-like structure that *B.borealis* could be producing to communicate among them, to signal a food resource, and consequently creating a feeding aggregation event (Baumgartner & Fratantoni, 2008; Tremblay et al., 2019).

Another goal when studying the aggregation event was to understand what type of prey were captured by sei whales. While observing these feeding strategies, it was possible to identify three species of prey, the longspine snipefish, *Macroramphosus scolopax*, the atlantic horse mackerel, *Trachurus trachurus* and the boarfish, *Capros aper*. The longspine snipefish was the species more observed with 48% (n=10), even though without statistically significant differences (figure 2.20). Besides the geomorphological structure of the Azores archipelago, that promotes a higher productivity and makes this region one of the world's highest cetacean biodiversity area, baleen whales movements to high latitudes are related to food availability and, while migrating, they define their distribution with basis on the ocean resources (Afonso et al., 2020; Pérez-Jorge et al., 2020). Therefore, this aggregation feeding event might have occurred due to a higher prey availability in the area that made the sei whales stay longer to feed and not just passing by as other studies have argued, in which it was inferred thatt sei whales forage only sporadically in the Azores (Silva et, 2019).

Also, with the photo-identification, it was possible to create a catalogue with the observed individuals during this feeding event and 79 individuals were identified (section 2.3.2.6). There was only one individual that was seen, at least, in two different days (on the 27th of August and on the 1st of September), meaning this animal stayed near Faial and Pico for, at least, seven days. Although there was only a match during this event period, large numbers of whales were recorded during these months (with 178 sightings) and older reports of sei whales aggregation events in other areas used only density model-based approaches and not photo-identification methods, having no identification of the individuals (Weir et al., 2021). Thus, it is not possible to infer if more individuals stayed longer or if they moved to other areas and there are no patterns recorded from the previous similar events.

As mentioned, during this event, there were observations never recorded before and a great number of whales were seen feeding and switching strategies in a lower average encounter depth. There were more encounters with calves than on the previous years and bigger groups of individuals being observed close to the boat. This event could be due to a change in prey production, due to climate change, as increasing temperatures influence the spring blooms, that can tend to occur earlier, but with a longer duration (Mészáros et al., 2021), and so, it can occur more often in the future, being important to keep monitoring this species' passage in the Azores and collecting data during the whale-watching surveys.

Until now, sei whales have been observed feeding occasionally and so, no legislation is available or implemented in the Azores archipelago to deal with these situations. The present results on the aggregation event show that sei whales were feeding for four months in Faial and Pico islands and if the main reason to this new sighting is the change in prey production due to specific conditions that were not studied and still be undetermined (e.g. temperature, primary production, climate change) so this event can be repeated in a near future. Thus, based on the velocity analysis of transiting and feeding behaviour, performed by the sei whale and the never recorded before in the Azores, a code of conduct was created to boats that are present on feeding zones (figure 2.21), representing additional measures to the existing legislation. The suggested code of conduct can be used by the whale watching operators, research and mainly by the regional authorities to legislate accordingly.

2.5. Conclusions and future research

The present study gives more and updated information about the habitat use and social ecology of the sei whale in the Azores and brings details about the never recorded before feeding aggregation event of *Balaenoptera borealis* near Faial and Pico Islands. It is known that sei whales migrate to north, to Labrador Sea, during spring, and in autumn they travel to south, towards winter grounds in north-western Africa (Pérez-Jorge et al., 2020; Prieto da Silva, 2014). This could mean that this baleen whale seems to be travelling south to Azores archipelago sooner or did not migrate to north and stayed in the area, as its sightings are getting more frequent in the late summer/autumn, contrary to what has been observed until now, in which sei whales were more frequent from spring to early summer. The recorded aggregation feeding event showed a greater abundance of observed whales and they were mainly feeding on pelagic fish, while switching between feeding strategies. The different dataset used, with different methodologies, show us the importance of the uniformization of the data collection by different observers and the necessity to standardized methodologies.

For future research, it would be important to study better the migration aspects of the sei whale, to understand if this species is travelling earlier to south or if it is not travelling more to north, towards the Labrador Sea, and stays longer in the Azores and to fully understand its patterns.

Additionally, using the photo-identification, it would be interesting to use data for a longer period than only during the aggregation event, as there are higher chances of having more matches. It would also be important to compare with other locations' catalogues, such as from Madeira or from the Labrador Sea, as a contribution to better know the migratory patterns of the sei whale.

To study this species' behaviour with more detail, aerial surveys could be used as the image would be more explanatory than what it is observed from the boats. Nevertheless, both methods could be gathered, implementing the use of drones during the surveys.

As previous studies concluded, aggregations of sei whales have been associated with higher densities of krill, but no association has been made between the local productivity of the Azores and the presence of this species (Pérez-Jorge et al., 2020). Nevertheless, an aggregation event was recorded in this region for the first time, and the whales were mainly feeding and transiting. Thus, it would be interesting to evaluate if the abundance of the identified prey was much higher than on the previous seasons and which are the main parameters that affect these values in this region. For instance, analysing if climate change has impact on these events, such as how the temperature increasing influences the spring blooms and chlorophyll levels. These variables could be analysed and compared between years and for future studies, it would be interesting to try to find the main environmental drivers for the registered event.

An additional study could be related to the analysis of the capacity of baleen whales to encounter the food and to gather in feeding grounds or in places where there is an uncommon accumulation of prey, as it might have happened in the Azores. Thus, could be interesting to understand how the changes in migration are made by these whales and how they detect the areas where there is more prey.

2.6. Acknowledgements of the paper

I would like to thank “Naturalist, Science and Tourism” and all the team of whale-watching for proving most of the data used in this study. I also thank Laura González for sharing the data from the MONICET project, and the companies that work with them, “Picos de Aventuras” and “AquaAçores”, that shared data from other islands. A thank to Miguel Machete for sharing data from POPA that made the results more robust.

Special thanks to Gisela and José Nuno for all their support and help on this project and for trusting me on present a part of this project on the “Beyond Whale-Watching Conference” (cover represented on figure IA.5). A thanks also to Rui Peres Santos, that had a great impact in the initial project and my formation in cetaceans.

2.7. References

Acevedo-Gutiérrez, A., Croll, D. A., & Tershy, B. R. (2002). High feeding costs limit dive time in the largest whales. *Journal of Experimental Biology*, *205*(12), 1747–1753. https://doi.org/10.1242/JEB.205.12.1747

Afonso, P., Fontes, J., Giacomello, E., Magalhães, M. C., Martins, H. R., Morato, T., Neves, V., Prieto, R., Santos, R. S., Silva, M. A., & Vandeperre, F. (2020). The Azores: A Mid-Atlantic Hotspot for Marine Megafauna Research and Conservation. *Frontiers in Marine Science*, *6*, 826. https://doi.org/10.3389/FMARS.2019.00826/BIBTEX

Baumgartner, M. F., & Fratantoni, D. M. (2008). Diel periodicity in both sei whale vocalization rates and the vertical migration of their copepod prey observed from ocean gliders. *Limnology and Oceanography*, *53*(5part2), 2197–2209. https://doi.org/10.4319/LO.2008.53.5_PART_2.2197

Borges, P. A. V., Amorim, I. R., & Gabriel, R. (2020). Azores. *Encyclopedia of Islands*, 70–75. https://doi.org/10.1525/9780520943728-019

Brodie, P., & Vikingsson, G. (2009). On the feeding mechanisms of the sei whale (Balaenoptera borealis). *Journal of Northwest Atlantic Fishery Science*, *42*. https://doi.org/10.2960/J.v42.m646

Caldeira, R. M. A., & Reis, J. C. (2017). The Azores confluence zone. *Frontiers in Marine Science*, *4*(FEB), 202943. https://doi.org/10.3389/FMARS.2017.00037/BIBTEX

Como trabalhamos – POPA. (n.d.). Retrieved May 22, 2023, from https://www.popaobserver.org/como-trabalhamos/

GEBCO Gridded Bathymetry Data. (n.d.). Retrieved May 31, 2023, from https://www.gebco.net/data_and_products/gridded_bathymetry_data/

Goldbogen, J. A., Calambokidis, J., Croll, D. A., Mckenna, M. F., Oleson, E., Potvin, J., Pyenson, N. D., Schorr, G., Shadwick, R. E., & Tershy, B. R. (2012). Scaling of lunge-feeding performance in rorqual whales: mass-specific energy expenditure increases with body size and progressively limits diving capacity. *Functional Ecology*, *26*(1), 216–226. https://doi.org/10.1111/J.1365-2435.2011.01905.X

Goldbogen, J. A., Pyenson, N. D., & Shadwick, R. E. (2007). Big gulps require high drag for fin whale lunge feeding. *Marine Ecology Progress Series*, *349*. https://doi.org/10.3354/meps07066

González García, L., Pierce, G. J., Autret, E., & Torres-Palenzuela, J. M. (2018). Multi-scale habitat preference analyses for Azorean blue whales. *PLOS ONE*, *13*(9), e0201786. https://doi.org/10.1371/journal.pone.0201786

Jefferson, T. A., Webber, M. A., & Pitman, R. L. (2015). *Marine mammals of the world: a comprehensive guide to their identification* (2nd ed.). Academic Press. https://doi.org/https://doi.org/10.1016/C2012-0-06919-0

Keen, E. M. (2017). Aggregative and feeding thresholds of sympatric rorqual whales within a fjord system. *Ecosphere*, *8*(3). https://doi.org/10.1002/ecs2.1702

Mészáros, L., Meulen, F. van der, Jongbloed, G., & Serafy, G. El. (2021). Climate change induced trends and uncertainties in phytoplankton spring bloom dynamics. *Frontiers in Marine Science*, *8*, 669951. https://doi.org/10.3389/FMARS.2021.669951/BIBTEX

Morato, T., Machete, M., Kitchingman, A., Tempera, F., Lai, S., Varkey, M. G., Dâmaso, C., Santos, M., Prieto, R., & Santos, R. S. (2008). Abundance of seamounts in the Azores and their effect on aggregating visiting species. *Environmental Science*. http://www.popaobserver.org

Peran, A. D., Pham, C. K., Amorim, P., Cardigos, F., Tempera, F., & Morato, T. (2016). Seafloor Characteristics in the Azores Region (North Atlantic). *Frontiers in Marine Science | Www.Frontiersin.Org*, *3*, 204. https://doi.org/10.3389/fmars.2016.00204

Pérez-Jorge, S., Tobeña, M., Prieto, R., Vandeperre, F., Calmettes, B., Lehodey, P., & Silva, M. A. (2020). Environmental drivers of large-scale movements of baleen whales in the mid-North Atlantic Ocean. *Diversity and Distributions*, *26*(6), 683–698. https://doi.org/10.1111/ddi.13038

Pérez, F. F. (2003). Large and mesoscale variability of the water masses and the deep chlorophyll maximum in the Azores Front. *Journal of Geophysical Research*, *108*(C7), 3215. https://doi.org/10.1029/2000JC000360

Prieto da Silva, R. (2014). *Sei whale (Balaenoptera borealis) Ecology and Management in the North Atlantic*. Universidade dos Açores.

Quartau, R., Tempera, F., Mitchell, N. C., Pinheiro, L. M., Duarte, H., Brito, P. O., Bates, C.

R., & Monteiro, J. H. (2012). Morphology of the Faial Island shelf (Azores): The interplay between volcanic, erosional, depositional, tectonic and mass-wasting processes. *Geochemistry, Geophysics, Geosystems*, *13*(4), 1–30. https://doi.org/10.1029/2011GC003987

Romagosa, M., Baumgartner, M., Cascão, I., Lammers, M. O., Marques, T. A., Santos, R. S., & Silva, M. A. (2020). Baleen whale acoustic presence and behaviour at a Mid-Atlantic migratory habitat, the Azores Archipelago. *Scientific Reports*, *10*(1), 1–11. https://doi.org/10.1038/s41598-020-63117-1

Sala, I., Harrison, C. S., & Caldeira, R. M. A. (2016). The role of the Azores Archipelago in capturing and retaining incoming particles. *Journal of Marine Systems*, *154*, 146–156. https://doi.org/10.1016/J.JMARSYS.2015.10.001

Segre, P. S., Weir, C. R., Stanworth, A., Cartwright, S., Friedlaender, A. S., & Goldbogen, J. A. (2021). *Biomechanically distinct filter-feeding behaviors distinguish sei whales as a functional intermediate and ecologically flexible species*. https://doi.org/10.1242/jeb.238873

Sei Whale Tracking - Falklands Conservation. (n.d.). Retrieved July 3, 2023, from https://falklandsconservation.com/sei-whale-tracking/

Sei What?! Researchers spot a large group of critically endangered sei whales off the coast of British Columbia. | WildWhales. (2021). https://wildwhales.org/2021/07/12/sei-what-researchers-spot-a-large-group-of-critically-endangered-sei-whales-off-the-coast-of-british-columbia/

Shirihai, H., & Jarrett, B. (2006). *Whales, Dolphins and Seals: A Field Guide to the Marine Mammals of the World*. Bloomsbury Wildlife.

Stern, S. J. (2009). Migration and Movement Patterns. *Encyclopedia of Marine Mammals*, 726–730. https://doi.org/10.1016/B978-0-12-373553-9.00168-1

The IUCN Red List of Threatened Species. (2018). *Balaenoptera borealis (Sei Whale)*. https://www.iucnredlist.org/species/2475/130482064

Torres, L. G., Nieukirk, S. L., Lemos, L., & Chandler, T. E. (2018). Drone up! Quantifying whale behavior from a new perspective improves observational capacity. *Frontiers in Marine Science*, *5*(SEP), 319. https://doi.org/10.3389/FMARS.2018.00319/BIBTEX

Tremblay, C. J., Van Parijs, S. M., & Cholewiak, D. (2019). 50 to 30-Hz triplet and singlet down sweep vocalizations produced by sei whales (Balaenoptera borealis) in the western North Atlantic Ocean. *The Journal of the Acoustical Society of America*, *145*(6), 3351–3358. https://doi.org/10.1121/1.5110713

van der Hoop, J. M., Nousek-McGregor, A. E., Nowacek, D. P., Parks, S. E., Tyack, P., & Madsen, P. T. (2019). Foraging rates of ram-filtering North Atlantic right whales. *Functional Ecology*, *33*(7), 1290–1306. https://doi.org/10.1111/1365-2435.13357

Visser, F., Hartman, K. L., Pierce, G. J., Valavanis, V. D., & Huisman, J. (2011). Timing of migratory baleen whales at the azores in relation to the north atlantic spring bloom. *Marine Ecology Progress Series*, *440*(October), 267–279. https://doi.org/10.3354/meps09349

Waring, G. T., Nøttestad +, L., Olsen +, E., Skov, H., & Vikingsson, G. (2008). Distribution and density estimates of cetaceans along the mid-Atlantic Ridge during summer 2004. *J. CETACEAN RES. MANAGE*, *10*(2), 137–146.

Weir, C. R., Taylor, M., Jelbes, P. A. Q., Stanworth, A., & Hammond, P. S. (2021). Distribution and abundance of sei whales off the west coast of the Falkland Islands. *Marine Mammal Science*, *37*(3), 919–933. https://doi.org/10.1111/MMS.12784

Werth, A. J., Potvin, J., Shadwick, R. E., Jensen, M. M., Cade, D. E., & Goldbogen, J. A. (2018). Filtration area scaling and evolution in mysticetes: trophic niche partitioning and the curious cases of sei and pygmy right whales. *Biological Journal of the Linnean Society*, *125*(2), 264–279. https://doi.org/10.1093/BIOLINNEAN/BLY121

Whale aggregation discovered in Falkland Islands Waters. (2021). https://www.keybiodiversityareas.org/kba-news/whale-aggregation-discovered-in-falkland-islands-waters-now-made-a-kba

Zahn, P., Kulike, L., & Bloechl, A. (2022). Temporal distribution of cetaceans south of Pico Island (Azores, Portugal) - data obtained during whale-watching 2020. *BioRxiv*, 2022.06.07.495087. https://www.biorxiv.org/content/10.1101/2022.06.07.495087v1%0Ahttps://www.biorxiv.org/content/10.1101/2022.06.07.495087v1.abstract

Appendix I – Tables and Figures

Date	Year	Month	Day	Time	Photo Code	N animals	N_Fin_Ident	ID Code	Right/left side	distinction degree (easy, medium, diffic	nr marks on thr dor	Age	behaviors	group size	association with other sps	N recaptures	Date1	Date2	Date3

Figure IA. 1 - Datasheet used for the photo identification.

```
    popa  pc    ter   sm
pc  0.049 -     -     -
ter 0.028 0.471 -     -
sm  0.371 0.194 0.033 -
fa  0.033 0.915 0.371 0.166
```

Figure IA. 2 - Pairwise comparison using Wilcoxon rank sum test to check the significancy of the differences between the percentage of encounters with calves or juveniles.

```
        Pairwise comparisons using Wilcoxon rank sum test with continuity correction

data:  bathy2$depth and bathy2$dataset2

           Aggrevent NT+MONICET POPA
NT+MONICET 7.8e-16   -          -
POPA       < 2e-16   < 2e-16    -
TOTAL      < 2e-16   1.4e-11    < 2e-16

P value adjustment method: BH
```

Figure IA. 3 - Pairwise comparison using Wilcoxon rank sum test to check the significancy of the differences between the bathymetry values of the different datasets.

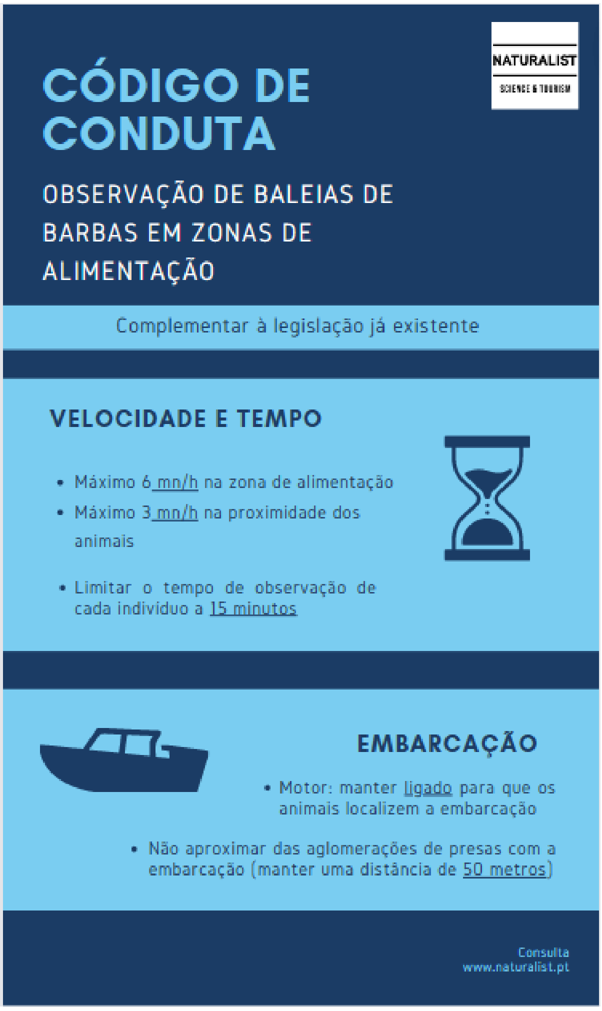

Figure IA. 4 - Portuguese version of the suggestion of code of conduct for the whale-watching in feeding zones.

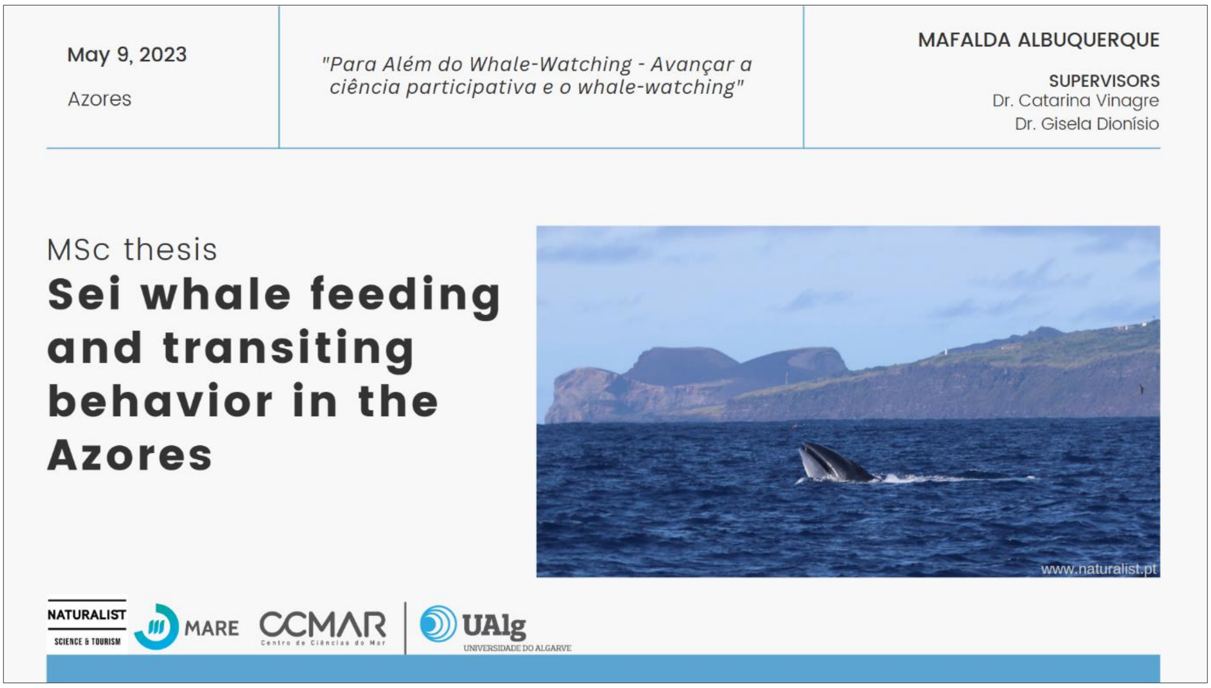

Figure IA. 5 - Presentation slide of the conference where the initial results of the thesis were presented.