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Fin whale *(Balaenoptera physalus)* identification and distribution around São Miguel island (Azores) and inferences on the movements towards other areas

UNIVERSIDADE DO ALGARVE
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Mestrado em Biologia Marinha

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(Maria Ana Ernesto)

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Abstract

Understanding the movement patterns, and their possible drivers, of highly migratory marine species such as fin whale *(Balaenoptera physalus)*, is vital for establishing appropriate conservation measures. After been drastically reduced during the whaling period, fin whale populations are now recovering which led IUCN to recently update their status from “Endangered” to “Vulnerable”. Studying the population structure of the North Atlantic fin whales is particularly challenging due to their mobile nature and the lack of clear geographic barriers. The IWC (International Whaling Commission) suggests seven stock structure hypotheses however, there has been evidence of movements between these areas. The Azores archipelago is known to be a migration corridor for the North Atlantic populations, especially during springtime yet, many questions still exist regarding the ecology and habitat use in the archipelago.

In this study, 11 years of opportunistic data from whale-watching platforms were used to create a photo-identification catalogue of fin whales around São Miguel. This catalogue was then compared with four other catalogues: one in the Azores and three from Iberian waters. The aim of this study was to assess potential migratory patterns and connections, understand the role of the Azorean archipelago and identify possible environmental drivers related to their presence. The composition of the photo-id catalogue and database enabled the identification of 256 individuals and accounted for 32 re-sightings around São Miguel. The results presented indicate possible migratory connections within the archipelago and Galicia (North-West Spain), suggesting a variation of the commonly accepted migratory routes of baleen whales. Our findings also suggest that oceanographic features and events (e.g., phytoplankton spring bloom) influence the timing of fin whale migration and distribution in the archipelago. Additionally, this study serves as a baseline to further investigations, highlighting the important role of opportunist data in enhancing our knowledge of the biology and distribution of fin whales with the intention of supporting effective conservation measures and management programs to this emblematic species.

Keywords: Fin whale; Cetaceans; Photo-id; Azores; São Miguel; whale-watching; migration

Resumo

A baleia comum *(Balaenoptera physalus)* é uma espécie cosmopolita distribuída por todos os oceanos do planeta. Este mamífero marinho, pertencente à ordem Cetacea, subordem Mysticeti (baleias de barbas ou rorquais) e membro da família Balaenopteridae. É geralmente aceite que as baleias comuns efetuam grandes migrações sazonais, deslocando-se no fim do verão, das zonas de alimentação em latitudes mais elevadas, em direção a latitudes mais baixas, a fim de se reproduzirem. Contudo, compreender os padrões de movimentação de espécies altamente móveis (como a baleia comum) e os fatores ambientais que as influenciam, é extremamente importante para estabelecer medidas de conservação apropriadas para a sua proteção.

As populações de baleia comum sofreram uma drástica diminuição devido à sua caça intensiva no último século. No entanto, em 1986, a Comissão Baleeira Internacional (CBI) emitiu uma moratória (sem termo pré-definido) que proibia a baleação comercial. O fim da atividade baleeira levou a uma recuperação gradual destas populações, resultando na alteração recente do estado de conservação, pela IUCN, de "Em perigo" para "Vulnerável" (2018). No entanto, algumas atividades antropogénicas (e.g. captura acidental, emaranhamento em redes de pesca, choque com navios, poluição sonora) continuam a ameaçar estas populações comprometendo os ecossistemas marinhos.

O estudo da estrutura populacional de baleias comuns é particularmente desafiante devido à sua natureza móvel e à ausência de barreiras oceanográficas definidas. A CBI sugere uma separação das populações de baleia comum, no Atlântico Norte, em sete stocks diferentes. No entanto, definir os limites e tamanho destes stocks continua a ser uma dificuldade, principalmente para o arquipélago dos Açores uma vez que se encontra numa zona limítrofe entre dois stocks diferentes (Este da Gronelândia (EG); Espanha- Portugal-Ilhas Britânicas (S)).

A região dos Açores (36°–41°N; 24°–32°W) é considerada um corredor migratório para algumas populações de cetáceos do Atlântico Norte, contudo, ainda existem bastantes dúvidas relativamente às rotas migratórias, ecologia e utilização do habitat ao largo do arquipélago. É provável que variáveis estáticas (profundidade, declive e distância à costa) e dinâmicas (temperatura da superfície do mar e concentração de clorofila-a) que caracterizam este habitat estejam intrinsecamente relacionadas com a distribuição temporal e espacial destas baleias.

Neste estudo foi utilizada a foto identificação (foto-id) como método não invasivo de identificação e acompanhamento dos indivíduos ao longo do tempo. Este método é bastante utilizado para algumas espécies de cetáceos uma vez que permite a sua identificação através da forma e tamanho das barbatanas dorsais ou caudais, em conjunto com marcas ou padrões distintos no corpo do indivíduo. Ao fotografar os indivíduos os investigadores obtêm dados que permitem a recolha de informação sobre a distribuição, o tamanho das populações, padrões migratórios, comportamentos e associações entre indivíduos. No entanto, no arquipélago dos Açores, poucos estudos utilizaram ainda foto-id de baleias comuns para averiguar possíveis padrões de movimentação.

Durante este trabalho, foi criado um catálogo de foto-id com o registo de 256 baleias comuns, identificadas através de dados recolhidos oportunisticamente por uma empresa de "whale-watching" (Futurismo Azores Adventures) com porto base em Ponta Delgada (ilha de São Miguel) desde 2009 até ao final de 2019. Durante este período foram contabilizados 32 reavistamentos ao largo de São Miguel. A maioria destes reavistamentos (23) ocorreram dentro do mesmo mês que o primeiro registo do individuo, o que sugere um curto período de residência nesta região (máximo de tempo contabilizado 14 dias). Cinco baleias foram identificadas pela primeira vez na primavera de 2014 e reavistadas meses depois (Outono/Inverno) na mesma região. Três baleias foram reavistadas em anos diferentes (Bp12 – 2014 e 2017; Bp75 – 2014 e 2016; Bp100- 2014 e 2017), com um tempo máximo entre avistamentos de três anos.

Adicionalmente, com o objetivo de melhor compreender as conexões migratórias entre o arquipélago dos Açores e a Península ibérica, o catálogo obtido para São Miguel foi comparado com outro pertencente ao grupo central do arquipélago (ilhas de Pico-Faial), cinco catálogos de foto-id foram comparados: dois correspondentes ao arquipélago, com dados recolhidos em São Miguel (desenvolvido neste trabalho) e no Faial; um catálogo correspondente a Portugal continental (Sagres); e dois catálogos com fotos recolhidas no norte de Espanha (Galiza e Mar Cantábrico). A comparação dos catálogos dos Açores permitiu identificar a correspondências entre duas baleias, com avistamento inicial em São Miguel e mais tarde no Faial. Uma outra correspondência foi confirmada entre um individuo avistado no Faial e quatro meses mais tarde fotografado na Galiza. Desta forma, os resultados aqui apresentados poderão indiciar uma ligação entre as ilhas do arquipélago dos Açores e uma possivel conexão entre o arquipélago dos Açores e a Galiza, sugerindo que as rotas migratórias desta espécie poderão ser mais complexas do que as atualmente estabelecidas e aceites.

Os resultados deste estudo sugerem também que a chegada destas baleias migratórias ao arquipélago é influenciada por características e eventos oceanográficos como o aumento drástico da concentração de clorofila durante o "bloom" primaveril de fitoplâncton. A concentração de clorofila-a é muitas vezes utilizada como um proxy de produção primária, já que o aumento da sua concentração, em termos gerais, está fortemente associado a um aumento de biomassa e disponibilidade de presas. No entanto, os resultados obtidos evidenciam um atraso de aproximadamente dois meses entre o aumento da concentração de clorofila e o aumento de avistamentos de baleias comuns. Este atraso poderá estar relacionado com o tempo necessário para que o zooplâncton, que se alimenta de fitoplâncton, atinja dimensões adequadas para a sua predação por parte das baleias. Contudo, para uma melhor compreensão das variáveis que influenciam os movimentos e os seus efeitos na distribuição de baleias comuns, teriam de ser analisadas mais variáveis do que as que foram brevemente exploradas durante este estudo.

O presente trabalho, realça a importância da utilização de dados oportunistas de forma a melhorar o nosso conhecimento sobre várias espécies, utilizando uma metodologia de baixo custo, que permite obter uma elevada quantidade de dados ao longo de grandes períodos de tempo. Desta forma, incentivamos o envolvimento de empresas marítimo turísticas (i.e "whale-watching", centros de mergulho) em projetos de ciência cidadã que visem contribuir para a consciencialização ambiental da população, principalmente em regiões como os Açores em que as atividades ecoturísticas têm vindo progressivamente a ser mais procuradas

Finalmente, esperamos que este trabalho sirva de base para futuras pesquisas e contribua para uma implementação mais eficaz de medidas que ambicionem promover uma maior sustentabilidade dos ecossistemas marinhos, conservando a biodiversidade e protegendo esta espécie emblemática.

Palavras-chave: Baleia comum; Cetáceos; Foto-id; Açores; São Miguel; migração; whale-watching

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List of Abbreviations:

ARGOS - Advanced Research and Global Observation Satellite

BDRI – Bottlenose Dolphin Research Institute

Bp – *Balaenoptera physalus*

CCF - cross-correlation function

Chl-a - Chlorophyll-a concentration

CITES - Convention on International Trade in Endangered Species

CMEMS - Copernicus Marine Environment Monitoring Service

EC - Easter Canada/ USA.

E-easy/ **M**- medium /**D**-difficult to identify

EG - East Greenland/ **WG -** West Greenland

EI - East Iceland/ **WI -** West Iceland.

EKE - Eddy kinetic energy

ER - Encounter rate

F - Faroe Islands

GEBCO - General Bathymetric Chart of the Oceans

GlobColour – Global Ocean Colour

GPS - Global Positioning System

ID – Identification

IUCN - International Union for Conservation of Nature

IWC - International Whaling Commission

MERIS - Medium Resolution Imaging Spectrometer

MODIS - Moderate Resolution Imaging Spectroradiometer

MPA- Marine Protected Area

N - Norway

n - Number of individuals

NAC - North Atlantic Current

NOAA - National Oceanic and Atmospheric Administration

OSTIA - Operational SST and Sea Ice Analysis

Photo-id – Photo-identification

S - Spain-Portugal-British-Islands

SeaWIFS - Sea-viewing Wide Field-of-view Sensor

SST - Sea Surface Temperature

VHF - Very high frequency

VIIRS - Visible Infrared Imaging Radiometer Suite

WWF – World Wildlife Fund

Chapter 1: Introduction

1.1 Ecosystem Role

Cetaceans (order Cetacea) are charismatic marine mammals usually characterized as flagship species and important ambassadors for marine conservation. The order is sub-divided in two major groups: the Odontoceti, generally defined as the toothed whales and dolphins, and the Mysticeti, the baleen whales, which have a filter-feeder bristle system instead of teeth (Evans & Hammond, 2004).

.Many cetacean species have an important influence in major trophic chains and the functioning of the ecosystem, affecting their prey population dynamics, community structure and diversity (Smith *et al.,* 2013; Roman *et al.,* 2014). Whales can impact nutrient availability in their region by increasing nutrient flow in the water column both by input of organic matter (defecation or creation of "whale falls) or by flowing nutrients to the euphotic zone increasing local productivity. Moreover, the movements associated with migrations can induce horizontal transportation of nutrients to oligo-trophic regions which can potentially influence the trophic chains with an increase of phytoplankton growth (Moore, 2008; Lavery *et al.,* 2012; Smith & Baco, 2013; Roman *et al.,* 2014; González García, 2019).

In this context, some cetaceans can be considered umbrella species, increasing the importance of their conservation, which directly influences the health of large ecosystems and other species (González García, 2019).

1.2 Studying cetaceans

Modern field studies of cetaceans began in the 1980s, after the rapid decline of populations due to extensive whale hunting ("Modern whaling") in the last century. Studying these species is particularly challenging since they are highly mobile with wide distributional ranges in marine environments which are continuously changing (González García *et al.,* 2018).

Spatio-temporal patterns of cetaceans have been studied using line transects (Silva *et al.,* 2014; Prieto *et al.,* 2017), photo-identification (photo-id) (Agler *et al.,* 1993; Alves *et al.,* 2019), biotelemetry (Silva *et al.,*2013; Prieto *et al.,* 2014; Pérez-Jorge *et al.,* 2019) and unmanned aerial systems, UAS (Torres *et al.,* 2005; Durban *et al.,* 2015). Biopsy sampling techniques (Noren & Mocklin, 2012; Crain *et al.,* 2014), such as stable isotopes and genetics analysis using skin and blubber which can be used to assess hereditary relations, contaminant levels, diet composition and foraging behaviour (Marsili *et al.,* 2000; Borrell *et al.,* 2012; Muñoz-Arnanz *et al.,* 2019; Taniguchi *et al.,* 2019). Lastly, passive acoustic is also a common method (Zimmer, 2011; Romagosa *et al.,* 2020) usually addressing cetacean presence, behaviour, and communication signals.

1.2.1 Using opportunistic data

Cetacean opportunistic data can be a useful and valuable tool, especially when studying rare species only sighted occasionally or just for a short period (e.g. beaked whales). This type of data is extremely cost-effective and allows a regular collection of large amounts of information on species distribution and diversity during long periods of time (Evans & Hammond, 2004). Although dedicated surveys collect more standardized data samples since they follow a strict scientific protocol, they are usually more constrained spatially and temporally due to their high logistic and extensive costs (Kiszka *et al.,* 2004; Silva *et al.,* 2013).

As a result, the use of opportunistic data collected by whaling records, stranding records, observations from fishing boats, or whale-watching boats, are becoming progressively more important as an alternative source of information and serve as a baseline to further studies regarding cetacean species (Gonçalves *et al.,* 1996; Silva *et al.,* 2013, 2014; González García, 2019).

In the Azores, the collaboration with the increasing number of maritime-touristic companies is a valuable resource for data collection. Cetacean occurrence data collection is easily combined with whale-watching activities since it does not greatly interfere with the tours and the onboard research will increase the value of the whale-watching experience itself (González García, 2019).

Therefore, citizen science and opportunistic whale-watching platforms, are simple cost-effective methods of collecting large, long term datasets with a regular spatial cover to monitor large pelagic species and contribute to their conservation, especially in Portuguese waters, where data is still deficient (Araujo *et al.,* 2017). Nonetheless, the lack of quantified effort and data bias related to the commercial interests are common limitations associated with these datasets and their effects should be minimized and taken into consideration to avoid misleading conclusions.

1.2.2 Photo-id

Photo-identification is a widely used technique to assess questions regarding species distribution ranges, movement towards other areas, site fidelity, population size, and behavioural patterns (Agler, 1990, 1992; Castro, 2010; Stevens, 2014; Araujo *et al.,* 2017). Weller et al. (2012) recorded grey whale *(Eschrichtius robustus)* movements across the Northern Pacific Ocean using photo-id, despite the genetic segregation between the areas established by Lang et al. (2011). Additionally, in 2005, researchers found photo-id matches between two catalogues from the Gulf of Maine and the Gulf of St. Lawrence suggesting that different individuals travelled between these neighbouring regions (Coakes *et al.,* 2005). Photo-id techniques were also used to determine the movements of reef manta rays in Indonesia (Germanov & Marshall, 2014), as well as population estimates for white sharks *(Carcharodon carcharias)* in South Africa (Towner *et al.,* 2013).

The use of this indirect mark and recapture method implies a certain number of assumptions to be successfully implemented, including:

- recognizable individuals will maintain recognizable marks which would not be changed or lost;
- the probability of recapture is not affected by marking the individual;
- all individuals would have an equal probability of being captured in any other sampling occasion.

Photo-id has significant advantages when compared with other methods as the individuals are not captured or physically harmed, and the natural marks, even though they can change, they cannot be lost (Hammond *et al.,* 2016; Schleimer *et al.,* 2019). Therefore photo-id can be applied to fin whales using dorsal fin shape and nicks (i.e. small cut in the edge of the dorsal fin) combined with pigment pattern and acquired natural marks (scars, teeth marks, etc.) (Boyd *et al.,* 2010; Hammond *et al.,* 2016). It allows a permanent record of the individuals sighted in a catalogue that can be compared with new photographs or other catalogues from different regions (Urian *et al.,* 2015).

Fin whale's catalogues in the Atlantic are mostly restricted to the Mediterranean Sea or to the Northwest side of the Ocean. The largest catalogue, the "North Atlantic Fin Whale Catalogue", belongs to Allied Whale at the College of the Atlantic (USA). It was created in 1981 and it counts with 841 individuals identified from photographs collected between 1974 and 2006 in the Gulf of St. Lawrence, coast of New York, Gulf of Maine, and Nova Scotia (Agler, 1990; Robbins *et al.,* 2008). Two more catalogues were also identified for the Gulf of St. Lawrence: the Mingan Island Cetacean Study (n=430 individuals) and the Groupe de Recherche et d'Éducation sur Les Mammifères Marins (n= 200)(Robbins *et al.,* 2008; Whooley *et al.,* 2011).

In the eastern North Atlantic, only a few fin whale catalogues were described and are mainly located in the Mediterranean Sea. The most relevant catalogue belongs to the Tethys Research Institute, in the Mediterranean, and contains the largest number of recorded individuals in this area (n=425) (Robbins *et al.*, 2008). Outside the Mediterranean, catalogues were recorded in the Bay of Biscay, North of Spain (n=55, 2020; Verballenas, unpublished data), in Galicia, Northwest of Spain (n=30, 2019; BDRI, unpublished data) in Wales (n=6, 2008), Iceland (n=2, 2008); and from the south coast of Ireland (n= 62, 2011) (Robbins *et al.*, 2008; Whooley *et al.*, 2011). In the Azorean archipelago Nova Atlantis identified 22 individuals (Robbins *et al.,* 2008), Whale Watch Azores photographed 313 individuals (2020, unpublished data) and the MONICET platform has registered 116 identified fin whales as of 2020.

The effort to integrate small local catalogues and compare them within or outside their geographic region is a baseline for assessing fin whale's distribution and migratory patterns.

Movements of fin whales sighted in the Azores continue to be very misunderstood. Recently, Silva *et al.,* (2019) used stable isotopes to understand fin whale's trophic ecology and their possible feeding grounds. The authors compared values of δ15N and δ13C in whale's skin from the Azorean region collected during spring, with the values of possible prey from different locations within the North Atlantic. They found an overwhelming amount of evidence suggesting that fin whales feed predominantly within the Iberian region, indicating an unknown migratory link between the areas and a potential feeding ground.

In fact, Gauffier *et al.,* (2020) proposed a sequential common feeding ground for both Icelandic and Iberian populations of fin whales, particularly those from the Strait of Gibraltar. The authors suggest that Icelandic populations migrating from the Azores forage during winter-spring in the same areas where populations from the Strait of Gibraltar feed during summer. This way the populations would share a common feeding ground but not at the same time.

1.3 Fin whale

1.3.1 Description

The fin whale is a part of the Cetacea suborder Mysticeti, or baleen whales, and is a member of the Balaenopteridae family, the rorqual whales (Boyd *et al.,* 2010). This family includes species such as fin, blue, sei, Bryde's, minke, Antarctic minke and humpback whales. It is the second-largest species on Earth ranging from 17 to 27 m in length and between 30.4 to 81.2 tons. Female adults are typically bigger than males and individuals from the southern hemisphere are usually larger than those from the northern hemisphere (Aguilar & García-Vernet, 2018). Fin whales have a very large sleek body with a distinct chevron pattern and a relatively low, backswept dorsal fin with less than a 45º angle and a variable shape and size (tip pointed or rounded). Both, chevron and fin can be used for photo-identification. Body colouration is mostly dark grey with a white ventral region, the asymmetrical head pigmentation with pale grey chevron and white lower jaw on the right side and a darker grey on the left side are unique characteristics of this species (Aguilar & García-Vernet, 2018). Fin whales can produce some of the loudest sounds in the ocean. They produce regular low-frequency calls, usually, around 20 Hz which can be recorded as repeated short irregular series or as part of a song, in long regular series, which might have an important role as a reproductive display since the latter are only produced by males during the breeding season (Watkins *et al.,* 1987; Castellote *et al.,* 2012).

Fin whales display a specific lunge-feeding behaviour which allows the whale to engulf large amounts of water and prey aggregations which are then filtered through the baleen plates (Pivorunas, 1972; Brodie, 1993; Schwenk & Ed, 2000). This species diet is mostly based on euphausiids however, it can shift according to the seasonality or prey availability of zooplankton, such as copepods, or small schooling fish, such as capelin, herring or blue whiting (Spilliaert *et al.*, 1991; Christensen *et al.*, 1992; Sigurjónsson & Víkingsson, 1997; Prieto *et al.,* 2012). In the North Atlantic and Mediterranean Sea, they feed mostly on the northern krill (*Meganyctiphanes norvegica*), but they may also incorporate in their diet small species targeted by fisheries such as Atlantic herring (*Clupea harengus*). Therefore, fin whale's abundance and population trends may have an important impact not only on an ecological/conservation level but also at an economic scale, influencing fisheries and tourism around the globe (Essington *et al.*, 2006).

1.3.2 Spatial and temporal distribution

As a cosmopolitan species, fin whales are spotted worldwide, mainly from temperate to polar latitudes, both in shelf coastal regions and deeper offshore waters (Aguilar & García-Vernet, 2018).

Morphological differences separate two main populations of fin whales, the Northern and Southern hemisphere populations (Aguilar, 2009). Moreover, genetic studies also suggested some degree of reproductive isolation between populations in the North Pacific and North Atlantic Oceans (Archer *et al.*, 2013).

In the North Atlantic, the estimated population is around 80,000 (Aguilar & García-Vernet, 2018; Pike *et al.*, 2020). Although genetic analyses suggested a single population in the North Atlantic (Bérubé *et al.*, 1998), the IWC (2009) has included a seven discrete stocks hypothesis within the North Atlantic populations (Figure 1.1) with some degree of dispersion between them. These categories were established based on genetic and non-genetic data associated with the identified feeding/breeding areas (Gauffier *et al.*, 2020). Four of the identified feeding grounds are in the Eastern North Atlantic including one in the Spain-Portugal-British-Islands called (S) stock. This one comprises the UK, southern Ireland, North of Spain, Bay of Biscay, mainland Portugal, Madeira, part of the Azorean archipelago, the strait of Gibraltar and the Mediterranean Sea, despite the genetic isolation suggested by some (Árnason *et al.*, 1991;Palsbøll *et al.*, 2004).

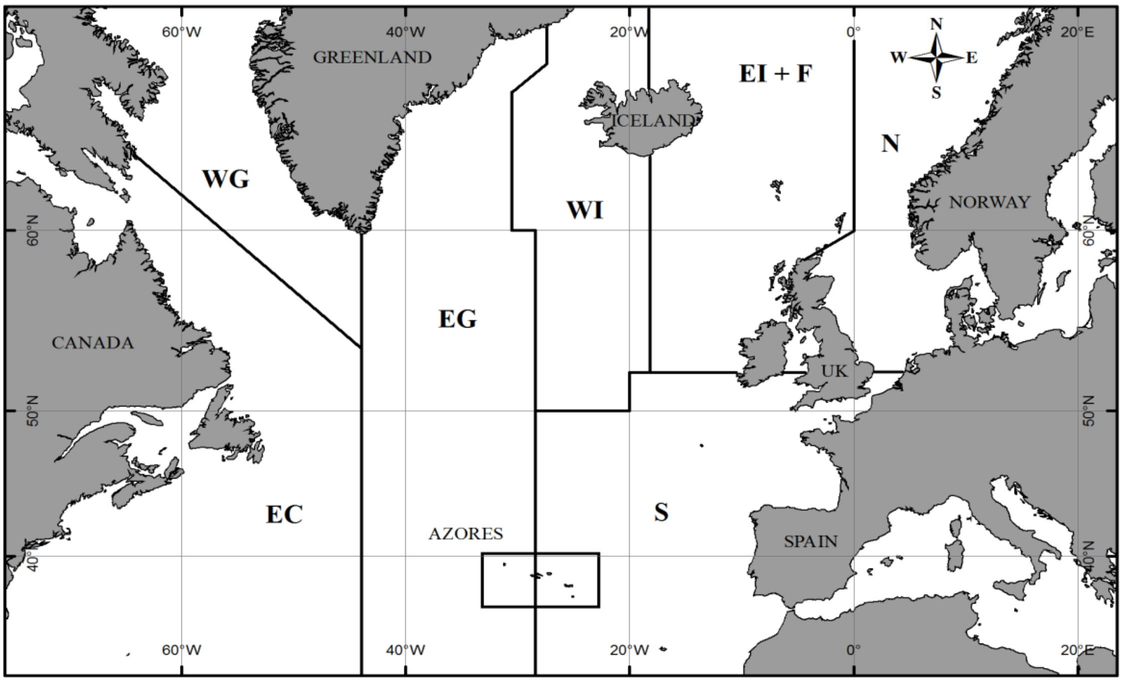

Figure 1. 1 North Atlantic IWC stock subdivision of fin whale population, WG: West Greenland; EG: East Greenland; EC: Easter Canada/ USA; WI: West Iceland; EI+F: East Iceland and Faroe Islands; N: Norway; S: Spain, Portugal, France and British Isles (International Whaling commission, 2009)

Nonetheless, stock structure and size, boundaries, winter grounds and migratory routes are still unclear (Coakes *et al.*, 2005; Gauffier *et al.*, 2020) mostly due to the species pelagic nature and large, possibly overlapping ranges (Delarue *et al.*, 2009).

In the Azores, stock boundaries and migration routes can be even more uncertain since the archipelago is situated in the edge between East Greenland (EG) and the S stock subdivisions of populations and different studies suggest a link between both EG and S foraging grounds (Silva *et al.*, 2019; 2013 respectively).

1.3.3 Migrations

Fin whales have been recorded pursuing long seasonal migrations (accepted model of baleen whale migrations), from tropical breeding grounds in winter to North Atlantic feeding grounds during summer, crossing the Azores annually during spring and early summer (i.e. baleen whale season) (Silva *et al.*, 2013; Prieto *et al.*, 2014; Aguilar & García-Vernet, 2018). Satellite tagging was used to show long-range movements of some fin whales, connecting the Azores to Greenland and Iceland (Silva *et al.*, 2013).

However, the low sample size and the fact that some whales also followed different routes suggests that movement strategies may vary between individuals according to their characteristics (sex, breeding status, body condition) and available environmental conditions (food availability) (Silva *et al.,* 2013; Lydersen *et al.,* 2020). Additionally, not all fin whales show long seasonal migration patterns, and some individuals might be considered residents or partially migrants (Edwards *et al.,* 2015; Valente *et al.*, 2017; Silva *et al.,* 2019).

The general model of fin whale migration also assumes a seasonal feeding–fasting cycle of migratory species (Clapham *et al.,* 2001), that may not occur: some baleen whale populations have been recorded foraging during migration and/or during the breeding season (Silva *et al.,* 2019; Gauffier *et al.,* 2020).

The sighting of fin whales in the Azores is usually stronger during the spring months being the most spotted baleen whale in the area (González *et al.,* 2014; Silva *et al.,* 2014). However, the presence of this species in the Azores during late autumn and winter months (i.e also off-season encounters) has also been recorded using passive acoustic data (Silva *et al.,* 2011; Nieukirk *et al.,* 2012; Romagosa *et al.,* 2020). The reported singing behaviour collected by Silva et al. (2011) together with sightings of mother-calf pairs in neighbouring regions (Freitas *et al.,* 2004; Carrillo *et al.,* 2010), suggests the existence of a breeding area near the Azorean archipelago (Nieukirk *et al.,* 2012; Romagosa *et al.,* 2020).

With the increasing controversy regarding fin whale migration patterns and the role of the Azorean archipelago new studies and methodologies should be implemented to provide new and easily accessible information.

1.3.4 Fin whale movements and environmental variables

Understanding the relationship between species distribution patterns and environmental variables is essential to predict their effects on the target species and the surrounding habitat and implement effective conservation measures (De Boer *et al.,* 2014; Fourcade *et al.,* 2014).

The great diversity of cetaceans in the archipelago of the Azores is a result of the high biological productivity and specific oceanographic features that characterize this region (Silva *et al.,* 2012; Prieto *et al.*, 2010). The distribution of baleen whales could be related to physical and biological variables such as bathymetry, slope, distance to the coast, salinity, Eddy Kinetic Energy (EKE), Sea Surface Temperature (SST) and chlorophyll-a concentration (Chl-a), as a primary production proxy (Visser *et al.*, 2011; Prieto *et al.*, 2014; Silva *et al.*, 2014; González García *et al.*, 2018). However to assess these relations, it is important to consider the potential temporal and spatial lags between the oceanographic processes and the observed biological responses (Redfern *et al.*, 2006; Visser *et al.*, 2011; González García *et al.*, 2018).

Previous studies regarding fin whale habitat preference highlighted the influence of static and dynamic oceanographic variables. Within the former, depth and distance to the coast, indicated that fin whales, contrary to other baleen whale species, use both coastal and oceanic areas (Panigada *et al.*, 2005, Ingram *et al.*, 2007; Gannier & Praca, 2007; González García *et al.*, 2014; Pérez-Jorge *et al.*, 2019). For the dynamic variables as SST, EKE and Chl-a, fin whales displayed a preference for colder waters, commonly associated with high productivity regions (González García, 2019; Pérez-Jorge *et al.*, 2019). A strong relation to areas with intense mesoscale activity (EKE) was also evident, such as upwelling areas, eddies and fronts which are also frequently linked to increasing marine productivity and prey aggregation (González García, 2019; Pérez-Jorge *et al.*, 2019).

Several authors also suggested a relationship between the timing of baleen whale's arrival to the Azores and predictable oceanographic events such as the onset of phytoplankton blooms during spring, proposing that these whales interrupted their migration to exploit high primary productivity (Visser *et al.*, 2011; Silva *et al.*, 2013; Sala *et al.*, 2015; Caldeira & Reis, 2017). The light conditions and high nutrient availability during winter allow an extraordinary increase of onset primary production leading to a phytoplankton spring bloom increasing prey densities which in turn induce the foraging behaviour of baleen whales (Visser *et al.*, 2011). However, studies have shown a typical lag between these blooms and baleen whale abundance of several weeks to months which corresponds to the required time for northern krill to reach suitable sizes for whale (Visser *et al.*, 2011; González García *et al.*, 2018; González García, 2019).

Assessing the influence of these variables is becoming increasingly relevant to understand population dynamics and forecast potential conservation and management measures, especially considering new threats capable of drastically changing ecosystems, such as climate change, extensive fishery, deep-sea exploration and marine pollution (Prieto *et al.*, 2014).

1.3.5 Threats and conservation

In the North Atlantic, the Azorean archipelago seems to be of great importance for many baleen whale species and the management of this migratory habitat is required to avoid not only direct threats as vessel collisions, entanglements, bycatch and noise pollution but also indirect threats such as ocean plastic pollution, overfishing, climate change and global ocean warming which may influence many changes in their usage of mid-latitude habitats and could lead to radical variations and degradation of ecosystems (Laist *et al.*, 2001; Evans & Hammond, 2004; Cañadas *et al.*, 2005; Panigada *et al.*, 2006; Azzelino *et al.*, 2012; Peréz- Jorge *et al.*, 2019).

Like most baleen whales, the fin whales' population stocks suffered drastic reductions during the whaling period, in the 19th and 20th centuries. The populations are now protected by global directives, such as the International Union for Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora. In fact, fin whales have shown a recovery (Edwards *et al.*, 2015), which is reflected in their conservation status by IUCN, which has recently changed (in 2018) from "endangered" (EN-A1d - population reduced by at least 70% in the last three generations/ 10 years, due to exploitation that has already ceased) to "Vulnerable" (VU-A1d- population reduced in at least 50% in the last three generations/10 years, due to exploitation that has already ceased).

In 1986, the IWC issued a moratorium ceasing the commercial whaling of all whale species and populations. Nonetheless, whaling is still a modern-day activity with the IWC recognizing 3 different types of whaling: (1) Aboriginal subsistence whaling, performed by indigenous communities and regulated by the IWC. (2) Commercial whaling suspended by the IWC and presently performed only by non-IWC members and countries objecting to the moratorium. This activity is not regulated by IWC, however, the countries share the "catching data" with the commission. (3) Special permit catches or scientific whaling, countries are asked to submit a permit research proposal to IWC, though, this submission is not mandatory and the role of the IWC is advisory only. Under these exceptions, since the whaling moratorium, the IWC recorded a total of 56,809 whale catches worldwide, mostly minke whales (45.842).

According to the IWC, in the North Atlantic, Norway and Iceland continue to hunt whales commercially in their Exclusive Economic Zone under the objection or reservation to the moratorium. Since 1986 Denmark (Greenland) caught 393 fin whales under the Aboriginal subsistence whaling permit. Whale catches under the "scientific permit" provision exception were operated in Iceland, until 2006, and by Japan, until 2014. In 2006, Iceland resumed official commercial whaling and started targeting fin whales (852 catches since then), a highly criticized decision since the species was still considered "endangered" by the IUCN.

In Japan, the elevated number of whale catches since 1986 in the North West Pacific and Antarctic region for "scientific research" (10 190 whales from 1985 to 2014) lead the International Court of Justice to rule, in 2014, that the nation's research program lacked the accepted scientific standards and should be concluded (Clapham *et al.*, 2015; *Whaling | WWF*, 2020). Japan continued with the activity and in 2018 withdrew from the international convention for the regulation of whaling and officially resumed commercial hunting (Wissmann & Wollensak, 2020). Even so, nowadays, whaling is no longer a major threat for fin whales although they are still largely affected by anthropogenic activities (Panigada *et al.*, 2006). According to Laist *et al.*, (2001), one of the most prevalent menaces for fin whales is ship strikes associated with one-third of all stranding appearances. NOAA fisheries also highlights other common threats, including entanglement (resulting in compromised feeding, fatigue, and severe injury) and ocean pollution (compromising guidance which can result in strandings).

As a highly mobile species with offshore habitats, protective measures for fin whales are very difficult to establish. Therefore, the use of photo-id and opportunistic data to monitor this species should be encouraged since it is a substantial contribution to determine potential transatlantic marine protected areas (MPAs), modify vessel trajectories and uncover new solutions that diminish bycatch events and fishing pressure, which is disrupting the ecological equilibrium of marine communities.

1.4 Theme justification

Studies addressing fin whale's distribution in the North Atlantic were usually focused on several species of baleen whales and in larger areas, such as the archipelago or even the Macaronesia (Evans & Hammond 2004; Silva *et al.*, 2013; González *et al.*, 2014; Edward *et al.*, 2005; Prieto *et al.*, 2017; Ojeda *et al.*, 2018; González García *et al.*, 2018; Valente *et al.*, 2018; Pérez-Jorge *et al.*, 2019; Schleimer *et al.*, 2019; Romagosa *et al.*, 2020). Moreover, a lack of information regarding photo-id is acknowledged, particularly bearing in mind the increasing controversy regarding fin whale migration routes.

Comparison of different photo-id catalogues within the Atlantic can hopefully improve our understanding of this species' movement patterns and the role of the Azorean archipelago as a migratory habitat. However, the largest catalogues in the Atlantic are mostly restricted to the Mediterranean Sea or the Northwest Atlantic (Robbins *et al.*, 2008).

The Azores provides great conditions for the research of this species due to their proximity to land (due to the abrupt continental shelf), a consistent number of sightings, and the easy access to long-term opportunistic data registered regularly by whale-watching companies, at least during the last 12 years.

1.5 Objectives

The aims of this study are: (1) to create a robust fin whale photo-id catalogue for São Miguel island using opportunistic data collected between 2008 and 2019; (2) compare it with several other catalogues from different regions to assess potential movement towards other areas, within the Eastern North Atlantic; and (3) identify possible environmental drivers related to their migratory patterns.

We expect to confirm possible links between the Azores and other locations within the S stock, using two major photo-id catalogues from the Azores archipelago (São Miguel and Faial), one catalogue from southeast mainland Portugal (Sagres) and two from northern Spain (Galicia and Bay of Biscay) to check for movements along the years and potential routes of long-range migrations within the North Atlantic.

A simple exploratory analysis using the opportunistic sighting data was performed to test the influence of environmental variables, particularly Chl-a, in fin whale migration patterns, habitat selection and their relation to the Azorean archipelago and São Miguel island.

Additionally, this study serves as a baseline to further investigations, enhancing our knowledge of the biology and distribution of fin whales with the intention of preparing effective conservation measures and management programs for this emblematic species.

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Chapter 2:

Fin whale *(Balaenoptera physalus)* identification and distribution around São Miguel island (Azores) and inferences on movements towards other areas

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2.1 Abstract

Understanding the movement patterns, and their possible drivers, of highly migratory marine species such as fin whale *(Balaenoptera physalus)*, is vital for establishing appropriate conservation measures. After been drastically reduced during the whaling period, fin whale populations are now recovering which led IUCN to recently update their status from “Endangered” to “Vulnerable”. Studying the population structure of the North Atlantic fin whales is particularly challenging due to their mobile nature and the lack of clear geographic barriers. The IWC (International Whaling Commission) suggests seven stock structure hypotheses however, there has been evidence of movements between these areas. The Azores archipelago is known to be a migration corridor for the North Atlantic populations, especially during springtime yet, many questions still exist regarding the ecology and habitat use in the archipelago.

In this study 11 years of opportunistic data from whale-watching platforms were used to create a photo-identification catalogue of fin whales around São Miguel. This catalogue was then compared with four other catalogues: one in the Azores and three from Iberian waters. The aim of this study was to assess potential migratory patterns and connections, understand the role of the Azorean archipelago and identify possible environmental drivers related to their presence. The composition of the photo-id catalogue and database enabled the identification of 256 individuals and accounted for 32 re-sightings around São Miguel. The results presented indicate possible migratory connections within the archipelago and Galicia (North-West Spain), suggesting a variation of the commonly accepted migratory routes of baleen whales. Our findings also suggest that oceanographic features and events (e.g., phytoplankton spring bloom) influence timing of fin whale migration and distribution in the archipelago. Additionally, this study serves as a baseline to further investigations, highlighting the important role of opportunist data in enhancing our knowledge of the biology and distribution of fin whales with the intention of supporting effective conservation measures and management programs to this emblematic species.

Keywords: Fin whale; Cetaceans; Photo-id; Azores; São Miguel; whale-watching; migration

2.2 Introduction

Fin whales (*Balaenoptera physalus,* Linnaeus, 1758) are a cosmopolitan cetacean species (suborder Mysticeti) with wide distribution, ranging from tropical to polar regions (Aguilar, 2009). Despite the intense hunting during the last century, the increasing population numbers of fin whales led the IUCN to change their conservation status, in 2018, from "Endangered" to "Vulnerable" (Cooke *et al.,* 2018). However, fin whales continue to be largely affected by human threats which jeopardize whale populations and marine ecosystems (Panigada, *et al.,* 2006).

In the North Atlantic, the fin whale population estimated is about 80,000 individuals (Aguilar & García-Vernet, 2018; Pike *et al.,* 2019; IUCN, 2020) and the International Whaling Commission (IWC) (2009) has included a seven discrete stocks hypothesis to separate North Atlantic populations based on genetic and non-genetic data (International Whaling Commission, 2009, 2017). Nonetheless, stock structure and size, boundaries, winter grounds, and migratory routes are still unclear (Donovan, 1991; Coakes *et al.,* 2005; Gauffier *et al.,* 2020). This is particularly true for the Azores, which is a transition zone between two Northeastern Atlantic identified stocks: East Greenland (EG) and Spain-Portugal-British-Islands (S) (Delarue *et al.,* 2008; Silva *et al.,* 2019).

The observations suggesting variations of the commonly accepted model of baleen whale migration have led to new studies questioning the previously well-established hypothesis (i.e. summer high latitude feeding grounds, and wintering breeding areas in low latitudes). Not only the previous migration model usually comprises a seasonal feeding–fasting cycle (Clapham *et al.,* 2001) already disputed for the Azorean region (Silva *et al.,* 2019; Gauffier *et al.,* 2020), as there is also contradictory evidence regarding fin whales' migratory paths linking both Greenland-Iceland foraging grounds (Silva *et al.,* 2013) and Iberian foraging grounds (Silva *et al.,* 2019) to the archipelago. The presence of both populations may be the result of a shared sequential feeding ground in the Azores, where Icelandic whales feed during winter and spring months in the same areas where later, during summer, Iberian whales also forage (Gauffier *et al.,* 2020). In addition, sightings of mother-calf pairs in adjacent areas (Freitas *et al.,* 2004; Carrillo *et al.,* 2010) and new acoustic evidence recorded fin whale calls during autumn and winter months seem to contradict the common belief of a simple migration corridor crossing the Azores during spring (Silva *et al.,* 2011; Nieukirk *et al.,* 2012; Romagosa *et al.,* 2020).

In the search for answers regarding these still misunderstood routes we propose the use of photo-identification (photo-id) as a simple, non-invasive mark and recapture method which contributes with good insight for distribution ranges, migration paths, site fidelity, population size and behavioural patterns for many marine species (Agler *et al.,* 1990; Agler *et al.,*1992; Castro *et al.,* 2011; Stevens, 2014; Araujo *et al.,* 2016). Many studies addressed photo-id of baleen whales by the distinctiveness of their natural markings and caudal/dorsal fin patterns, depending on the targeted species (Evans & Hammond, 2004; Calambokidis *et al.,* 2009; Lang *et al.,* 2011; Constantine *et al.,* 2012). This technique can be applied to fin whales using dorsal fins shape and nicks combined with pigment pattern and acquired natural marks such as scars (Hammond *et al.,* 1990; Boyd *et al.,* 2010).

In the North Atlantic, larger fin whale catalogues are mainly limited to the Northwest Atlantic and the Mediterranean Sea. The largest, with over eight hundred individuals, the 'North Atlantic Fin Whale Catalogue' was created in 1981 (Agler *et al.,* 1990; Robbins *et al.,* 2007). The 23,665 photographs comprised in the catalogue were collected in the Gulf of St Lawrence, coast of New York, Gulf of Maine and Nova Scotia from 1974 to 2006 (Robbins *et al.,* 2007). The Tethys Research Institute (TRI) contains the photographs of most of the recorded fin whales in the Mediterranean (n=425) (Zanardelli *et al.,* 1992; Bendinoni *et al.,* 2003; Robbins *et al.,* 2007). In the Azores, Nova Atlantis identified 22 individuals (Robbins *et al.,*2008), Whale Watch Azores photographed 313 individuals (2020, unpublished data) and the MONICET platform has 116 whales registered, as of 2020. The integration of these catalogues to form a large dataset and the comparison of the identified individuals can be of great use to assess the unclear, seasonal, long-range movements performed by fin whales and increase our knowledge about their distribution and spatial dynamics in the North Atlantic (Wursig &Jefferson, 1990; Coakes *et al.,* 2005).

To corroborate the possible connections between the Azores and other locations two major catalogues from the Azores archipelago (São Miguel and Faial), one catalogue from southeast mainland Portugal (Sagres) and two from northern Spain (Galicia and Bay of Biscay) were compared to search for possible connections within the Spain-

Portugal-British-Islands stock (S) as suggested by Silva et al. (2019) and Gauffier et al. (2020).

In addition, it is likely that these migratory behaviours are closely linked to static and dynamic environmental variables and their influence on the migratory habitats. The specific topography of the archipelago with the temperate climate, geographic isolation, and presence of extreme environments (e.g. thermal vents) allows a wide range of marine ecosystems and habitats with complex food-webs making it a hotspot for biodiversity (Sala *et al.,* 2015; Afonso *et al.,* 2020).

The variations of habitat use of baleen whales are mainly determined by the oceanographic variables and the effects in prey density and distribution (González García *et al.,* 2018; López *et al.,* 2019; Pérez-Jorge *et al.,* 2019). Previous studies highlighted the influence of both static variables, such as bathymetry, distance to the coast and slope, and the influence of dynamic variables as salinity, Sea Surface Temperature (SST), Eddy Kinetic Energy (EKE) and chlorophyll-a concentration (Chl-a) (Panigada *et al.,* 2005, 2007; Gannier & Praca 2007; Laran & Gannier, 2008; González García *et al.,* 2018; López *et al.,* 2019; Pérez-Jorge *et al.,* 2019). It is thought that fin whales prefer highly dynamic areas, with elevated EKE and SST gradients associated with intense mesoscale activity and cooler waters usually related to high productivity and food aggregation to enable efficient foraging both in coastal and oceanic areas (González García *et al.,* 2018; López *et al.,* 2019; Pérez-Jorge *et al.,* 2019).

Chl-a concentration is commonly used as a proxy for phytoplankton biomass and is thought to be closely related to the distribution of baleen whales (Visser *et al.,* 2011). These Chl-a concentrations are considerably higher during the spring phytoplankton bloom, showing a direct impact on baleen whales' migrations paths and their arrival to the archipelago (Visser *et al.,* 2011; Prieto *et al.,* 2016). However, studies have shown a temporal lag of a few weeks to months between these events and baleen whale presence, corresponding to zooplankton development until suitable sizes for foraging (Visser *et al.,* 2011; González García *et al.,* 2018). Research related to habitat preferences and oceanographic drivers can be used to establish effective conservation strategies, especially in the face of global climate change, that influences the timing of spring phytoplankton bloom and, consequently, has a great impact on marine species distribution (Laran & Gannier, 2008). In this study, a simple exploratory analysis of environmental variables' influence in fin whale's distribution and migration patterns is performed, using opportunistic cetacean occurrence data.

The use of opportunistic data is also addressed, as it allows a cost-effective, regular collection of information, during long periods, on species distribution, population structure and diversity (Wursig & Jefferson, 1990; Evans & Hammond, 2004; Coakes *et al.,* 2005). Despite the challenges associated with opportunistic data, its use is becoming increasingly important for studying cetacean species and addressing species management and monitoring programs, conservation measures and mitigation of anthropological threats, especially in areas with progressively more data collected by maritime-touristic companies such as the Azores.

The aims of this study are 1) to create a complete up-to-date fin whale photo-id catalogue for São Miguel, using 11 years of opportunistic data, 2) compare the identified fin whales to investigate movements and potential long-range migration between the Iberian region and the Azorean archipelago, and 3) perform a simple exploratory analysis of the environmental variables that may influence the temporal and spatial distribution of fin whales around São Miguel. We also expect this study to contribute to the improvement of management, monitorization, and conservation efforts in the Azores region.

2.3 Materials and Methods

2.3.1 Study area:

The Azores archipelago (Portugal) is located in the North Atlantic, between 36°–41°N and 24°–32°W, and it is integrated into the Macaronesia region. With a complex current circulation pattern, the archipelago is mainly affected by the Gulf Stream cooler branch, the North Atlantic Current (NAC), flowing northeastward (45º-48ºN) and by the warmer water masses of the Azores Front/Current System passing in the southern part of the islands (32º-37ºN) (González García *et al.,* 2018). These currents contribute to the average SSTs, ranging from 15º to 20ºC in winter and 20º to 25ºC during the summer months (Sala *et al.,* 2015; González García *et al.,* 2018).

The archipelago is composed of nine volcanic islands, spread across an area of 630 km wide crossing the Mid-Atlantic Ridge (Sala *et al.*, 2015; González García *et al.*, 2018) and categorized into three groups: Western group (Flores and Corvo), Central group (Graciosa, São Jorge, Pico, Faial and Terceira) and the Eastern group (São Miguel and Santa Maria). The three groups are separated by deep waters (> 2000m) with a complex topography and specific oceanographic features that influence the diversity of marine habitats ranging from the continental shelf's shallow waters to high depths (Prieto *et al.*, 2017).

In the Azorean archipelago, São Miguel (Figure 2.1) is the largest and most populated island. The sea surveys used for this study were conducted mostly off the South coast of this island, departing from Ponta Delgada (occasional trips departed from Rabo de Peixe on the north coast).

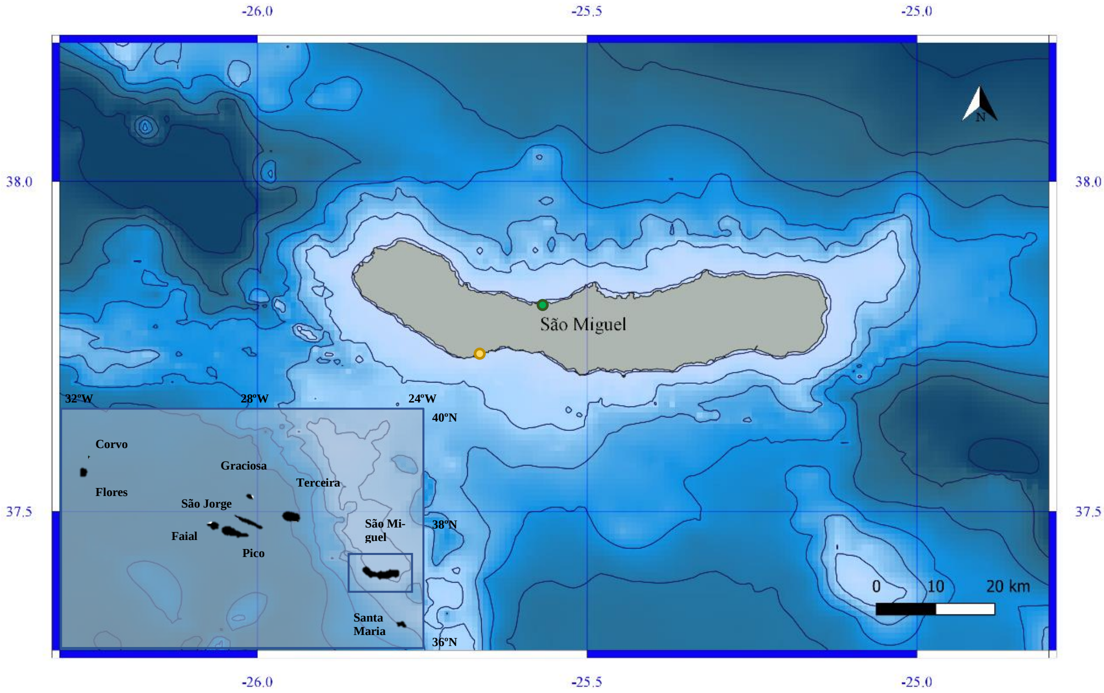

Figure 2. 1 Study Area: Azores Archipelago (inset) and enlarged area of São Miguel with batythemtry data. Yellow dot marks Ponta Delgada harbour. Green dot marks Rabo de Peixe.

2.3.2 Cetacean data collection:

The data used for this project was collected between 2009 to 2019 during commercial trips from Futurismo Azores Adventures, a whale-watching company with the main base port in Ponta Delgada, São Miguel. This company combines tourist activities such as whale and dolphin watching with marine biology research projects done with the data collected during the daily trips.

The trips were dependent not only on the sea state and weather conditions but also on the number of tourists interested in the activity. Data was collected during the whole year but more extensively during the spring and summer months. The tours have the approximate duration of 3h (two tours per day during spring and summer) and they are conducted in different boat types: two bigger catamarans (18 m, max. 76 people), rigid-hulled inflatable boats (8 m, max. 12-24 people) and a fibreglass boat (12 m, max. 36 people).

The use of land-based lookouts is a very important and characteristic feature of the Azorean whale-watching. The search for cetaceans starts before the trips, by people located in strategic high points of the coast looking for the cetaceans with powerful binoculars (Steiner 20x80). The transmission of the location and behaviour of the animals to the boats continues during the trips via VHF radio. As most of the sightings occurred first from the shore, the boats are guided directly towards the whales. Nonetheless, some encounters occurred spontaneously.

When close to the cetaceans one of the biologists on board registers the GPS location, time and duration of the sighting together with the species, group size, group composition and behaviour. Photos are taken whenever is possible. Ideally, all the individuals are photographed on the left and right sides to match both sides of the same individual and depending on the species, the tail (fluke) can also be photographed. Only the sightings with the confirmation of the species identification were considered for this study.

2.3.3 Environmental data: Chl-a and SST

The Chl-a concentration data was obtained from GlobColour (http://globcolour.info). A space-time interpolation product (L4) was used: the "Cloud Free" with a spatial resolution of one km over the Atlantic (46ºW-13ºE, 20ºN-66ºN) which includes our study area. Product results from the combination of multiple sensors (e.g SeaWIFS, MODIS, MERIS and VIIRS).

SST data was obtained from Global Ocean- Operational SST and Sea Ice Analysis (OSTIA), run by Met Office (UK) with a gridded spatial resolution at 0.05° x 0.05° (approx. 6 km) using satellite data both from infrared and microwave products (*CMEMS*, 2020). For this project, we extracted the monthly Chl-a and SST products over the Azores archipelago (36-41ºN, 32-24ºW) and São Miguel (37-38.5ºN,26.5-24.5ºW)

2.3.4 Spatial and temporal distribution

To examine temporal patterns in the occurrence of fin whales, the number of sightings per month and year was calculated using Microsoft Excel. Sighting frequency (monthly and yearly) was also calculated from 2009 to 2019. To understand the relation between whale sightings and habitat variables and look for possible patterns of distribution within the study area, a simple exploratory analysis was conducted.

Since this is an opportunistic dataset and the animals were first spotted from land, it is not possible to calculate an effort of sightings per area or unit of time. Instead, as an effort-related estimate, we calculated an encounter rate (ER) dividing the number of trips with fin whale sightings per the total number of trips. This ER was calculated for each month and year of our study period and compared with Chl-a concentration and SST.

$$\text{ER}= \frac{number\ of\ trips\ with\ Bp\ .sightings}{total\ number\ of\ trips}$$

To map the spatial distribution of fin whales sighted around São Miguel, QGIS 3.10.11 software was used. The GPS coordinates collected during the sightings were plotted together with the bathymetry acquired from the General Bathymetric Chart of the Oceans (GEBCO, 2012) and the coastline of São Miguel retrieved from Instituto Hidrográfico de Portugal. We created a heatmap (point density interpolation using Kernel Density Estimation; 0.05º radius and 0.01-pixel size) using all recorded fin whale sightings with GPS locations available to identify the area with a higher density of sightings.

Behaviour recorded during sightings was categorized in: foraging, diving, travelling, socializing, and not identified, and the percentage of each behaviour was estimated. The percentage of the number of associations with other species was also determined.

2.3.5 Photo-id: São Miguel Catalogue

2.3.5.1 Photograph collection

To create a photo-id catalogue for fin whales off São Miguel, we collected a total of 20.036 photographs of fin whales taken between 2009 to 2019 during whale-watching trips by "Futurismo Azores Adventures" mainly on the south coast of São Miguel. As the photographs were collected opportunistically and dependent on weather conditions and the number of trips conducted each year, the number of photographs is not even along the study period with a higher number of photographs and identified whales from 2014 to 2016.

Whenever it was not possible to photograph both sides of the whale, the right side was preferred given the asymmetrical body pigmentation, unique to fin whales. Photos were taken at a perpendicular angle with a special focus on the dorsal fin and chevron pattern.

2.3.5.2 Organization of the photographic catalogue

Prior to identification, all photographs were organized by date and underwent a quality control check removing the ones with insufficient quality for photo-identification (un-focused, splashes of water, with sun glare, poor angle). Of the 20.036 photographs, 10.630 were considered appropriate for photo-id and were organized and matched by eye to new photographs. Pictures were cropped and edited using Windows Live Photo Gallery to enhance some characteristics of individuals and improve clarity.

For each new individual sighted, the photo with the best quality for identification, more representative of the distinctive features, was chosen and copied for the existing catalogue. If the individual sighted matched one of the individuals in the catalogue, the same identification code had to be given, and a new photograph, taken during the second encounter, was added to the catalogue. A re-sighting rate was calculated by dividing the number of re-sightings (identified individuals sighted more than once) per total number of identified individuals. When possible, a complete set of photographs of both sides, chevron, dorsal fin and distinct marks was included. A new sequential code was attributed to each individual (BP# (left/right side)) and all the data collected regarding the individual identified and the specifications of the trip were copied and organized according to: date, ID number, GPS coordinates, side of the individual, degree of marking, number of nicks and types of marks as well as interaction with other species and behavioural information. During this process, the pictures were separated according to the side of the dorsal fin (Left/Right) and Windows Live Photo Gallery was used to tag specific codes to each photo according to the place and the marks in every individual to facilitate comparison of new individuals with the existing catalogue.

The individuals were separated into 3 different categories according to their distinctiveness (E-easy, M- medium, D-difficult to identify). The percentage of each class was calculated together with the percentage of right and left side photographs of individuals. A discovery curve representative of the cumulative number of identified individuals per year was calculated

The percentage of identifiable individuals was calculated by dividing the number of individuals that showed some degree of identifiable marks divided by the total number of individuals registered during the trips, multiplied by 100. Additionally, we calculated the percentage of the number of nicks in dorsal fins in our sample.

$$\frac{individuals\ with\ identifiable\ marks}{total\ number\ of\ individuals\ registered} * 100$$

2.3.6 Photo-id: Catalogue comparison

To assess possible connections within the archipelago and between the Azores and the Iberian Peninsula we compared four fin whale catalogues between each other and with our São Miguel catalogue. The first catalogue belongs to “Whale Watch Azores” and comprises photographs of 313 individuals sighted around Faial island from 2010 to 2018. The data for the second catalogue, with 59 identified individuals from 2012 to 2019, was compiled by “Mar Ilimitado” based in Sagres, Southwest Portugal. The third catalogue provided by “Bottlenose Dolphin Research Institute (BDRI)” counts 30 identified individuals recorded between 2017-2018 in Galicia, North of Spain. Finally, the fourth catalogue with 55 identified fin whales from "Verballenas" contains sightings recorded in the Cantabrian Sea (Bay of Biscay) from 2011 to 2019.

To facilitate photo-id comparisons, individuals of each catalogue were separated by left and right side of the dorsal fin and grouped in 6 categories according to easily identifiable features: "number of nicks" in the dorsal fins (divided in 1, ≥2), "Tip cut", "well-scared individual", "unusually shaped dorsal fins" and "normal".

Firstly, individuals from the same category were compared, if no match was found, the individual being analysed was compared to the following groups until every photograph in the catalogue was compared. This procedure facilitated and reduced the time required to match individuals. A dataset was prepared with the dates and locations of the matches found during this study.

2.3.7 Environmental variables and movements around São Miguel island

The relation between the sightings coordinates and the static environmental variables (distance to the coast, depth, and slope) was investigated using QGIS software (QGIS Development Team, 2019. QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.org).

Dynamic variables (Chl-a and SST) were plotted using R software (R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/) for the area surrounding the archipelago. We used monthly mean data for the archipelago (36-41ºN, 32-24ºW) to avoid missing values of the daily satellite dataset and to focus on the general influence of each variable during our study period.

Chl-a concentration (mg/m3) was also considered since it is a proxy for primary production. Monthly means were used along each year to check for seasonality and interannual differences. We plotted the average Chl-a concentrations of all years per month (12 plots with the mean monthly concentrations of 11 years) to compare with possible variations in Chl-a patterns that may have affected the fin whale ER. A Shapiro–Wilks test concluded that the variables had a non-normal distribution (p<0.05), hence we performed a Spearman correlation test between the variables and the ER (Chl-a & ER;

SST & ER) to measure the strength of association between them. Time-series and cross-correlation (CCF) between the dynamic environmental variables and frequency of sightings/ER were calculated using the R package “astsa” (https://github.com/nick-poison/astsa/) to consider the association and possible lag between the events. This is particularly relevant when considering variations in Chl-a concentration and the delay between the phytoplankton bloom and the influence in the upper trophic levels.

Time-series plots were used to compare monthly Chl-a concentrations with monthly fin whale ER a look for potential influences. Months with an unexpected number of sightings recorded were compared with average Chl-a concentration for the same and prior months.

2.4 Results

2.4.1 Temporal and spatial distribution

Fin whales are regularly sighted in the Azores. In, the 11 years of study, 4325 trips were recorded (Figure 2.2), from which 945 (Appendix I; Table 1A) included sightings of the target species. Fin whales were mostly spotted during the spring months despite the higher number of trips conducted during summer (Appendix II; Figures 1A and 2A). In summer, better meteorological conditions and more tourism usually allow a higher number of whale-watching trips to be conducted. (Figures 2.2 and 2.3).

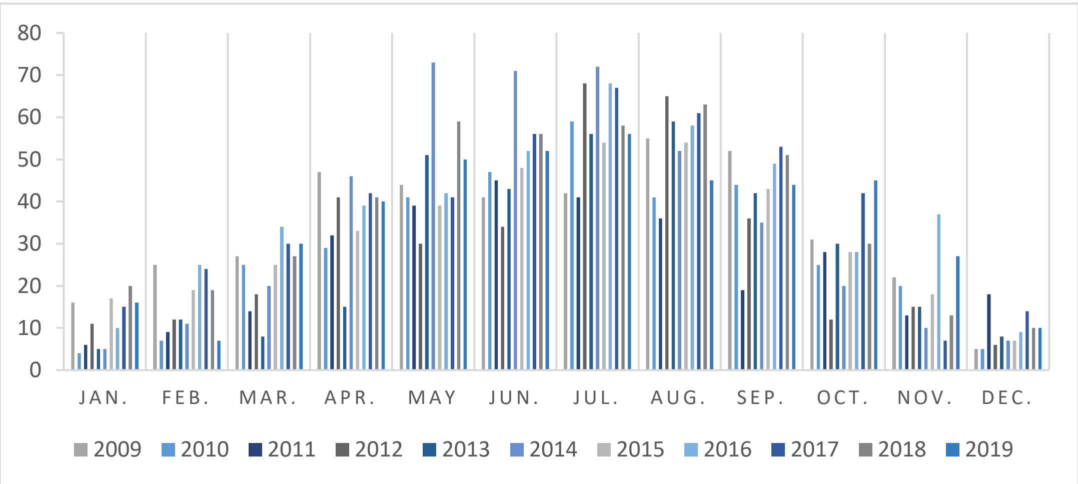

Figure 2. 2 Number of trips registered by "Futurismo Azores Adventure". Rough estimation of effort conducted during the 11 years of study

ER (number of trips with fin whale sightings/number of trips) increased from May reaching a maximum of 0.789) and decreases from May to September (0.024) (Figure 2.3; Appendix I; Table 2A).

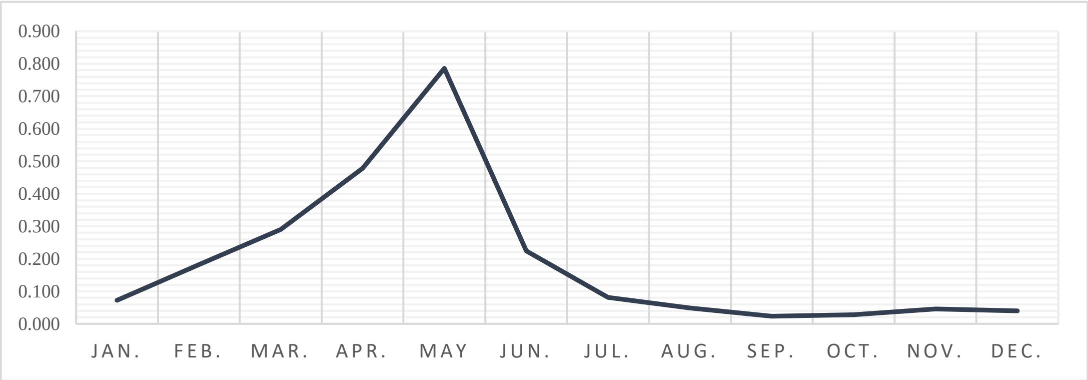

Figure 2. 3 Mean representation of Encounter Rate (number of trips with *Balaenoptera physalus* /total number of trips) throughout the months of our 11 years study period

As represented in Figure 2.4 a higher density of sightings was recorded south of Ponta Delgada (areas represented with a darker red colouration) but sightings occurred frequently from Ferraria to Ribeira Quente.

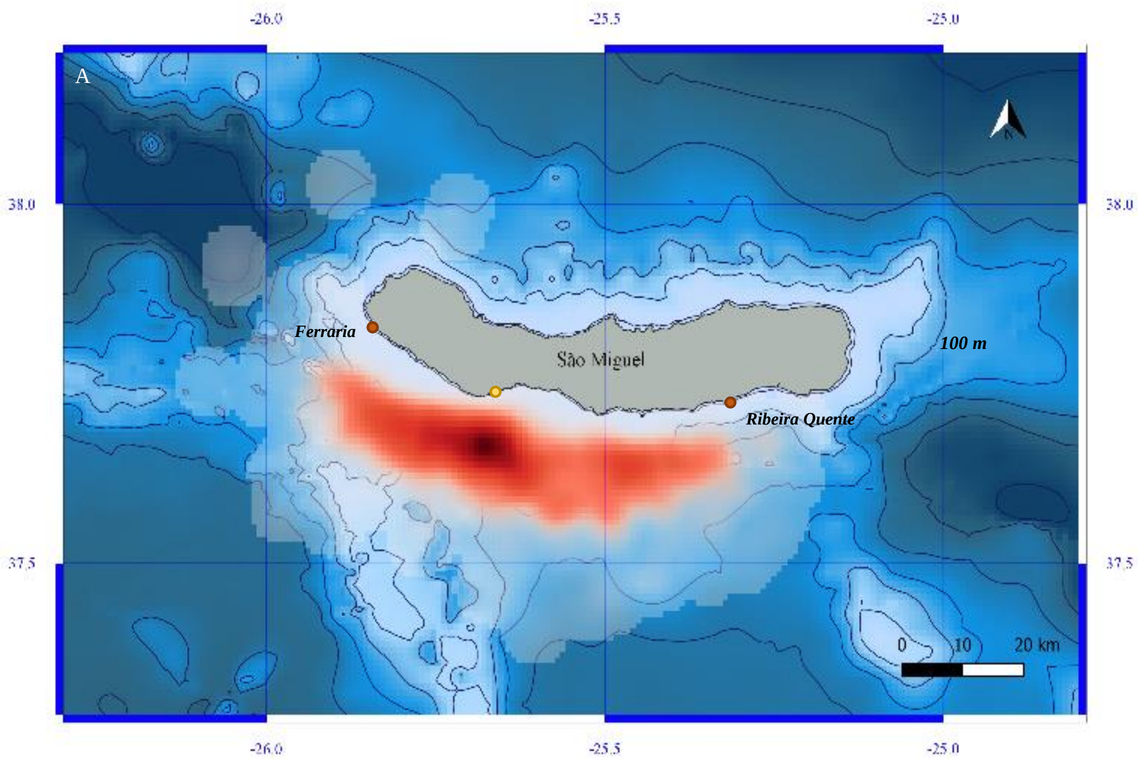

Figure 2. 4 Density of sightings during the study period. Dark red colours represent higher densities, lighter red colours lower densities. Bathymetry map emphasizing the 100m isobath. The yellow dot marks Ponta Delgada, while the red dots indicate the locations of Ferraria and Ribeira Quente.

Interspecific associations were recorded with five identified cetacean species: most frequently with common dolphin (17%) and blue whale (13%), followed by association with bottlenose dolphin (5%), sei whale (1%), false killer whale (1%) and fish species (5%). Individuals were usually sighted alone (48%) or in small groups (usually 2 to 5 ; maximum 15 individuals). Diving was the most common behaviour (41%) followed by traveling (34%), socializing and foraging were much less common (2%).

2.4.2 Photo-id sightings

Of the 945 trips where fin whales were sighted, only 213 trips had an adequate photographic record to use for photo-id. A total of 256 fin whales were identified. Individuals were identified using 149 images of the right side of the dorsal and 175 images of the left side. Photographs of both sides were matched for 64 individuals, which represent 25% of all identified whales.

Most of the photographs successfully used for identification were collected from March to July which corresponds also to the period with more re-sightings registered (Figure 2.5). The total re-sighting rate was 15% and most of these occurred in 2014 when 11 whales were re-sighted within that year. No re-sightings occurred in 2009, 2010, 2013 or 2018.

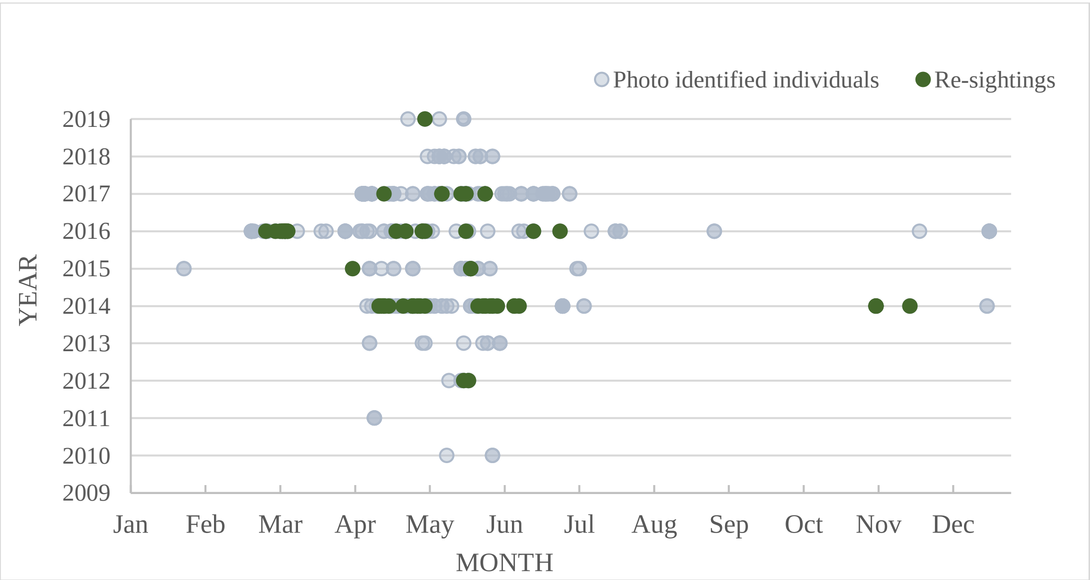

Figure 2. 5 Daily temporal distribution of *Balaenoptera physalus* photo-identified individuals around São Miguel between 2009 and 2019: individuals identified (light blue); re-sighted (dark blue).

We counted 32 re-sightings of previously identified individuals along the study period: three whales were re-sighted in different years (Bp12 – 2014 and 2017; Bp75 – 2014 and 2016; Bp100- 2014 and 2017), with a maximum gap of three years between encounters (Bp100); 29 re-sightings occurred within the same year, 23 of which were within the same month (Appendix I; Table 3A.).

The minimum amount of time that whales spent in the study area (i.e., the time we could confirm based on photo-id) ranged from one to 14 days after the individual was identified for the first time. The whale with the higher number of re-sightings (BpA18) was encountered four times in consecutive days (03/03/2016-06/03/2016). In 2014 a total of five whales apparently left the study area returning months later (Bp11- 4/2014 and 11/2014; Bp21- 5/2014 and 11/2014; Bp123- 4/2014 and 11/2014; Bp126- 4/2014 and 11/2014; BpA6- 4/2014 and 11/2014). The right side of Bp21 was photographed twice in May 2014 (1/5/2014 and 3/05/2014) and once in November 2014. These sightings agree with the expected northward and southward migrations, respectively (Figure 2.6).

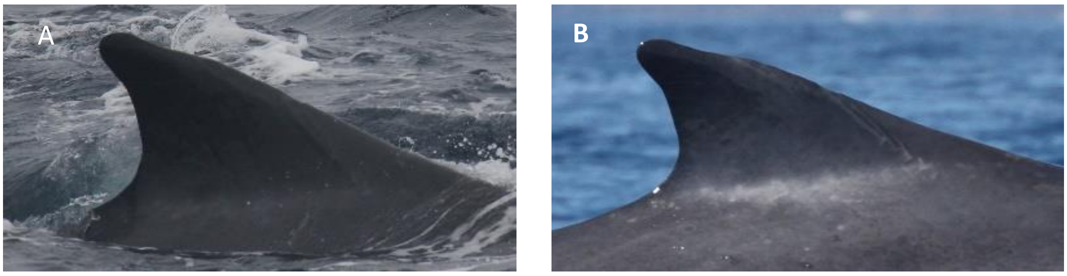

Figure 2. 6 Re-sighting between seasons. Photographs from "Futurismo Fin Whale Catalogue": right side of Bp21 sighted twice in May 2014 (1/5/2014 and 3/05/2014) – expected northward migration (A) and in November 2014 – expected southward migration (B).

Considering the total estimated number of fin whales in all trips (827) only 32% of the recorded fin whales were identified and catalogued. The number of fin whales catalogued ranged from three (2010/2011) to 72 (2017). The growing discovery curve (Figure 2.7) illustrates the cumulative number of individuals identified between 2010 and 2020 suggesting an open population with new individuals crossing the region every year. A higher number of individuals was catalogued between 2014 and 2017 due to the higher number of available photos, allowing us to identify a higher number of whales.

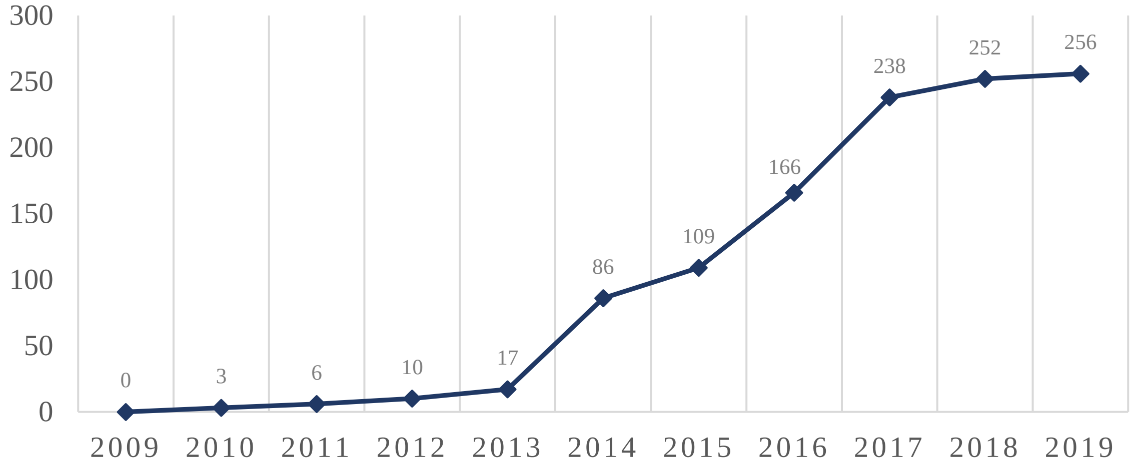

Figure 2. 7 Discovery curve of *Balaenoptera physalus* cumulative number of individuals off São Miguel between 2009 and 2019. As supporting information, the number of trips with Bp. Sightings were: in 2009-32; 2010-34; 2011-15; 2012-42; 2013-104; 2014-183; 2015-93; 2016-155; 2017-142; 2018-121; 2019-14.

- Scaring and dorsal fin shape

Dorsal fins were divided according to the identification difficulty in E-easy, M- medium, and D-difficult to identify. Most individuals were considered difficult to identify (65%- Left side photographs; 55%- Right side photographs). Sixty-one percent of individuals were classified as difficult to identify mostly due to lack of scaring and nicks on the dorsal fins and ambiguous photographs.

Most individuals did not show any nicks in the dorsal (59%) and only a small percentage had 3 or more nicks (2%). Some individuals displayed unusual features which allowed a more confident identification process.

Furthermore, some photographed individuals displayed some interesting features, showing some morphological characteristics common from both blue and fin whales. These include anomalies in colouration patterns, shape of the head, lacking the asymmetric head colouration associated with fin whales, a combination of features in the baleen plates and unusual dorsal fin shapes (Spilliaert *et al.*, 1991; Martine Bérubé & Aguilar, 1998).

2.4.3 Photo-id: Catalogue comparison

Only two re-sightings were confirmed between the different study locations. One whale was spotted in São Miguel and Faial with almost three years difference between the first sighting in São Miguel, May 2014, and the second sighting in March 2017 in Faial. The second re-sighting was a whale firstly sighted in Faial (07/06/2017) and then in Galicia (07/10/2017). This last individual's identification was obvious due to the atypical pigmentation of the individual (Hypopigmentation). This leucistic fin whale had several white patches in the body, head, dorsal fin, and fluke giving great confidence to the identification (Appendix I; Figure 3A). This individual was not sighted in any of the other study locations. No matches were found with "Mar Ilimitado" Catalogue in Sagres, neither with "Verballenas" in the Bay of Biscay. Despite the proximity, we did not find any matches between the Galicia and the Bay of Biscay catalogues suggesting different migration routes or populations. Yet, it is important to consider that fin whale catalogues collected in the Azores are considerably larger (Faial= 358 individuals; São Miguel =256) than the ones collected in mainland Europe (Bay of Biscay=54; Galicia=30; Sagres= 59).

2.4.4 Environmental variables and movements around São Miguel island

- Static variables: distance to the coast, slope and depth

Fin whales were mostly sighted further than 5 km from the coast usually ranging between 5 km and 15 km (7.5%) from the southern shore of São Miguel (range: 1.32-34.57 km, median: 10.86 km). Over half of the sighted whales (56%) were in waters between 500 and 1000 m deep. The maximum depth assigned to a fin whale sighting was 3222 m, Northwest of São Miguel island in a location known as "Fossa do Hirondelle". Sightings were recorded within a wide range of slopes (range: 0.27-41.21º, median: 6.28º), however, most whales were encountered below 12º with a higher percentage of recordings between 2º and 4º (28%) and between 4º and 6º (16%).

- Dynamic variables: time-series - SST and Chl-a concentration

Monthly average Chl-a concentrations reached the highest values during the months of March and April attaining values over 0.60 $mg.m^{-3}$ of Chl-a around São Miguel (Appendix II; Figure 4A). Concentration decreased during the end of spring and summer with particularly low values in August and September with only a small area in the vicinity of the islands (close to shore) showing Chl-a values over 0.10 $mg.m^{-3}$ (Figure 2.8.C). In October Chl-a concentration started to increase again until next year's spring (Figure 2.8).

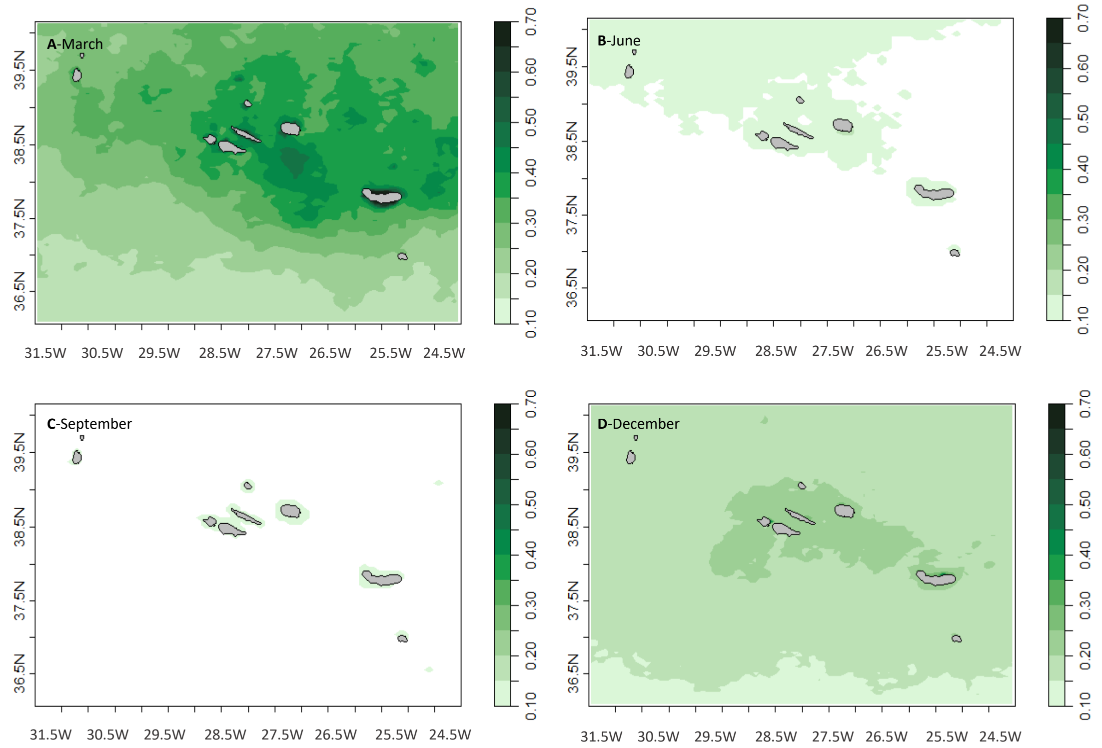

Figure 2. 8 Mean monthly Chl-a concentration maps for Azores archipelago during an 11year study period (top left corner- March; top right corner- June; bottom left corner- September; bottom right corner- December)

Spearman's rank correlation coefficient indicated a significant negative correlation between SST concentration values and the ER (p-value= 0.00022; rho= -0.31640) (Appendix II; Figure 5A). The test also showed a significant positive correlation between Chl-a concentration values and the ER (p-value= 0.00075; rho= 0.28976). Time-series of the two target dynamic variables were plotted together with the ER time-series. Clear seasonal cycles in SST and Chl-a concentrations were observed. SST cycles had minimal inter-annual variations with consistently lower values during winter and higher during summer. Chl-a concentrations also showed seasonal cycles with high peak values in March/April, which declined to very low values in August/September and then began to increase, in accordance with the graphical representations (Figure 2.9 and 2.10). The highest concentrations were detected in 2010 and 2014 with the lowest recorded in 2012.

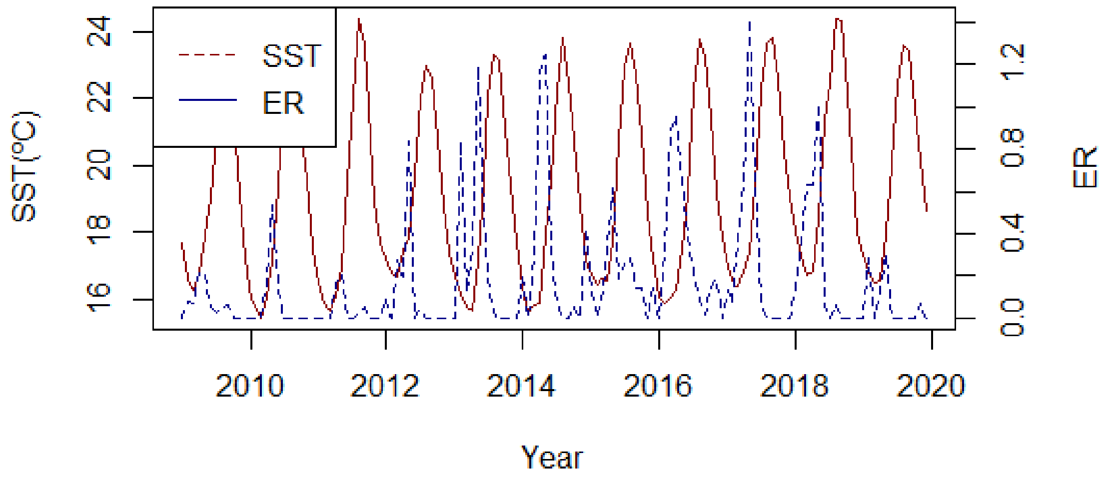

Figure 2. 9 Time-series showing the variation in mean monthly sea surface temperature (ºC) and the ER of *Balaenoptera physalus* around São Miguel, from 2009 to 2019

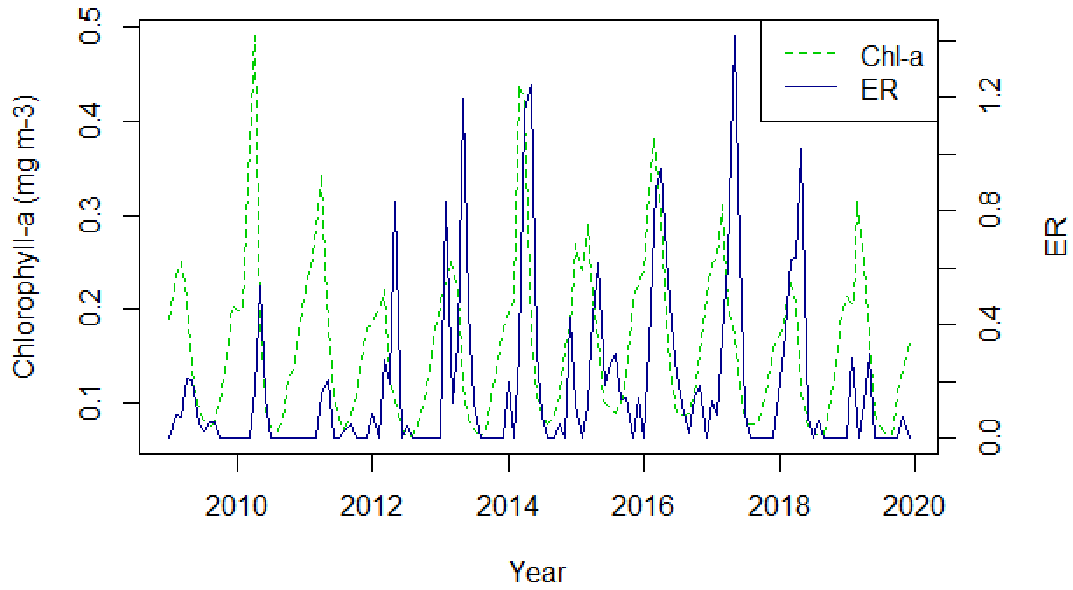

Figure 2. 10 Time-series showing the variation in mean monthly chlorophyll-a concentration (mg.m-^{3}) and the ER of *Balaenoptera physalus* around São Miguel, from 2009 to 2019

ER time-series showed consistently higher values during May and the lowest rates between September and October. ER values were clearly lower until 2013 when a peak was detected followed by the greatest ER values in 2014. Some years also showed a two-peak sequence in ER, usually, the bigger peak corresponding to the beginning of spring and the second corresponding to unusual sightings off-season.

The synchrony detected between the Chl-a and ER time-series lead us to investigate the cross-correlation (CCF) between Chl-a and fin whales ER to consider the lag between the time-series. We also calculated the CCF value between the Chl-a and the number of sightings to account for potential data bias. Cross-correlation values showed a lag of 1 to 2 months between the chlorophyll-a and the ER time-series, suggesting that the peak of Chl-a will preceded the ER peak by 1 to 2 months (R^2 values: Chl-a(-1) = 0,57; Chl-a(-2) = 0,57). According to the CCF between Chl-a and the number of sightings, we concluded that the values were consistent with a slightly higher R^2 value for the 2-month lag. (R^2 values: Chl-a(-1) (0.52); Chl-a(-2) (0.58)) (Appendix II; Figure 6A).

Considering the mentioned off-season peaks registered in the ER time-series and calculated lag between the effect of Chl-a variations in sightings, we plotted the mean Chl-a concentration for the two months preceding the recorded encounters and found that months with an unexpected number of sightings had uncommon variations in Chl-a concentrations during the prior months, suggesting a correlation between the Chl-a levels and whale sightings (Appendix II; Figure 7A).

2.5 Discussion

There are still large gaps in our knowledge of fin whale's ecology, distribution, and movement patterns across the Atlantic and particularly in the Azores (Silva *et al.*, 2019; Gauffier *et al.*, 2020; Romagosa *et al.*, 2020). Long-term opportunistic occurrence data have proven to be of great use and value in cetacean research, especially when their limitations and potential bias are well understood and put into consideration throughout the experience (González García *et al.*, 2018). In the light of new studies, the continued collection of photographs to increase the dataset and update the photo-id catalogue is beneficial. Regular comparison of the available catalogues to increase the number of identified individuals and re-sightings increases the confidence of results (Stevens, 2014), leading to new findings associated with fin whale's movement and migration patterns. Collaborative studies are especially important when considering species with wide ranges of distribution and/or deficient data (Araujo *et al.,* 2017; González García, 2019). Furthermore, the use of low-cost, opportunistic data to identify species is a great opportunity to develop productive collaborations and citizen science projects concerning cetacean's ecology and distribution (Evans & Hammond, 2004; Araujo *et al.,* 2017; González García, 2019).

2.5.1 Photo-id: sightings

Photo-id can provide very useful information concerning residence time and site fidelity around the Azores, as well as insights on species' movements towards other areas. This study successfully identified 256 fin whales off the coast of São Miguel island. The set of features used for identification, including dorsal fin shape, number of nicks and scarification pattern, allowed re-identifications over the study period. A common concern in photo-id studies when determining the number of identified individuals is the existence of photographs from both left and right sides which can belong to the same individual, even if the observers cannot match them. However, we believe that this bias is not of major concern in this study, as it is in species that travel in compact groups which the large and unclear number of individuals may confuse the observers (e.g. dolphin species). On the contrary, our target species is usually sighted alone or in small groups, therefore, it is much easier to verify in each trip if photographs of left and right sides belong to the same individual. Nonetheless, matches between left and right sides might have been undetected if photographed on very different occasions. The removal of low-quality photographs might result in an underestimation in the number of different individuals and a lower estimation of re-sightings.

The re-sightings between different years and seasons within the same year, together with the hypothesis of breeding and feeding grounds in the vicinity of the archipelago (Freitas *et al.,* 2004; Carrillo & Ritter, 2010; Silva *et al.,* 2019; Gauffier *et al.,* 2020) open the possibility to some potential seasonal site fidelity for fin whales in the Azores.

Moreover, the sightings of the individuals firstly identified in spring 2014 and then re-sighted in November of the same year may indicate that these whales are travelling together (even with multiple days between sightings). Furthermore, these individuals either stayed in this region for seven/eight consecutive months or travelled closer to the archipelago during their southward migration, possibly due to better environmental conditions (Appendix II; Figure 7A.3). Nonetheless, more data and photographic evidence are needed to confirm this hypothesis, as the re-sighting rates were not particularly high to assess group composition and, at least, some whales exhibited large-scale movement patterns (Silva *et al.*, 2013). It is likely, however, that the number of re-sighting was significantly underestimated since only 32% of the fin whale individuals registered were successfully photographed and, in some years, there were not any quality photographs available (2009) or only from a single event (2011) which could influence the results. The longest time between re-sightings was three years, which does not necessarily mean that the individuals were not present in the area during this period, but that they were not identified within the available photographs or encountered during whale-watching trips. The increasing values of the calculated discovery curve, even at a low rate in the last years, suggest an open population with an annual exchange of individuals, though, the previously mentioned underestimation of the population can also impact these cumulative values and bias the curve (as we cannot guarantee the photographic coverage of every individual). Therefore, to increase the confidence of the results, the effort to collect viable photographs must be improved to construct a more consistent dataset with less discrepancy between the study periods and regions of study (Agler, 1990; Evans & Hammond, 2004; Stevens, 2014).

Additionally, errors during the photo-id process may also have impacted the number of matches. During this study, we did not use any software for the photo-id procedures for two main reasons: (1) These programs are generally developed for cetacean species that have more distinct shaped dorsal fins, more nicks and irregularities in the fin trailing edge and are usually more heavily marked (especially teeth marks) than fin whales (for example dolphins); (2) The dataset used belongs to a whale-watching company with multiple biologists working onboard the vessels and with access to the photographic data, therefore the creation of an easily understandable and simple protocol was necessary to efficiently continue with the construction of the "Futurismo Fin Whale Catalogue". Nonetheless, these types of software, (i.e. with artificial intelligence or machine learning algorithms), could be more accurate and useful than eye comparison, so future research should include this possibility, especially to account for larger datasets and catalogues (Towner *et al.*, 2013; Stevens, 2014).

Photo-id is also a subjective process that could lead to an over or underestimation of individuals, thus, to avoid mismatches, confirmation must be done by multiple identifiers (Agler, 1992). The number of matches can also be influenced by the distinctiveness of the individuals, well-marked individuals are more easily matched due to their recognizable characteristics even if the quality of the photograph is not good (Stevens, 2014).

2.5.2 Photo-id: Catalogue comparison

The individual matched between Faial and São Miguel suggest either an exchange of individuals between the areas, which would be expected due to their proximity, or an annual route adaptation to benefit from the most appropriate environmental conditions associated with each island (i.e., tracking resources). However, one re-sighting is not sufficient to conclude if the individual stayed within the archipelago region or if he travelled long distances crossing the islands in their routes (Hartman *et al.*, 2008).

Nonetheless, this re-sighting is a clue to understand fin whale movements, which can be easily explored if different touristic companies share their recorded data. A collective platform to compile, store and disseminate opportunistic cetacean data in collaboration with whale-watching companies, MONICET, has been already put into place in the Azores since 2009 (www.monicet.net). However, the huge potential of the platform has still room for improvement, for example upgrading the current platform, increasing the cooperation between companies and keeping the photo-id catalogues up to date. (Azevedo *et al.*, 2014).

These results also evidenced a long-distance movement within the Atlantic Ocean, contrarily to the previous telemetry studies in the region that recorded movements towards East Greenland and Iceland (Silva *et al.*, 2013). The re-sighted whale travelled from Faial to Galicia with exactly 4 months between the encounters (Methion & Díaz López, 2019; Steiner *et al.*, 2020). This re-sighting corroborates recent studies suggesting an Iberian foraging ground (Methion & Díaz López, 2019; Silva *et al.*, 2019; Steiner *et al.*, 2020) or a resident Iberian population that foraged in the Azores in latter spring (Gauffier *et al.*, 2020), raising a new interest to the migration patterns of these whales, previously thought to be fully understood and more reasons to invest in the research of this species. Matches were not found with the catalogues from Sagres or Cantabrian sea, suggesting that fin whales spotted in the Azores could have a migration route including Galician waters, but so far, were detected traveling neither to south Portuguese waters nor to the Bay of Biscay, although it is possible that the individuals encountered in the Azores may travel to these areas.

We propose a continuance of the catalogue comparison between these locations and the possible addition of new catalogues. Creating a platform and a network of photo-id combining whale-watching companies' data, such as MONICET, across the North Atlantic would be very beneficial to fin whales and other migratory species. It gives us a great deal of information about species movements and distribution with little effort in a cost-effective and simple way.

2.5.3 Spatial and temporal distribution

Understanding the limitations of our dataset is extremely important to avoid misinterpretations and false conclusions, especially when dealing with opportunistic datasets. An exact effort cannot be successfully calculated as usually used in cetacean research (Silva *et al.*, 2014; Correia *et al.*, 2015), given that the animals are firstly located from land and occurrence data is recorded by the boats which are directly piloted to the animals. However, our results can be compared within the dataset, between different years and seasons.

It is important to understand the priorities of the whale-watching activity, for instance, as shorter routes are usually favoured over longer ones, increasing the number of encounters close to Ponta Delgada. Trips are also very dependent on weather conditions and time constraints to keep in a schedule which can influence the routes. Moreover, emblematic or rare species are usually preferred over more common ones to increase the value of the activity. Nonetheless, data collected opportunistically usually provide information otherwise inaccessible with regular spatial cover and long-term series (Evans & Hammond, 2004; González García *et al.*, 2018).

In this study, we accounted for 945 fin whale sightings mostly recorded during spring, which agrees with the classical model of baleen whale migration and previous telemetry studies in the region. This period corresponds to the migration from subtropical and tropical, breeding, winter areas to high latitude, productive, summer feeding areas (Silva *et al.*, 2013; Prieto *et al.*, 2014). Nonetheless, our findings complement the idea of a large wintering offshore area for fin whales surrounding the archipelago, as suggested by Romagosa et al. (2020) or possible latitudinal migrations routes (Mizroch & Breiwick., 1984;

Mizroch *et al.,* 2009). The existence of such wintering area could explain the low frequency but recurrent sightings in the Azores during the winter months, supporting the relevance of the archipelago for this species (Silva *et al.*, 2011, 2014; Nieukirk *et al.*, 2012).

The low number of sightings during winter can also be due to insufficient effort rather than a lack of presence (Stevens, 2014), as the trips depend on meteorological conditions and number of tourists to perform the activity. Effort varies considerably between seasons, with an evident decrease during the autumn and winter months. Our ER is considerably greater from March to mid-June, with more fin whale encounters per number of trips. However, the number of trips is much higher from June to September, suggesting that the increase in sightings is not completely related to the increase of effort and that fin whales are indisputably sighted more frequently during spring. Identification errors may occur, nonetheless, this bias can be reduced by increasing the number of qualified and experienced observers and biologists or guides who record the data.

The highest density of sightings south of Ponta Delgada showed in the heat density maps (Figure 2.4) is probably more associated with the routes chosen for the whale-watching purpose rather than species habitat preferences. As the trips start from Ponta Delgada more sightings in the vicinity are expected. However, the heat density map for fin whale sightings showed a preference for the west side of the island in contrary to previous findings for other species (e.g. sperm whales, Atlantic spotted dolphin, Risso's dolphins and pilot whales) (González García, 2019) which indicated a stronger presence of sightings to the east of Ponta Delgada (Vila Franca do Campo). Therefore, the higher number of fin whale sightings towards the west should not be entirely related to the trip's itinerary. This discrepancy might be related to the type of diet of these species and their foraging areas. We believe that species distributions around the island are closely related to food availability. Cetacean diet studies together with prey distributions assessment can reduce the impacts of overfishing and avoid disruption of trophic chains and ecosystem balance by adjusting fishing quotas, improve target catch and reducing bycatch.

The presence of fin whales in the archipelago was originally thought to be of circumstantial passage during their northward's migration, however, recorded feeding behaviour in the archipelago (Visser *et al.,* 2011; Silva *et al.,* 2013), and even the presence of whale faeces in the water (González García, 2019), suggested that the whales stop their migration to forage for a few days. Our results are in accordance with these recordings and showed ~~a~~ frequent travelling behaviour, as expected in migratory habitats, and frequent diving behaviour, which can be associated with foraging behaviour, especially when moving in the same area without a clear path. Additionally, a fraction of the whales were confirmed to be foraging.

The sightings with recorded associations between fin and blue whales were of particular interest. These species have been commonly sighted together in different regions (Gavrilchuk *et al.*, 2014; Friedlaender *et al.*, 2015; Baines *et al.*, 2017) and hybridization events have been recorded multiple times (Árnason *et al.*, 1991; Spilliaert *et al.*, 1991; Bérubé *et al.*, 1998). Studies identifying second-generation hybrids (Pampoulie *et al.*, 2020) have underlined the importance of studying these associations and the probably underestimated number of hybrids to protect the already fragile population of blue whales in the North Atlantic. Therefore, the associations recorded in this study together with recorded individuals with characteristics of both species could allow the possibility of hybrid whales in the Azores (although genetic analyses would be essential to confirm hybrid individuals) and highlight the importance of understanding the threats to blue whale's reproductive output and recovery rate.

2.5.4 Environmental variables and movements around São Miguel island

Oceanographic features, such as depth and slope are known to be correlated with fin whale presence by influencing primary production (Panigada, Notarbartolo di Sciara, *et al.*, 2006; Azzellino *et al.*, 2012; Pennino *et al.*, 2017; Díaz López & Methion, 2019; González García, 2019; Pérez-Jorge *et al.*, 2019; Schleimer *et al.*, 2019). Our results point to a relation between the variables explored and the locations of fin whale sightings by suggesting a preference of slope, distance to the coast, and depth classes, both in offshore waters and within the continental shelf, probably driven by prey resources (Pennino *et al.*, 2017). Our bathymetry results agree with the previous depths associated with the archipelago (mean=722 m (González García, 2019);<2.500 m (Pérez-Jorge *et al.*, 2019)) and with occurrences in the Mediterranean (Panigada, Notarbartolo di Sciara, *et al.*, 2006; Azzellino *et al.*, 2012) and North-East Atlantic, where fin whales were related to depths outside the 200 m isobath, usually in the edge of the continental shelf (Víkingsson *et al.*, 2015; Díaz López & Methion, 2019). These values are likely related to local oceanography and bathymetry which influences chlorophyll distribution and prey aggregation (González García, 2019; (Schleimer *et al.*, 2019). Fin whales' ER was negatively related to SST values in the archipelago. Cooler waters are commonly related to higher chlorophyll concentrations (González García, 2019; Pérez-Jorge *et al.,* 2019) typically associated with oceanographic events such as eddies or local upwelling.

In contrast, fin whales' ER was positively related to Chl-a concentration, linking the increase in fin whale sightings to primary production intensification. The annual spring phytoplankton bloom at the Azores begins to develop in December/January and increases until the end of April (Visser *et al.*, 2011). Fin whales are sighted annually in the archipelago, usually from March to June (Silva *et al.*, 2013; Pérez-Jorge *et al.*, 2019), however, the timing of their arrival changes slightly over the years probably linked to the timing of the onset of the phytoplankton bloom (Visser *et al.,* 2011).

Fin whales feed mostly on secondary production (krill), therefore, it is necessary to consider the possible lag between the bloom and the krill maturation time until it reaches adequate sizes to be foraged by whales (Croll *et al.,* 2005; Santora *et al.,* 2010). Our results compare the complete time-series of Chl-a concentrations and the whales' ER, indicating a 1 to 2 months lag when between the series. This interval is relatively shorter than the 3-4 months documented by González García (2019) and Visser et al. (2011), respectively. However, these studies compared the time frame of different stages of the spring phytoplankton bloom with the whale peak abundance, which explains the slightly different results.

We were also interested in the off-season records and the relation between months with anomalies in Chl-a concentrations and off-season sightings. Our exploratory results pointed to a possible relation between the unexpected increase of Chl-a concentrations and the occurrence of fin whale sightings in the following months outside their migratory season (Appendix II; Figure 7A). However, our investigations were only preliminary and further in-depth statistical analysis are needed to address this relation. Long-term research monitoring phytoplankton and zooplankton communities, as well as their correlation to baleen whale sightings, would be very helpful to understand the effects of Chl-a variations in pelagic migratory animals.

2.6. Conclusions

The recorded sightings data underlined the importance of the Azorean archipelago for fin whales, particularly during spring. The dataset provides information about the most common behaviours, associations, and distribution of the observed whales. Photo-id proved to be a useful tool and practical technique for the identification of 256 fin whales around the Azores. It was possible to account for re-sightings of the same whales, in the area surrounding São Miguel, one re-sighting within the Archipelago (between Faial and São Miguel), and one between the Azores (Faial) and Galicia, which contribute to the increasing deal of evidence suggesting that migratory patterns and routes of baleen whale might be more complex than previously established. This study highlights the beneficial role of photo-id, especially in regions where whale-watching activities are very well established and where a collective effort to integrate data and create cohesive datasets should be encouraged.

The influence of static and dynamic variables in fin whale distribution was explored, indicating a close relation between Chl-a concentration and fin whale occurrences in the region. Prey availability is a known driver to cetacean species' movements (Coakes *et al.,* 2005; Pérez-Jorge *et al.,* 2019) and our results support the hypothesis that ocean resources can influence the timing of fin whale migration and distribution in the archipelago.

Furthermore, to understand the possible key drivers in fin whale movements it is necessary to include other environmental variables in addition to the ones briefly explored in this study (e.g. EKE; salinity; tidal and current patterns; krill biomass; Net primary production) (Pennino *et al.,* 2017; González García, 2019; Pérez-Jorge *et al.,* 2019; Schleimer *et al.*, 2019). The additional use of telemetry data and studies regarding habitat preference and species distribution with different temporal and spatial resolutions improve the confidence in results and contribute to the increasing knowledge about the species. In this context, further research using our dataset would be very informative since it provides a remarkably high amount of data regarding fin whale sightings (total of 945 trips with fin whale encounters, and 213 sightings of fin whales with photographic registered data in the last 11 years of study) when compared to other studies in the archipelago (Visser *et al.*, 2011; Silva *et al.*, 2014; Prieto *et al.*, 2017; González García, 2019; Pérez-Jorge *et al.*, 2019).

We highlight the importance of opportunistic data as a cost-effective method to monitor highly mobile species and promote the engagement of local companies and communities to improve data collection and raise awareness for marine conservation. Notwithstanding, stricter data collection protocols should be established, and survey effort should be increased to provide an even coverage between seasons and years, improve the overall quality of the data, reduce bias and overcome the limitations of this study.

Moreover, in the light of the recent discoveries regarding fin whales in the Azores (Pérez-Jorge *et al.*, 2019; Silva *et al.*, 2019; Romagosa *et al.*, 2020), and in the face of global climate change, it is critical to recognize the environmental drivers and identify the areas of particular importance for cetaceans to effectively diminish the threats caused by anthropogenic activities or environmental changes, which could lead to the disruption of ecosystems, habitat degradation and increase mortality (e.g. ship strikes, plastic pollution, entanglements)(Maxwell *et al.*, 2013; Pérez-Jorge *et al.*, 2019).

The implementation of transatlantic Marine Protected Areas (MPAs) and management of marine traffic by assessing the costs and benefits of modifying vessel operations to minimize overlap with whale distribution (David *et al.*, 2011) can be solutions to effectively mitigate the growing pressures on the North Atlantic fin whale populations. Furthermore, the implementation of dynamic MPAs would allow a more flexible and real time management response according to environmental changes and species distribution patterns (Maxwell *et al.*, 2015). Therefore, dynamic management can have a positive impact on whale conservation by, for example, alerting ships of whale presence and adopting seasonal traffic closure in known breeding grounds (Maxwell *et al.*, 2015). These strategies can significantly reduce, for instance, bycatch in small cetacean species and ship collision incidents; and are examples of new, sustainable and effective management measures that should be explored (Panigada *et al.*, 2008; Clapham, 2015; Maxwell *et al.*, 2015; Pérez-Jorge *et al.*, 2019).

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Appendix I: Supporting tables

Table 1A. Fin whale sightings per month and year recorded by "Futurismo Azores Adventures"

MONTH / YEAR	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL COUNT
2009		2	2	10	9	2	1	3	3				32
2010				5	22	7							34
2011				5	8			1	1				15
2012	1		5	8	25		3						42
2013		10	1	5	61	20	7						104
2014	1		6	53	91	22	6			1		3	183
2015	2		3	14	24	9	14	16	6	4		1	93
2016		8	30	37	27	21	15	5	1	4	7		155
2017	2	2	11	26	58	37	6						142
2018	3	7	17	26	60	4		4					121
2019		2		5	15						2		24
TOTAL COUNT	**9**	**31**	**75**	**194**	**400**	**122**	**52**	**29**	**11**	**9**	**9**	**4**	**945**

Table 1A. Monthly Encounter Rate of fin whales around S. Miguel for all years between 2009 and 2019. ER = number of Bp sightings / trips carried out each month.

YEAR / MONTH	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
JAN.	0.000	0.000	0.000	0.091	0.000	0.200	0.118	0.000	0.133	0.150	0.000
FEB.	0.080	0.000	0.000	0.000	0.833	0.000	0.000	0.320	0.083	0.368	0.286
MAR.	0.074	0.000	0.000	0.278	0.125	0.300	0.120	0.882	0.367	0.630	0.000
APR.	0.213	0.172	0.156	0.195	0.333	1.152	0.424	0.949	0.619	0.634	0.125
MAY	0.205	0.537	0.205	0.833	1.196	1.247	0.615	0.643	1.415	1.017	0.300
JUN.	0.049	0.149	0.000	0.000	0.465	0.310	0.188	0.404	0.661	0.071	0.000
JUL.	0.024	0.000	0.000	0.044	0.125	0.083	0.259	0.221	0.090	0.000	0.000
AUG.	0.055	0.000	0.028	0.000	0.000	0.000	0.296	0.086	0.000	0.063	0.000
SEP.	0.058	0.000	0.053	0.000	0.000	0.000	0.140	0.020	0.000	0.000	0.000
OCT.	0.000	0.000	0.000	0.000	0.000	0.050	0.143	0.143	0.000	0.000	0.000
NOV.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.189	0.000	0.000	0.074
DEC.	0.000	0.000	0.000	0.000	0.000	0.429	0.143	0.000	0.000	0.000	0.000

Table 3A Number and dates of *Balaenoptera physalus* photo-id re-sightings per individual from 2009 to 2018

ID	***Re-sightings***	***1º sight.***	***2º***	***3º***	***4º***
10	3	14/04/2014	15/04/2014	18/04/2014	
11	2	16/04/2014	06/11/2014		
12	2	06/11/2014	16/04/2017		
16	2	24/04/2014	28/04/2014		
21	3	01/05/2014	03/05/2014	23/11/2014	
45	2	26/02/2016	01/03/2016		
47	3	04/03/2016	05/03/2016	06/03/2016	
75	2	28/04/2014	19/05/2016		
100	2	09/06/2014	28/05/2017		
120	2	16/06/2016	27/06/2016		
123	2	16/04/2014	06/11/2014		
126	2	30/04/2014	20/11/2014		
164	2	25/05/2014	27/05/2014		
168	3	28/05/2014	31/05/2014	11/06/2014	
169	2	28/05/2014	30/05/2014		
179	2	02/06/2014	09/06/2014		
202	2	20/05/2017	20/05/2017		
205	2	18/05/2017	18/05/2017		
A06	3	15/04/2014	16/04/2014	06/11/2014	
A07	2	18/05/2012	20/05/2012		
A18	4	03/03/2016	04/03/2016	05/03/2016	06/03/2016
A25	2	20/04/2016	01/05/2016		
A28	2	01/05/2016	02/05/2016		

Appendix II: Supporting figures

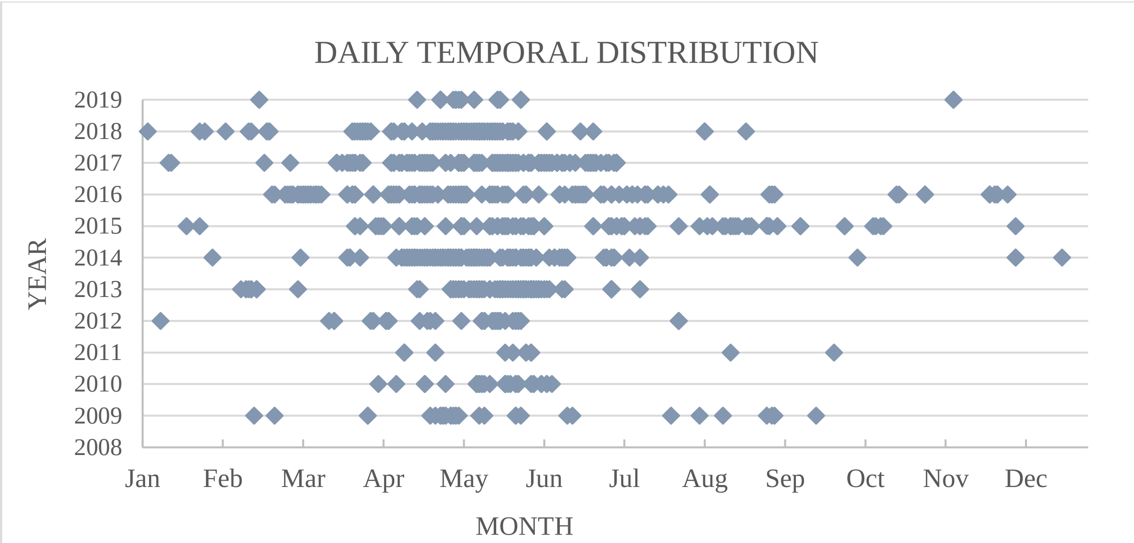


Figure 1A Daily Temporal distribution of *Balaenoptera physalus* around S. Miguel between 2009 and 2019 (year/number of sightings: 2009/32; 2010/34; 2011/15; 2012/42; 2013/104; 2014/183; 2015/93; 2016/155; 2017/116; 2018/121; 2019/10

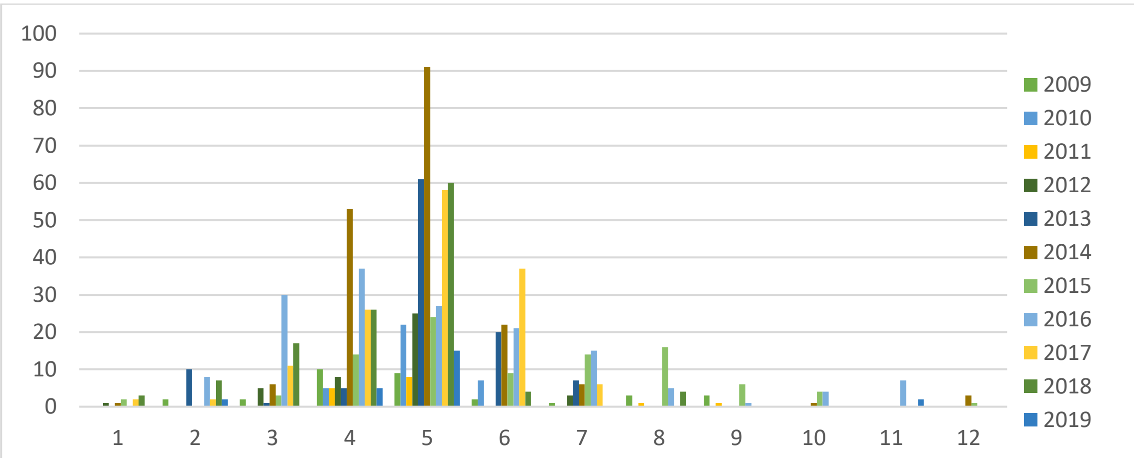


Figure 2A Monthly Temporal distribution of *Balaenoptera physalus* around S. Miguel for all years between 2009 and 2019

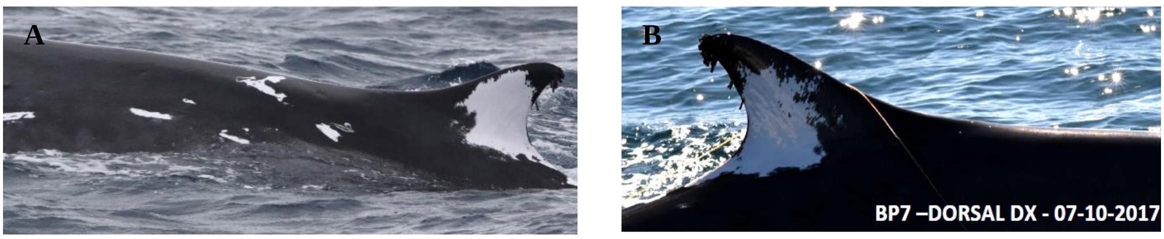


Figure 3A Re-sighting between locations. A- Photograph from "Whale watch Azores" based in Faial, first photographed by Lisa Steiner on the 7th of June 2017; B- re-sighting photograph by "BDRI" based in Galicia exactly 4 months later on the 7th of October 2017

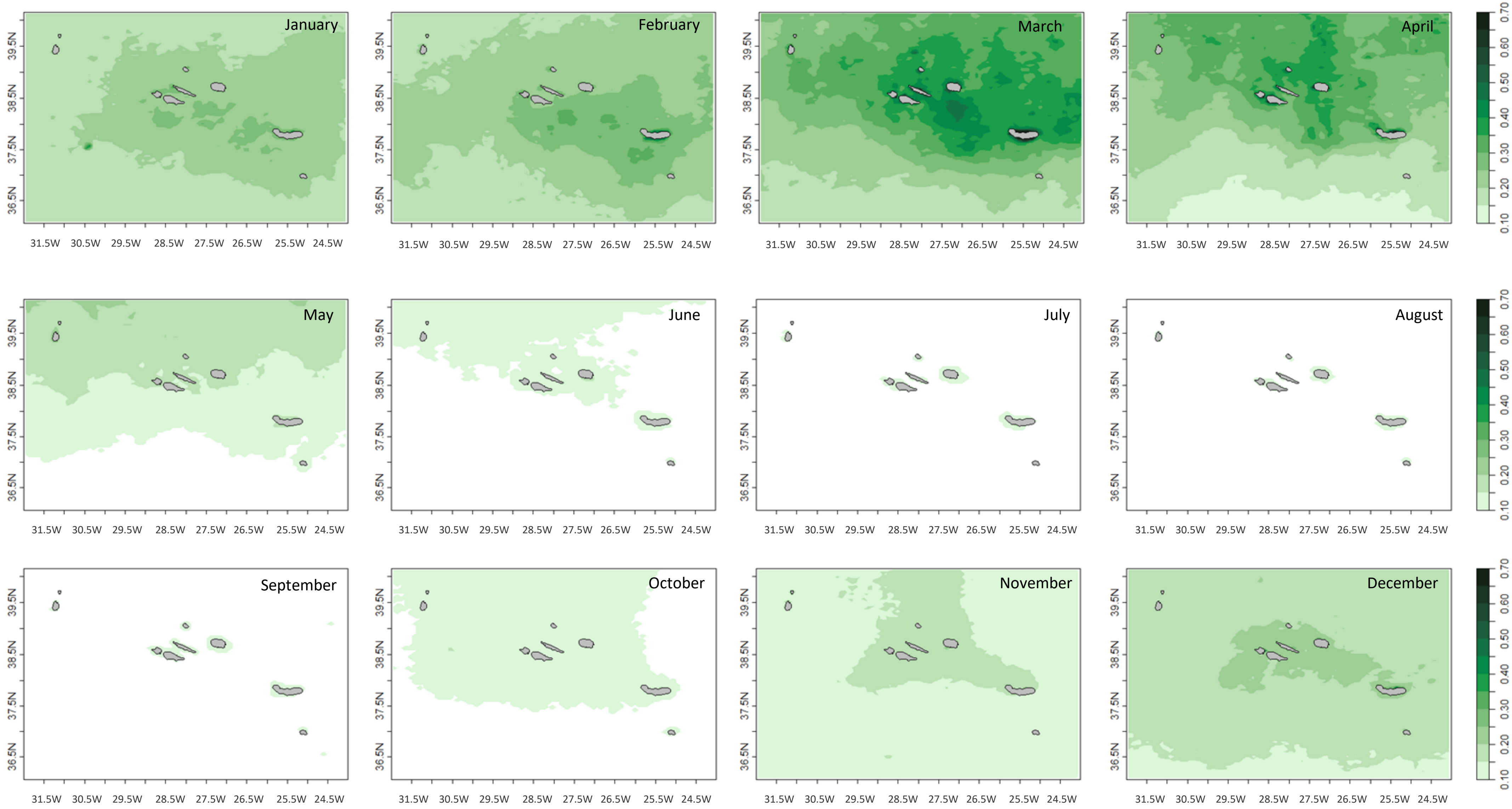


Figure 4A Combined mean monthly Chlorophyll-a concentration maps for Azores archipelago during a 11year study period

A.

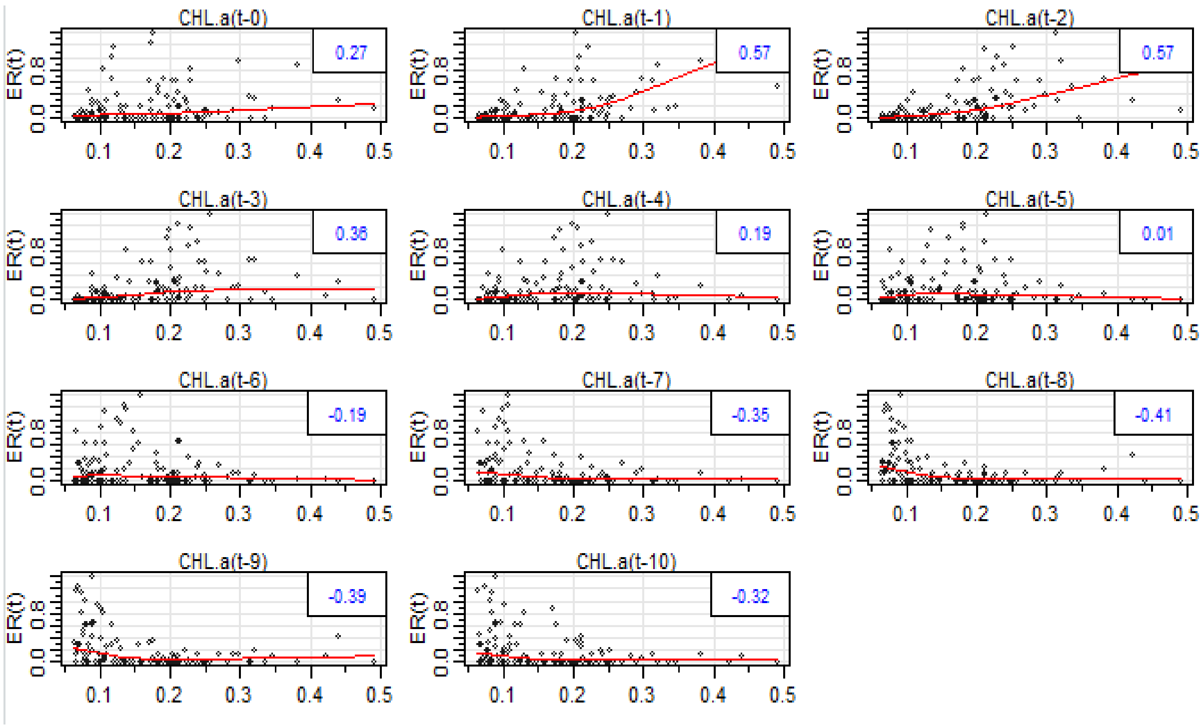
```
> shapiro.test(ER)

        Shapiro-Wilk normality test

data:  ER
W = 0.55995, p-value < 2.2e-16

> shapiro.test(CHL.a)

        Shapiro-Wilk normality test

data:  CHL.a
W = 0.89345, p-value = 2.925e-08

> shapiro.test(SST)

        Shapiro-Wilk normality test

data:  SST
W = 0.91033, p-value = 2.39e-07
```

B.

```
> cor.test(CHL.a,ER, method =("spearman"),exact= FALSE)

        Spearman's rank correlation rho

data:  CHL.a and ER
S = 309207, p-value = 0.02636
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.1933167

> cor.test(SST,ER, method =("spearman"),exact= FALSE)

        Spearman's rank correlation rho

data:  SST and ER
S = 466992, p-value = 0.01191
alternative hypothesis: true rho is not equal to 0
sample estimates:
       rho
-0.2183262
```

Figure 5A Statistical results of: A-Shapiro- Wilk normality test for: ER; Chl-a and SST values; B- Spearman's correlation test between ER and Chl-a values and between ER and SST values.

A



B.

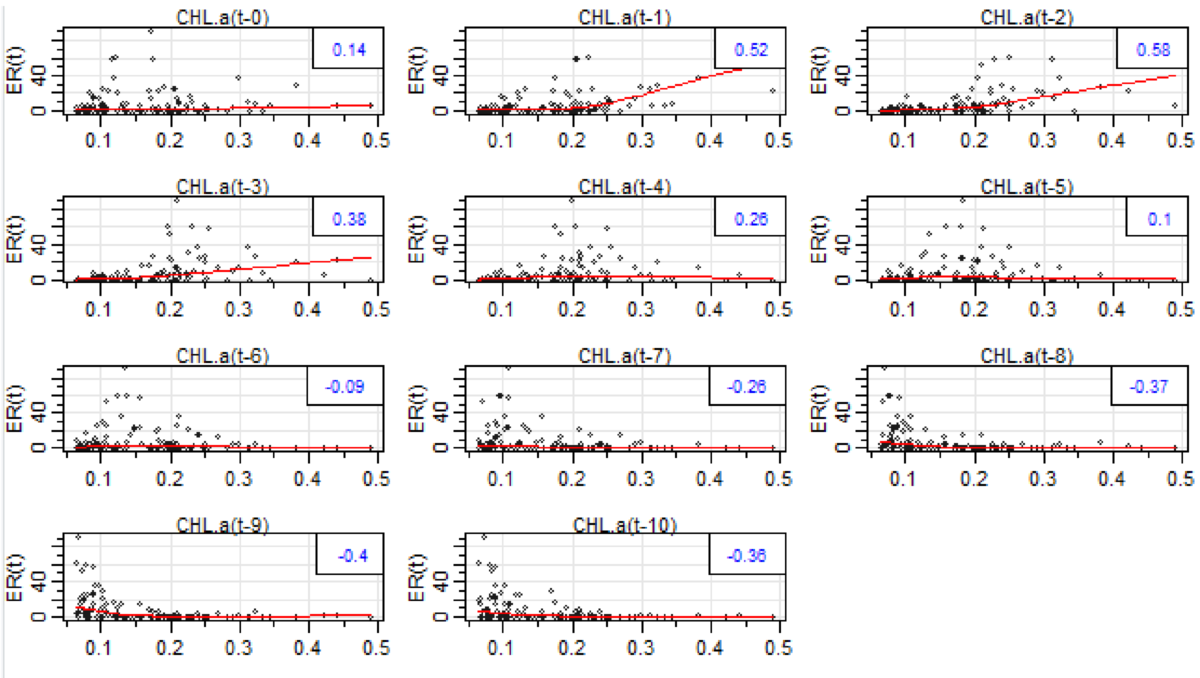


Figure 6A Cross Correlation function results: A- between Chl-a and ER (greater R2 values: Chl-a(-1) = 0,57; Chl-a(-2) = 0,57); B- between the Chl-a and number of sightings (greater R2 values: Chl-a(-1) (0.52); Chl-a(-2) (0.58)

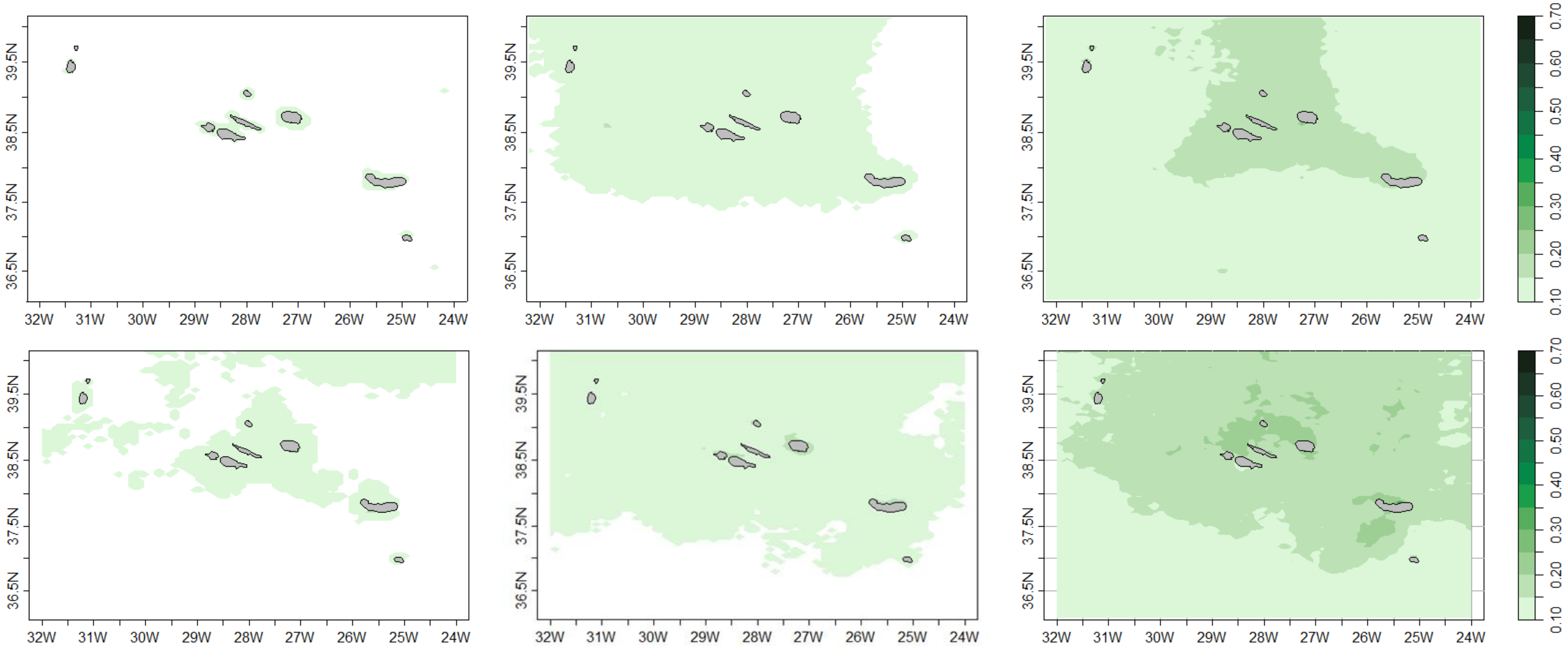


Figure 7A. 1 Comparation between the combined monthly mean of Chlorophyll-a concentration maps (11 years) with monthly mean values of a particular year associated with an unusual high number of fin whale sightings. Top: combined monthly mean of Chlorophyll-a concentration maps for September October and November respectively; Bottom: monthly mean of Chlorophyll-a concentration maps for September October and November of 2016, respectively

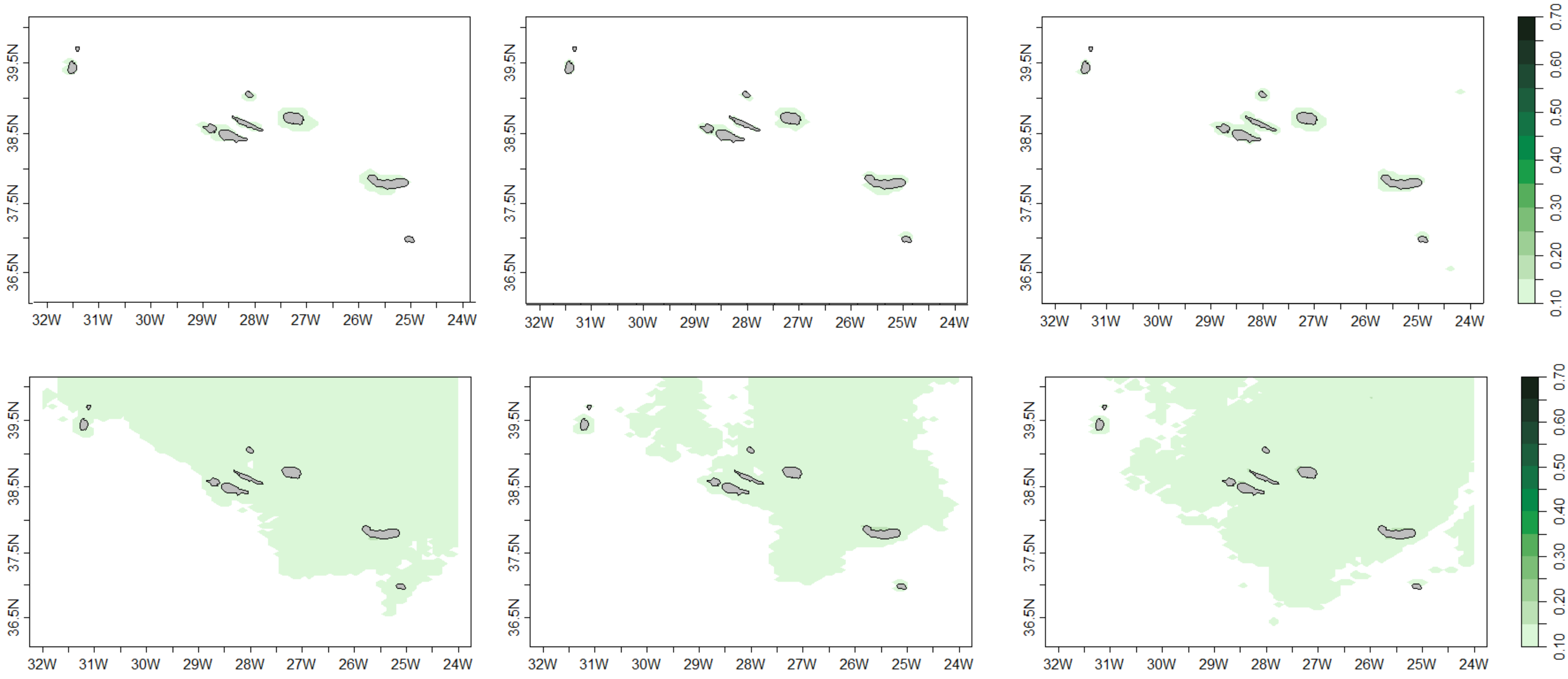


Figure 7A. 2 Top: combined monthly mean of Chlorophyll-a concentration maps for July August and September respectively; Bottom: monthly mean of Chlorophyll-a concentration maps for July August and September of 2015, respectively

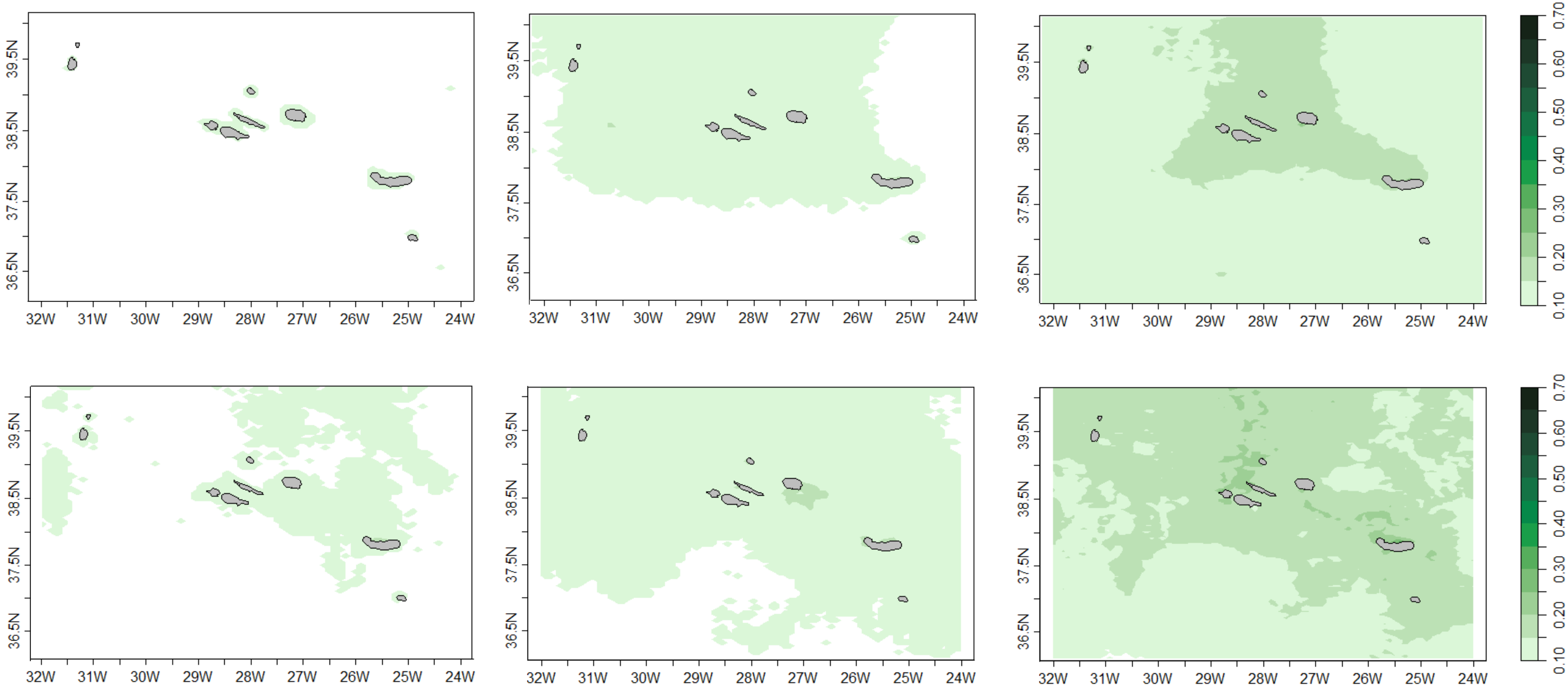


Figure 7A. 3 Top: combined monthly mean of Chlorophyll-a concentration maps for September, October and December respectively; Bottom: monthly mean of Chlorophyll-a concentration maps September, October and December of 2014, respectively.