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Interspecific interactions between short-beaked common, Atlantic spotted and striped dolphins in the Pico Island, Azores

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Mestrado em Biologia Marinha

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Declaração de autoria de trabalho

Interspecific interactions between short-beaked common, Atlantic spotted and striped dolphins in the Pico Island, Azores

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

I hereby declare to be the author of this work, which is original and unpublished. Authors and works consulted are properly cited in the text and included in the reference list.

(Lara Rodrigues Costa)

(Lara Rodrigues Costa)

Abstract

The interspecific tendency of association is well known for many species, including primates, birds and cetaceans. While the exact factors that promote these interactions are still largely uncertain, it is highly probable that one or both species benefit from their association. Three cetacean species share the same habitat in the Azores and have the same feeding habitats, short-beaked common dolphin (*Delphinus delphis*), striped dolphin (*Stenella coeruleoalba)* and Atlantic spotted dolphin (*Stenella frontalis*)*,* being occasionally seen together. This project aims to evaluate these associations and determine the main factors influencing these interspecific interactions and their benefits. This study collected data in the surrounding waters of Pico Island, Azores, during seven consecutive years (2012-2018), using opportunistic platforms such as whale watching boats, that despite some limitations, have already been proven to be a way of cost-efficient data collection and a source of reliable data for research. A total of 1452 trips that resulted in 1289 sightings of *Delphinus delphis*, 317 sightings of *Stenella coeruleoalba*, 488 sightings of *Stenella frontalis* and a total of 82 interspecific interactions sightings (including at least two of these three target species) were analyzed, studying the behavior, bathymetry, distance to coast and presence of calves for each sighting. Statistical tests were performed to proceed to multiple comparisons between the drivers and the observations with and without interactions, revealing that in the majority of the statistical analysis only the striped dolphin had associations with the interactions, with the common dolphin showing less frequent associations and the spotted dolphin not showing any. The results showed that only the striped dolphin had an association with interaction and the main driver was concluded to be the increase of the foraging success, while the common dolphin showed to be driven by social reasons, such as the increase of the group size and the Atlantic spotted dolphin did not show any tendency to associate.

Keywords: Association, Azores, Cetaceans, Interspecific interactions, Sympatry

Resumo

Interações intraespecíficas (mesma espécie) e interespecíficas (espécies diferentes) são omnipresentes, sendo que em biologia o termo "interação interespecífica" descreve uma agregação temporária de indivíduos de duas ou mais espécies diferentes que se encontram envolvidas em atividades semelhantes. Estas interações estão geralmente divididas em 5 grupos funcionais: (1) agressão, (2) epimelético, (3) diversão/brincadeira, (4) alimentação simultânea e (5) sexual. Esta tendência interespecífica de associação é bem conhecida para uma ampla gama de espécies, incluindo insetos, primatas, aves e cetáceos, embora os fatores que promovem essas interações ainda sejam geralmente mal conhecidos, é extremamente provável que uma ou ambas as espécies se beneficiem dessa associação, considerando-se então uma interação positiva (comensalismo ou mutualismo, respetivamente). Alguns dos benefícios parecem ser: (1) redução do risco de predação e aumento de proteção; (2) aumento de benefícios sociais e/ou (3) aumento do sucesso da atividade de alimentação.

Três espécies de cetáceos partilham o mesmo habitat nos Açores e possuem os mesmos hábitos alimentares, golfinho-comum-de-bico-curto (*Delphinus delphis*), golfinho-riscado (*Stenella coeruleoalba*) e golfinho-pintado do Atlântico (*Stenella frontalis*), sendo ocasionalmente observadas em conjunto, em "*mixed groups*". Este projeto tem como objetivo analisar essas associações e determinar os principais fatores que influenciam estas interações interespecíficas e os seus eventuais benefícios, percebendo (1) se o habitat é um fator determinante na promoção destas interações interespecíficas, (2) qual é o fator que promove estas interações e (3) estas interações variam de espécie para espécie? Os dados a analisar foram recolhidos nas águas envolventes da Ilha do Pico, Açores, durante sete anos consecutivos (2012-2018), utilizando plataformas oportunistas de investigação, nomeadamente embarcações de observação de cetáceos, que apesar de algumas imitações, já foram provadas como uma forma económica de recolha de dados e uma fonte de dados para investigação confiada.

O Arquipélago dos Açores encontra-se no meio do Nordeste do Oceano Atlântico e estende-se por mais de 480 km, entre 37° a 40°N e 25° a 32°W, encontra-se a 2000 km da América do Norte e a 1500 km da Europa, compreende nove ilhas separadas por águas profundas, divididas em três grupos diferentes, grupo Ocidental (Flores e Corvo), grupo Oriental (São Miguel e Santa Maria) e o grupo Central (Graciosa, São Jorge, Pico, Faial e Terceira), em que o Faial, Pico e São Jorge constituem o que é chamado de Triângulo dos Açores. Este arquipélago é influenciado pela

entrada de meandros e filamentos provenientes da Corrente do Golfo. O estudo realizou-se no sul da ilha do Pico, por vezes chegando ao sul de São Jorge e/ou do Faial. A ilha possui uma temperatura da água que varia dos 15 ºC aos 25 ºC no inverno e verão, respetivamente, apresentando também um ciclo sazonal de clorofila *a* muito bem definido, com concentrações maiores na primavera. É um *hotspot* de biodiversidade marinha já conhecido, com 28 espécies de cetáceos descritas.

Durante os 7 anos de estudo, realizaram-se um total de 1452 viagens comerciais de *whale watching* (através das empresas Espaço Talassa e Futurismo) resultando em 2094 observações das espécies alvo, incluindo, 1289 observações de D*elphinus delphis*, 317 observações de *Stenella coeruleoalba* e 488 observações de *Stenella frontalis*, incluindo um total de 82 observações de "*mixed groups*" que continham pelo menos duas das três espécies alvo. As espécies são encontradas com base em vigias que se encontram em pontos estratégicos da ilha com binóculos potentes, que posteriormente informam os *skippers* das embarcações via rádio da localização das mesmas. As viagens realizaram-se praticamente durante todo o ano, com exceção da época de inverno (devido ao baixo turismo e às más condições meteorológicas). Em cada avistamento o biólogo a bordo da embarcação observou os animais e registou a espécie, tempo do avistamento, localização (usando um GPS Garmin Etrex20), tamanho e composição do grupo (número de adultos, juvenis, crias e recém-nascidos e a presença ou ausência de outra espécie) e o comportamento.

Foram analisados fatores como o comportamento, batimetria, distância à costa e presença de crias que foram posteriormente testados estatisticamente em R Studio, onde se verificou a normalidade e posteriormente se realizaram comparações múltiplas (através do teste de chi-square e post hoc test pelo método de bonferroni, respetivamente) entre as observações com e sem interações. Dados de batimetria e distância à costa foram obtidos através do EMODnet e do QGIS (usando-se o *plugin* NNJoin). Os dados de comportamento, foram por sua vez divididos em seis categorias de comportamentos predominantemente observados: (1) Alimentação; (2) Socialização; (3) Deslocação; (4) Descanso; (5) Outros e (6) Não identificado. Concluindo-se que para a maioria dos testes realizados, só o golfinho riscado apresentou diferenças estatisticamente significativas entre as observações com e sem interação, sendo que o golfinho comum apresentou poucos resultados estatisticamente significativos e o golfinho pintado não apresentou nenhum.

O número de observações com e sem interações variou consideravelmente, na totalidade foram registados 1847 observações sem interação e 82 observações com interação, sendo possível identificar as interações entre o golfinho comum e o golfinho riscado foram as mais comuns (N = 74), seguindo-se pelas interações entre o golfinho comum e golfinho pintado, golfinho riscado e golfinho pintado e as três espécies juntas (N = 4, N =2 e N = 2, respetivamente). Em relação a observações sem interação, o golfinho comum apresentou 1147 avistamentos, o golfinho riscado 237 e o golfinho pintado 463. Sendo que só o golfinho riscado apresentou uma associação com a interação nos testes estatísticos realizados.

Os comportamentos observados em interação também variaram quando comparados com os comportamentos observados sem interação, sendo que em interação observou-se maioritariamente socialização e alimentação, enquanto sem interação observou-se maioritariamente socialização (com o barco) e deslocação. Apenas o golfinho riscado apresentou uma associação com a interação nos testes estatísticos realizados e essa associação foi com o comportamento de alimentação, significando que quando esta espécie se encontra em interação esse comportamento é mais frequente. A batimetria em que as espécies foram observadas não apresentou diferenças estatisticamente significativas entre observações com interação e sem interação, contudo no estudo da distância à costa o golfinho comum mostrou-se associado à interação, significando que quando está em *mixed groups* é encontrado mais longe de costa.

A maioria das observações de golfinhos comuns e golfinhos pintados foram frequentemente registadas com crias no grupo, contrariamente ao que foi observado para o golfinho riscado, isto foi observado para as observações com e sem interação. Contudo foi possível observar que o golfinho comum quando está em associação é observado com 1.5 vezes menos crias no grupo quando comparado com as observações sem interação, sendo uma diferença estatisticamente significativa, permitindo concluir que quando esta espécie associa a presença de crias pode ser um dos fatores determinantes.

Os resultados permitiram concluir que apenas o golfinho riscado apresentou uma associação com interação. Mostrou-se também que a interação modifica o comportamento e a composição do grupo, sendo que para o golfinho riscado o fator promotor para essa interação foi aumento do sucesso da atividade de alimentação, por sua vez o golfinho comum apresentou como fator promotor de interação o aumento do tamanho do grupo, o golfinho pintado não apresentou

tendência para interação nem apresentou nenhuma associação com os fatores estudados, não se podendo concluir relativamente aos fatores que a promovem.

Resumindo, os resultados deste estudo indicam que estes tipos de interações são raros na área de estudo, e que quando estes acontecem o habitat aparenta ter um papel importante na promoção destas interações, sendo que o fator determinante varia de espécie para espécie. O golfinho comum aparenta ser motivado por razões sociais (de modo a aumentar o tamanho do grupo), o golfinho riscado aparenta ser motivado por razoes de alimentação e o golfinho pintado não apresentou tendência para se associar. Estas respostas diferentes por parte das três espécies ajudam na fomentação da capacidade dos golfinhos de adaptarem ao seu ambiente, que se encontra constantemente a sofrer alterações devido a pressões antropogénicas tais como *overfishing*, alterações climáticas e a acidificação dos oceanos.

Palavras-chave: Associação, Açores, Cetáceos, Interações interespecíficas, Simpatria

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List of Abbreviations:

BB – Leaping Backwards
BF – Leaping Forward
BS – Leaping Sideways
BR – Bow Riding
Dd – *Delphinus delphis*
FO – Foraging
H - Hiding
Kg – Kilograms
Km – Kilometers
LB – Lob Tailing
m – Meters
M - Milling
MAR – Mid Atlantic Ridge
NI – Non-identified
OT - Others
R - Resting
Sc – *Stenella coeruleoalba*
SD – Standard Deviation
Sf – *Stenella frontalis*
SO -Socializing
SP – Spy Hoping
SST -Sea Surface Temperature
TA – Traveling Average
TF – Traveling Fast
TS – Traveling Slow

1. State of the art

1.1. The importance of cetaceans

Cetaceans are one of the most important marine groups. They can have significant effects on the function and structure of ecosystems (Braulik *et al.*, 2017), they are charismatic and iconic components of the ocean biodiversity (Bowen, 1997; Braulik *et al.*, 2017; Gonzalez Garcia, 2019) which makes them flagship species for social awareness. Cetaceans play key roles, such as "engineers" (influencing the material fluxes, causing physical changes in the ocean environment, and influencing the species diversity) (Roman *et al.*, 2014) and "sentinels" (they reflect and integrate ecological changes) (Moore, 2008) in the marine ecosystem. They also have active roles both in bottom up and top-down forces (Bowen, 1997; Roman *et al.*, 2014; Kiszka *et al.*, 2015; Roman & McCarthy, 2010), since they are marine mammals, they have lungs, which obligates them to come to the surface to breathe regularly, although they can feed at depths, these vertical movements they do, favors nutrient transport as a result of the water mixing (Lavery *et al.*, 2012; Roman *et al.*, 2014; González García, 2018), they also usually defecate near the surface (which enriches the water with organic matter) (González García, 2018), also the placentas and carcasses enhance the productivity (Roman *et al.*, 2014; González García, 2018). As a result of their migratory behavior, cetaceans can also contribute for the nutrients' horizontal movements (Roman *et al.*, 2014). As for their protection, cetaceans have already been considered "umbrella species" which signifies that their conservation will have direct effects on the conservation of a various number of other species (González García, 2019).

1.2. Association and competition in dolphins

The interspecific associations between two or more dolphin species imply sympatric ecology (Frantzis & Herzing, 2002; Bearzi, 2005). The term 'sympatry' in this study means "the co-occurrence of two or more dolphin species in the same immediate habitat" (Bearzi, 2005). Species that depend on the same prey items and occur in the same habitat tend to share the available resources if food is not a limiting factor, consequently reducing competition (Roughgarden, 1976) and promoting mixed-species associations (Selzer & Payne, 1988; Gowans & Whitehead, 1995). The majority of the studies show that sympatric dolphin species tend to avoid direct competition (Bearzi, 2005). However, if the feeding resources do not support competing predators, sympatric species can adopt (1) different prey preferences (Gowans & Whitehead, 1995); (2) different feeding times or days or different seasons (Gowans & Whitehead, 1995; Bearzi, 2005) or different feeding in different depths (Norris & Dohl, 1979; Bearzi, 2003). Therefore, a slight difference in feeding behavior may promote sympatry without resource competition (Hoelzel, 1998). Hence, the importance of studying individual species behavior so that in association differences may be detected.

1.3. Association drivers/benefits *vs* costs

Among the complex behaviors marine mammals exhibit, mixed-species associations (Au, 1991) are still involved in some enigmatic. Some inter-specific interactions, particularly of dolphins, consist of mixing different species swimming side-by-side while maintaining somewhat well-defined boundaries of their single-species sub-group (Frantzis & Herzing, 2002; Kanaji & Miyashita, 2021). The drivers of these associations are equivocal and elusive (Baraff & Asmutis-Silvia, 1998; Curé *et al.*, 2012; de Lima *et al.*, 2021). Although mixed-species association must confer benefits that outweigh its costs. Generally, there are three evolutionary mechanisms (1) reciprocal altruism (when a costly behavior is favored among partners that are reciprocating, it's similar to mutualism but implies costs) (Hemelrijk, 1994), (2) mutualism (when there is a positive interaction between individuals, that will end up with them beneficiating with it) (Noë & Hammerstein, 1995; Acevedo-Gutiérrez, 2009) and (3) kin selection (when an individual's behavior affects the fitness's of others, normally relatives, that will then transmit the behavior non-randomly) (Hamilton, 1964; Acevedo-Gutiérrez, 2009). Increased mixed-species associations may confer some advantage in daily activities, such as hunting since it allows a more efficient prey detection; the more individuals, the larger the scouted area and therefore, prey encounter rates increase and higher the probability for food detection (Baird, 1994; Baraff & Asmutis-Silvia, 1998; Bearzi, 2005; Acevedo-Gutiérrez, 2009). Through association, individuals may be able to (1) reduce predation risk and increase protection (Norris & Dohl, 1979; Pook & Pook, 1982; Fitzgibbon, 1990; Stensland *et al.*, 2003; Bearzi, 2006; Acevedo-Gutiérrez, 2009; Syme *et al.*, 2021), (2) gain social benefits (Stensland *et al.*, 2003; Koper & Plön, 2016; Syme *et al.* 2021) and (3) improve their foraging activity (Norris & Dohl, 1979; Stensland *et al.*, 2003; Acevedo-Gutiérrez, 2009; Koper & Plön, 2016; Bacon *et al.*, 2017; Syme *et al.*, 2021). However, this benefit may also be a cost by increasing (1) the risk of detection by predators (Gittleman, 1989; Baird, 1994), (2) the level of intragroup aggression (intra-specific competition) (Abrams, 1987; Gittleman, 1989; Koper & Plön, 2016), (3) the chance for disease transmission (Gittleman, 1989) and (4) the increase of the possibility for group aggression (Gittleman, 1989). The association advantages and/or costs depend on the particular species involved (Quérouil *et al*., 2008). Dolphins are highly social animals and can be reported in groups of various dimensions (Gowans *et al*., 2007; de Lima *et al*., 2021). Some species tend to form small groups while others form large groups. Although interactions between cetacean individuals are difficult to observe (Danaher-Garcia *et al*., 2020), there are data for at least 54 different species of cetaceans (Frantzis & Herzing, 2002; Syme *et al*., 2021). Frequently for highly social species, the first step to take in order to comprehend their social structure and interspecific and heterospecific relationships, is to understand their demographics and population long-term associations (Danaher-Garcia *et al*., 2020). Interspecific interactions between species of the family *Delphinidae* are believed to be beneficial for at least one of the species (Norris & Dohl, 1979; Baraff & Asmutis-Silvia, 1998; Scott & Cattanach, 1998), conferring some advantages over those that do not associate (Quérouil *et al*., 2008).

In the archipelago of the Azores, mixed-species interactions between the common, the bottlenose, the striped, and the Atlantic spotted dolphin are commonly observed (Quérouil *et al*., 2008). The short-beaked common dolphin and the striped dolphin seem to form these associations when common dolphins cannot create a single-species group and, in a way, depending on the striped dolphins (Frantzis & Herzing, 2002). In Hawaii, for the Pantropical spotted dolphins (*Stenella attenuata*) and Hawaiian spinner dolphins (*Stenella longirostris*) it was concluded that they formed mixed-species associations based on social signal and common communication (Psarakos *et al*., 2003). In a study done in the North Pacific Ocean, there were observed various mixed-species association between striped dolphin (*Stenella coeruleoalba*) and short-beaked common dolphin (*Delphinus delphis*) and it was concluded that these species tend to associate as a result of food share (Kanaji & Miyashita, 2021) and not as a result of habitat/niche overlap (Kanaji *et al*., 2017). This conclusion is not something unexpected, since it has already been achieved when studying the same interaction between other species, such as the Pacific white-sided dolphin (*Lagenorhynchus* obliquidens) and Northern right whale dolphin (*Lissodelphis borealis*) (Kanaji & Miyashita, 2021).

In dolphins, the females are more likely to create sub-groups with juveniles (Perrin, 2002). Hence, males have a higher probability of associating with other heterospecific sub-groups (Baraff & Asmutis-Silvia, 1998; Danaher-Garcia *et al*., 2020). If the chance for multispecies associations increases in cases where a habitat and prey overlap (Norris & Dohl, 1979; Fitzgibbon, 1990; Clua & Grosvalet, 2001; Quérouil *et al*., 2008; Bacon *et al*., 2017), how do these species solve the apparent inter-specific competition?

1.4. Definition of association

Mixed-species associations "are temporary aggregations of individuals of two or more different species involved in similar activities for periods ranging from several minutes to hours, days or even years" (Clua & Grosvalet, 2001; Stensland *et al*., 2003; Quérouil *et al*., 2008; Syme *et al*., 2021). The tendency to associate with conspecifics and other species varies significantly from species to species (Ward & Webster, 2016). Many species, terrestrial and aquatic, are capable of maintaining long-term associations as well as a high level of social fluidity, since the individuals associate or not depending on the environment, conspecifics and/or their needs (e.g., resting, mating and foraging) (Danaher-Garcia *et al*., 2020). Studies referring to mixed-species associations advocate functional reasons for these associations to occur and do not consider them to happen randomly. However, it is possible that polyspecific associations may not bring any advantage easily detected for the individuals involved, such as in the African Mangabey (Waser, 1982).

Polyspecific associations exist when species with a high social capacity and similar foraging ecology, group in order to increase the avoidance to predators and promote the success of the feeding activity (Struhsaker, 1981; Au, 1991). These associations are known to occur in many species such insects (Denno *et al*., 1995), fishes (Au, 1991; Kordas *et al*., 2011; Milazzo *et al*., 2013), birds (Sullivan, 1984), pinnipeds (Bearzi, 2006), antelopes (Fitzgibbon, 1990) and primates (Klein & Klein, 1973; Struhsaker, 1981; Waser, 1980, 1982; Hemelrijk, 1994). Among marine mammals these associations tend to be more difficult to detect (Bacon *et al*., 2017). External factors such as season, prey availability, region and behavioral state (Stensland *et al.*, 2003; Bearzi, 2005; Smultea *et al.*, 2014) seem to influence these polyspecific associations. Although in cetaceans mixed-species groups have already been observed in more than 30 different species (Frantzis and Herzing, 2002) in different marine habitats (Au & Perryman, 1985). Nonetheless, there is evidence for mixed-species associations in Risso's dolphin (Bearzi, 2005; Maze-Foley & Mullin, 2006; Bacon *et al.*, 2017; Zahn *et al.*, 2020; de Lima *et al.*, 2021), pilot whales (Baraff & Asmutis-Silvia, 1998; Curé *et al.*, 2012), bottlenose dolphin (Politi *et al.*, 1992; Frantzis & Herzing, 2002; Maze-Foley & Mullin, 2006; Deakos *et al.*, 2010; Ilangakoon & Alling, 2016; Koper & Plön, 2016; Pietroluongo *et al.*, 2020; Zahn *et al.*, 2020; de Lima *et al.*, 2021), common dolphin (Barlow, 1995; Pietroluongo *et al.*, 2020; Zahn *et al.*, 2020; de Lima *et al.*, 2021), striped dolphin (Barlow, 1995; Ilangakoon & Alling, 2016; Zahn *et al.*, 2020), pantropical spotted dolphin (Au & Perryman, 1985; Balance *et al.*, 2006; Maze-Foley & Mullin, 2006; Ilangakoon & Alling, 2016) and long-snouted spinner dolphin (Au & Perryman, 1985; Balance *et al.*, 2006; Ilangakoon & Alling, 2016).

1.5. Cetaceans' hybridization

Natural interspecific hybridization is believed to have a higher importance than once though, although it is still largely unknown (Amaral *et al.*, 2014). In a recent review it was shown that a significant number of cetacean species hybridize (Amaral *et al.*, 2014). As so, it is important to understand its occurrence and the factors that promote it, such as habitat disturbance and various life history traits and demographic traits, such as parental care, population sizes, climatic conditions, body sizes, behavior and timing of reproduction (Antoniou *et al.*, 2018). The study of the causes and consequences of interspecific hybridization might be beneficial to natural selection and recombination in natural populations (Antoniou *et al.*, 2018), also providing insights in the area of the phenotypic and genotypic changes during speciation (Mullen *et al.*, 2008).

Studies have already detected the hybridization between *Stenella coeruleoalba* and *Stenella clymene* (McGowen *et al.*, 2009; Amaral *et al.*, 2014) and between *Stenella coeruleoalba* and *Stenella longirostris* (Amaral *et al.*, 2014) and also between *Delphinus delphis* and *Stenella coeruleoalba* (Bearzi *et al.*, 2016; Antoniou *et al.*, 2018). The cross between *D. delphis* and *S. coeruleoalba* identified 15 hybrids, completely fertile and able to reproduce, not only with other hybrids but also with individuals of their parental species (Antoniou *et al*., 2018). The bottlenose dolphin (*Tursiops truncatus*) is also known to hybridize with at least six different species (including the common dolphin) and being able to generate fertile hybrids (Gridley *et al*., 2018; Espada *et al*., 2019).

1.6.The study area

The Azorean archipelago is located in the middle of the warm-temperate waters of the North Atlantic, being one of the most remote oceanic archipelagos in the area (Afonso *et al*., 2019), spreading along the Mid-Atlantic-Ridge (MAR) and extending for more than 480 km (Silva *et al*., 2003), being a 2000 km from North America and 1500 km from Europe (Gonzales García, 2019). It is part of the Portugal's Economic Zone (EEZ), being one of the largest ones in the European Union, having around 1 million km^2 (Afonso *et al*., 2019). It is a unique and diverse ecosystem, and it is characterized by steep submarine walls (Silva *et al*., 2008; Hartman, 2014), composed by nine volcanic islands that are separated by deep waters (> 2000 m) with scattered seamounts (Santos *et al*., 1995; Silva *et al*., 2008). As a result of being a volcanic island it does not possess continental platform, only having shallow waters very close to shore (< 200 m) (Silva *et al*., 2013) (with the exception of seamounts and islets) (Silva *et al*., 2013), and the entire archipelago is under the influence of a diverse variety of oceanographic factors, such as the entry of meanders and filaments from the Gulf Stream (Caldeira & Reis, 2017), the archipelago is also influenced by the cold North Atlantic Current and the Azores Current (Silva *et al*., 2008; Caldeira & Reis, 2017; Gonzales García *et al*., 2018) and the Azores anticyclone (Najarro *et al*., 2020), showing for example a wide range of thermal variability.

The archipelago also presents a well-defined seasonal cycle for chlorophyll *a* (Chl-*a*), with higher concentrations of Chl-*a* in the spring as a result of the spring bloom (González García *et al*., 2018). The Chl-*a* and the sea surface temperature (SST) show an inverse pattern, which means that usually when SST is lower, Chl-*a* concentration is higher (Caldeira & Reis, 2017), that contribute for its different habitat types of heterogeneity, supporting a varied number of transient and resident species, including 28 cetacean species (reviewed in Prieto & Silva 2010; Silva *et al*. 2013), with four of these being resident species (*Delphinus delphis, Grampus griseus, Physeter* *macrocephalus* and *Tursiops truncatus*) and the other 24 being seasonal visitors (examples: *Stenella frontalis, Balaenoptera musculus, Balaenoptera borealis*, etc.). As a result of its' importance, since the year of 2011 each island is a natural park ("Parque Natural de Ilha") (DLR 15/2007/A; DLR 19/2008/A) and its management is carried by "Parque Marinho do Arquipélago dos Açores" (Azores Marine Park) (DLR 28/2011/A, posteriorly altered to DLR 13/2016/A). It is characterized by its high salinity, low nutrient regime and high temperature waters (Santos *et al.*, 1995; Johnson & Stevens, 2000). It constitutes a "food-rich oasis in the oligotrophic central North Atlantic" (Hartman, 2014), as a result of the nutrient-rich upwelling currents, the dynamic circulations patterns, the Azores anticyclone and the runoff from the land (Najarro *et al.*, 2020), as a result it is the habitat for a various number of marine species, it is also very important for migratory species, being used as a breeding and foraging area (Gonzalez García, 2019). The islands' dynamism helps with processes, such as bottom-up and biomass aggregation, helping in the creation of local hotspots (Ballance *et al.*, 2006). Unfortunately, anthropogenic threats have been increasing, such as the boat traffic and the noise pollution (Hartman, 2014). These impacts may be worst for the resident species, as it is the case of *D. delphis* since they are constantly exposed to these threats (Hartman, 2014).

1.7.The focal species

1.7.1. Delphinus delphis

General characteristics. The short-beaked common dolphin (*Delphinus delphis* Linnaeus, 1758) belongs to the family *Delphinidae*, suborder Odontoceti and it is a small odontocete that is one of the most colorful dolphin species, having a greyish color with a very characteristic and distinctive yellow hourglass in the flank and a white belly (Figure 1.2) (Jefferson *et al.*, 1993; Amaha, 1994). They have a medium beak and a tall and slightly falcate dorsal fin (Jefferson *et al.*, 1993), that when achieving the adult stage can have a white center (Amaha, 1994). They are active and energetic animals (Jefferson *et al.*, 1993).

Age and growth. Their longevity rounds the 25 to 30 years, reaching their mating age by the age of 2 – 3 years, with a gestation that lasts for 10 to 12 months, allowing them to give birth every 1 to 3 years (Murphy *et al.*, 2013). Generally the males are bigger than the females, with a male adult can reach 2 – 2,6 m and 200 kg, while a female adult can reach 1,93 – 2,3 m with calves being about 0,8 – 0,85 m (Jefferson *et al*., 1993; Neuman & Orams, 2005; Frantzis, 2009; Murphy *et al*., 2009)

Distribution. It is a very abundant and widely distributed species in tropical to warm temperature waters (Jefferson *et al*., 1993; Braulik *et al*., 2021; Mussi *et al*., 2021), found worldwide (Bearzi *et al*., 2003; Pace *et al*., 2015; Pietroluongo *et al*., 2020). Its' absolute limits are 60° N and 50° S (Jefferson *et al*., 1993). It occurs in many geographically separate populations since it is not panmictic (Bearzi *et al*., 2003). This specimen is one of the most common species in the Mediterranean Sea (Bearzi *et al*., 2005). However, their population has experienced a vast decrease during the last decades, for still not well-known reasons (Bearzi *et al*., 2003).

This species is found in both neritic and pelagic habitats (Notarbartolo Di Sciara *et al*., 1993; Cañadas *et al*., 2002; Bearzi *et al*., 2003; Cañadas & Hammond, 2008; Pietroluongo *et al*., 2020). Although it is more frequently observed in the Azores in coastal areas (Silva *et al*., 2003). Its spatiotemporal occurrence is related to seasonal fluctuations in the sea-surface temperature and the upwelling currents (Bearzi, 2005; Pietroluongo *et al*., 2020) it was also already correlated with the presence of the Atlantic spotted dolphin, in the Azores it has been supposed that the common dolphin is less frequent during the summertime as a result of the appearance of this species and the consequent increase of food competition (Silva *et al*., 2013). The preference for offshore or shallower waters is still a topic for discussion since both situations have been already observed (Bearzi, 2005). However, one possible justification for the change between depths was the suggestion that the common dolphin shift habitats by following the movements of migration of the anchovies (*Engraulis encrasicolus*) (Borja *et al*., 1998). The influence of the depth and slope on the common dolphin's distribution has already been studied in the Alboran sea (Cañadas *et al*., 2002). There is no data on species distribution prediction concerning depth and slope. It is one of the most sighted species in the Azores Archipelago, since it is resident in there (Figure 1.1).

Group size and social structure. This species stays in large schools that often divide into smaller sub-groups of around 30 individuals but start by reaching thousands of individuals (Bearzi *et al*., 2003; Bearzi, 2005). They are highly social and normally travel in groups that can reach thousands of individuals, usually those groups are found divided by age and sex (Jefferson *et al*., 1993).

Diet. These animals work together to gather their preys into a small "ball" near to the surface for a better and easier catch, some of the main prey items of these individuals are small pelagic fish, such as sardine, anchovy and mackerel (Reynoso, 1991; Bearzi, 2005; Brophy *et al*., 2009;

Frantzis, 2009; Pietroluongo *et al*., 2020; Zahn *et al*., 2020), they were also already seen feeding in small crustaceans and cephalopods (Jefferson *et al*., 1993; Brophy *et al*., 2009; Frantzis, 2009; Zahn *et al*., 2020). Although this species is an opportunistic feeder, its diet can suffer slightly changes accordingly with the availability of the most abundant and catchable prey (Klinowska, 1991).

General issues. Although the causes are still to be determined, this species has dealt with a considerable worldwide decline (Cañadas *et al*., 2002; Bearzi *et al*., 2003, 2005; Cañadas & Hammond, 2008; Bearzi *et al*., 2016; Pietroluongo *et al*., 2020; Mussi *et al*., 2021). The exception is the Alboran Sea, where a significant population remains (Cañadas & Hammond, 2008). Some of the possible factors that may have been responsible for these declines are the multifactorial and increasing anthropogenic threats, such as depletion of food resources as a result of overfishing, by-catch and toxic pollution (Au & Perryman, 1985; Bowen, 1997; Bearzi *et al*., 2003; Cañadas & Hammond, 2008; Brophy *et al*., 2009; Frantzis, 2009; Bearzi *et al*., 2016; Cruz *et al*., 2016; Pietroluongo *et al*., 2020; Braulik *et al*., 2021). Despite this decline, the species as listed as least concern 'conservation dependent' in the 2008 IUCN Red List of Threatened Animals (Braulik *et al*., 2021), this means that despite their decay, their whole world population (Bearzi *et al*., 2003, 2005; Pace *et al*., 2015; Pietroluongo *et al*., 2020) still has a significative quantity. They are also considered as a threat for the fishing stocks and thus they were killed by fishermen (Santos *et al*., 2004; Brophy *et al*., 2009; Bearzi *et al*., 2016). Fortunately, now they are protected by law in some countries, including Portugal (Silva & Sequeira, 2003; Santos *et al*., 2004; Cruz *et al*., 2016).

Associations. This species was already observed forming mixed-species associations with other cetaceans' species and these associations are somehow common (Jefferson *et al*., 1993), such as the bottlenose dolphin (Politi *et al*., 1992; Clua & Grosvalet, 2001; Koper & Plön, 2016), Risso's dolphin (Cañadas *et al*., 2002; Frantzis & Herzing, 2002; Frantzis, 2009; Bearzi *et al*., 2016), striped dolphin (Barlow, 1995; Clua & Grosvalet, 2001; Cañadas *et al*., 2002; Frantzis & Herzing, 2002; Cañadas & Hammond, 2008; Quérouil *et al*., 2008; Pace *et al*., 2015; Braulik *et al*., 2021; Mussi *et al*., 2021), Atlantic spotted dolphin (Clua & Grosvalet, 2001; Quérouil *et al*., 2008; Zahn *et al*., 2020; de Lima *et al*., 2021), pilot whales (Cañadas *et al*., 2002; Braulik *et al*., 2021), orcas (Jefferson *et al*., 1991) and sperm whale (de Lima *et al*., 2021).

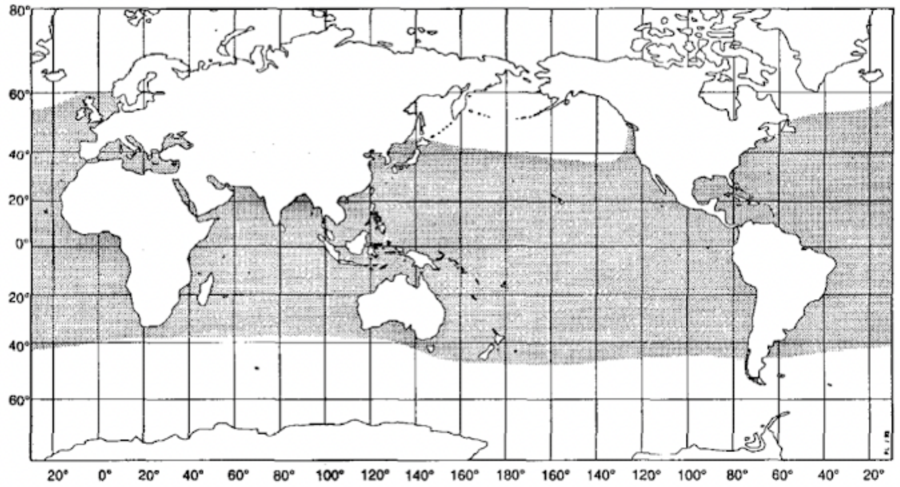

Figure 1.1 – Representation of the *Delphinus delphis* world distribution. Source: Jefferson *et al.*, 1993.

Figure 1.2 – Representation of the common dolphin, showing their identifier colors, the greyish/black back, light grey tail, yellow patch and white belly. Source: Heckel *et al.*, 2020.

1.7.2. Stenella coeruleoalba

General characteristics. The striped dolphin (*Stenella coeruleoalba* Meyen, 1833) belongs to the family *Delphinidae*, suborder Odontoceti. Their color pattern is their main characteristic, with them showing a white or pinkish belly with a grey body, having a light grey flank and a black stripe (that is called "flame") on their sides, that starts at the beginning of the head and ends in the anal region (Jefferson *et al.*, 1993). They show a moderate long beak and a falcate dorsal fin (Jefferson *et al.*, 1993) (Figure 1.4). They are very fast swimmers and usually are easily alarmed than other species (Jefferson *et al.*, 1993) and usually demonstrate a multiplicity of aerial behaviors (Archer, 2018).

Age and growth. Their longest lifespan recorded was almost 58 years and they achieve sexual maturity between the age of five to 15 years, with a gestation lasting for 12 to 13 months (Archer, 2018). When adults they can reach the 2.6 m and 156 kg, with the males being slightly larger than the females, newborns are about 1 m (Aguilar, 1991; Jefferson *et al*., 1993; Frantzis, 2009) and a little more than 10 kg (Aguilar, 1991).

Distribution. The striped dolphin is a widely distributed small delphinid common in warm-temperate tropical waters (Archer & Perrin, 1999; Archer, 2018). With them being more frequent in water from 18°C to 22°C, but being also recorded in waters from 10°C to 26°C (Archer & Perrin, 1999). Its absolute limits are 50° N and 40°S (Figure 1.3). It is believed that this species is the most abundant cetacean species in the Mediterranean Sea (Aguilar, 1991; Fortuna *et al*., 2007; Frantzis, 2009; Bearzi *et al*., 2016). They can usually be found outside the continental shelf (Archer & Perrin, 1999; Ballance *et al*., 2006; Frantzis, 2009) and are often associated with waters influenced by upwelling or with convergence zones (Reynoso, 1991; Ballance *et al*., 2006). In the Atlantic its numbers are estimated to be around the 57 000 individuals (Archer, 2018).

Group size and social structure. Striped dolphins' schools may vary in size (between regions), being able to achieve the thousands of individuals (Jefferson *et al*., 1993; Archer, 2018). Still, the great majority of the schools observed were composed of less than 500 individuals, but more than 100 individuals (Miyazaki & Nishiwaki, 1978; Jefferson *et al*., 1993; Archer, 2018), with the mean size being 121 animals (Archer & Perrin, 1999). The schools can be classified into three different types: mixed schools, juvenile schools, and adult schools (Miyazaki & Nishiwaki, 1978), since they were found to be divided by age and sex (Jefferson *et al*., 1993).

Diet. Their diets consist of benthopelagic or pelagic fish (Frantzis, 2009; Archer, 2018; Zahn *et al*., 2020), squid (in the Mediterranean waters), lantern fish (in the waters of the northeast Atlantic), cod, anchovy (in the coastal waters of the northeast Atlantic) (Jefferson *et al*., 1993; Archer, 2018; Zahn *et al*., 2020) and crabs (Zahn *et al*., 2020). They were already characterized as opportunistic feeders in previous studies (Bearzi, 2005).

General issues. This specimen was defined as 'vulnerable' given a new IUCN listing (Reeves & Notarbartolo di Sciara, 2006; Frantzis, 2009; Bearzi *et al*., 2016). They are vulnerable to incidental capture in fishing gear, such as driftnets (Au & Perryman, 1985; Bowen, 1997; Fortuna *et al*., 2007; Bearzi *et al*., 2016). PCBs and organochloride pollutants have also been related with their death (Frantzis, 2009).

Associations. This species was already observed forming mixed-species associations with the following cetaceans: Risso's dolphin (Frantzis & Herzing, 2002; Bacon *et al*., 2017); common dolphin (Barlow, 1995; Clua & Grosvalet, 2001; Cañadas *et al*., 2002; Frantzis & Herzing, 2002; Cañadas & Hammond, 2008; Pace *et al*., 2015; Bearzi *et al*., 2016; Zahn *et al*., 2020; Braulik *et al*., 2021; Mussi *et al*., 2021); Atlantic spotted dolphin (Clua & Grosvalet, 2001; Quérouil *et al*., 2008) and bottlenose dolphin (Clua & Grosvalet, 2001; Quérouil *et al*., 2008).

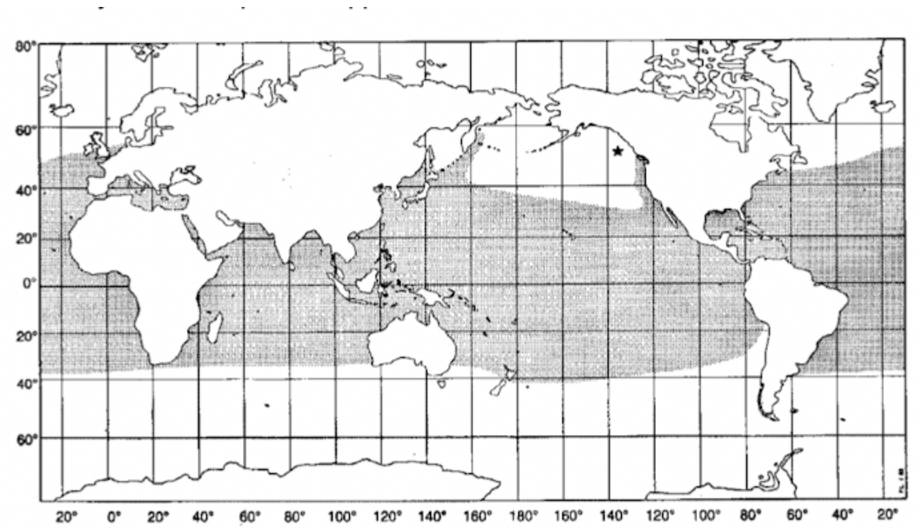

Figure 1.3 – Representation of the *Stenella coeruleoalba* world distribution. Source: Jefferson *et al*., 1993.

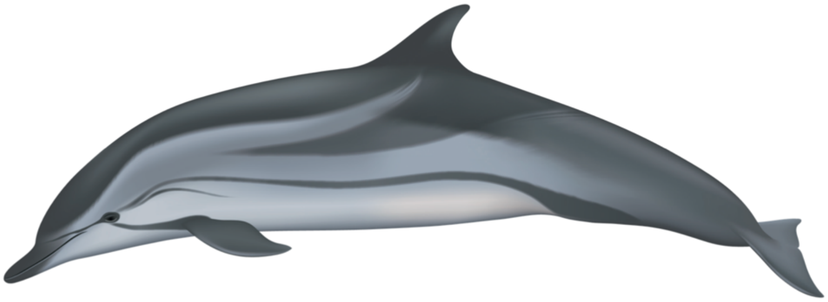

Figure 1.4- Representation of the striped dolphin, showing their identifier stripes in their sides. Source: Heckel *et al*., 2020.

1.7.3. Stenella frontalis

General characteristics. Atlantic spotted dolphin (*Stenella frontalis* G. Cuvier 1829) belongs to the family *Delphinidae*, suborder Odontoceti. Their coloration suffers some development during their lifetime, since they are born without the spotted background coloration and it only starts to show when they start aging, with the heavy spotting being something characteristic from the

Atlantic spotted dolphins (Jefferson *et al.*, 1993; Perrin *et al.*, 2009; Najarro, 2020) (Figure 1.6). They are acrobatic animals and very avid bowriders (Jefferson *et al.*, 1993). The dorsal fin is tall and falcate (Perrin *et al.*, 2009).

Age and growth. It is a small and slender dolphin, with the adults being able to reach 2.3 m and 143 kg (Jefferson *et al.*, 1993; Najarro, 2020), newborns are 0.8 – 1.2 m (Jefferson *et al.*, 1993). Their life expectancy is 30 to 40 years (Najarro, 2020) and they reach the sexual maturity between the age of nine to 10 years in females and 18 years in males.

Distribution. Is a highly variable geographically species (Perryman *et al.*, 1994; Najarro *et al.*, 2020), only found in the Atlantic (Perrin *et al.*, 2009). It is endemic to the tropical and warm-temperate Atlantic, occurring at the Azores archipelago (Perryman *et al.*, 1994; Perrin *et al.*, 2009), and it is one of the most common/frequent small cetaceans (Perrin, 2002). It is also a resident species in the shallow waters of the Great Bahama Bank (Herzing *et al.*, 2003), but usually inhabits the continental shelf (Perryman *et al.*, 1994), although it has already been observed inhabiting deep oceanic waters (Jefferson *et al.*, 1993). Its' absolute limits are 50° N and 25° S (Perrin *et al.*, 2009) (Figure 1.5). It has a seasonal distribution pattern being more present in the warmer months, meaning that its distribution and presence is known to be influenced by the water temperature, although Najarro, 2020 concluded that its possible for that influence to be indirect, meaning that the factor that influences that distribution and presence is actually the growth of primary production that will consequently increase the availability of fish.

Group size and social structure. Their pods are relatively small, being composed by less than 50 individuals generally (Jefferson *et al.*, 1993). Although the moving groups usually consist of up to 100 individuals, since it is common to smaller groups to join bigger ones (Perrin *et al.*, 1994). It was already observed group segregation based on sex and age, although there was still considerable flux in the creation of the groups (Perrin *et al.*, 1994). The spotted dolphin is more probable to exchange rubs and pets with other individuals from the same age group and sex (Perrin, 2002). The females are also common to associate with other females from the same age group, and pregnant females associate with other females that have gave birth in the same year (Perrin, 2002). This species is believed to develop individual bonding and recognition being considered as very complex in social organization, the association between the calf and the mother (and other females from the group) tends to be very strong during the first three years of the calf life (Najarro, 2020).

Diet. This species has been observed feeding on small cephalopods (Perryman *et al.*, 1994) and benthic fish, such as lizardfish, conger eel, flounders, clinid (Herzing *et al.*, 2003; Zahn *et al.*, 2020), squids (Jefferson *et al.*, 1993; Perrin *et al.*, 1994; Perrin, 2002; Perrin *et al.*, 2009; Zahn *et al.*, 2020) and clupeid fishes (Perrin *et al.*, 1994; Fertl & Wursig, 1995). In the Azores they have already been seen feeding on clupeid fish in aggregation with the Cory's shearwaters, the dolphins as a group gathered the ball of fish near the surface in a coordinate way (Fertl & Würsig, 1995; Perrin, 2002).

General issues. One factor that is influencing these dolphins are the high concentrations of contaminants. As well as the noise pollution resultant from ships (Najarro, 2020). Unfortunately, they are still proposedly capture in a small-scale and they are also victims of by-catch and ghost nets (Bowen, 1997; Perrin, 2002). This species main predators are sharks and orcas (*Orcinus orca*) (Perrin *et al.*, 1994; Perrin, 2002) being also sometimes attacked by different endoparasites (Najarro, 2020).

Associations. This species has already been observed in interaction with other cetaceans' species, such as Risso's dolphin (Bacon *et al.*, 2007); striped dolphin (Clua & Grosvalet, 2001; Quérouil *et al.*, 2008); common dolphin (Clua & Grosvalet, 2001; Zahn *et al.*, 2020; de Lima *et al.*, 2021); bottlenose dolphin (Herzing & Johnson, 1997; Clua & Grosvalet, 2001; Herzing *et al.*, 2003; Melillo *et al.*, 2009; Zahn *et al.*, 2020; de Lima *et al.*, 2021) and sei whale (Zahn *et al.*, 2020).

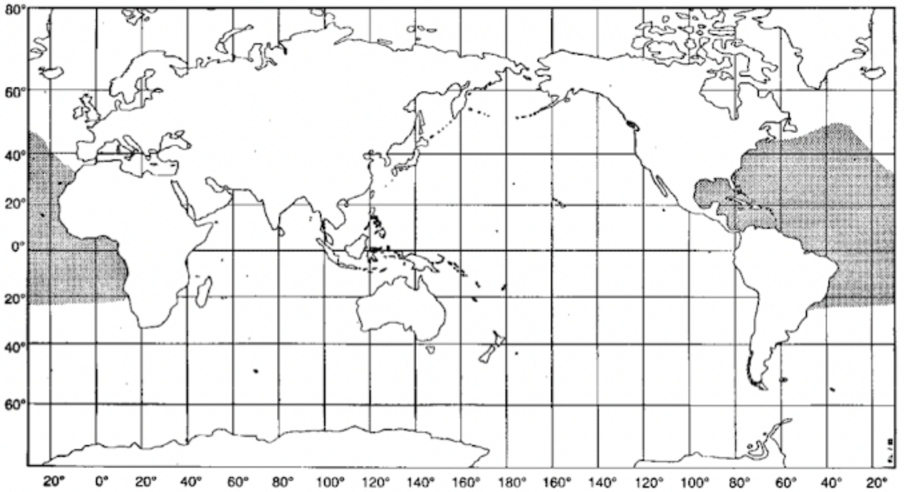

Figure 1.5 – Representation of the *Stenella frontalis* world distribution. Source: Jefferson *et al.*, 1993.

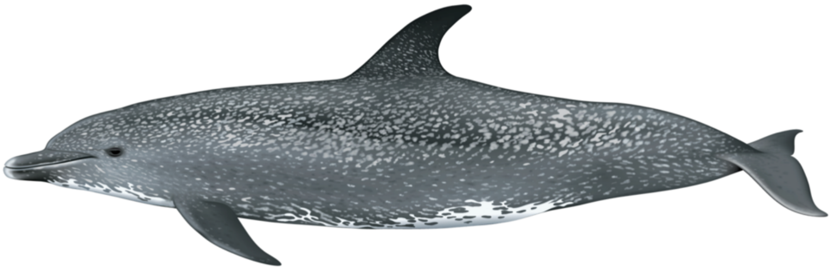

Figure 1.6 - Representation of the Atlantic spotted dolphin, showing their identifier spots in their body. Source: Heckel *et al*., 2020.

1.8.Theme justification

All the three species have been sighted every year in Pico, Azores, being some of the main targets of the whale watching companies. *Delphinus delphis* are one of the four resident species of the archipelago, being sighted all year-round, *Stenella coeruleoalba* and *Stenella frontalis* are two of the migratory ones, with them being mainly sighted in spring and summer and only in summertime, respectively.

This cetacean's study brings useful knowledge to minimize the data gap existent for these species around Pico Island, especially for *Stenella coeruleoalba* and for *Stenella frontalis*. We will validate the viability of the opportunistic data used to assess cetaceans' associations, distribution and ethology.

Azores archipelago is very rich in cetacean biodiversity, with 28 species already sighted so far (Santos *et al*., 2016). Pico Island conditions are favorable for this type of research since the three focal species are present and quite frequent to be observed, also it has been observed an increase of data collection effort by biologists. Thus, the data available is of enough quality, consistency and precision to be suitable for research on group composition, social structure and association patterns of these species.

By understanding how they interact and the drivers and consequences of these interactions, the conservation of these three species and the management plans can be improved, and hopefully can be extended for more cetaceans' species and other places besides the Azores archipelago.

1.9.Thesis objectives

The main objectives of this study are to understand:

1) If the habitat is the key factor promoting these inter-specific interactions.
2) Which is the main driver for these associations
3) If these associations are species dependent, meaning that the main driver changes from species to species.

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Interspecific interactions between short-beaked common, Atlantic spotted and striped dolphins in the Pico Island, Azores

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2.1. Abstract

The interspecific tendency of association is well known for many species, including primates, birds and cetaceans. While the exact factors that promote these interactions are still largely uncertain, it is highly probable that one or both species benefit from their association. Three cetacean species share the same habitat in the Azores and have the same feeding habitats, short-beaked common dolphin (*Delphinus delphis*), striped dolphin (*Stenella coeruleoalba)* and Atlantic spotted dolphin (*Stenella frontalis*)*,* being occasionally seen together. This project aims to evaluate these associations and determine the main factors influencing these interspecific interactions and their benefits. This study collected data in the surrounding waters of Pico Island, Azores, during seven consecutive years (2012-2018), using opportunistic platforms such as whale watching boats, that despite some limitations, have already been proven to be a way of cost-efficient data collection and a source of reliable data for research. A total of 1452 trips that resulted in 1289 sightings of *Delphinus delphis*, 317 sightings of *Stenella coeruleoalba*, 488 sightings of *Stenella frontalis* and a total of 82 interspecific interactions sightings (including at least two of these three target species) were analyzed, studying the behavior, bathymetry, distance to coast and presence of calves for each sighting. Statistical tests were performed to proceed to multiple comparisons between the drivers and the observations with and without interactions, revealing that in the majority of the statistical analysis only the striped dolphin had associations with the interactions, with the common dolphin showing less frequent associations and the spotted dolphin not showing any. The results showed that only the striped dolphin had an association with interaction and the main driver was concluded to be the increase of the foraging success, while the common dolphin showed to be driven by social reasons, such as the increase of the group size and the Atlantic spotted dolphin did not show any tendency to associate.

Keywords: Association, Azores, Cetaceans, Hybridization, Interspecific interactions, Sympatry

2.2. Introduction

Intra-specific (same species) and interspecific or mixed-species (different species) interactions or associations are omnipresent. In biology, the term “interspecific interactions” describes a temporary aggregation of individuals of two or more different species that are involved in similar activities (Clua & Grosvalet, 2001; Stensland *et al*., 2003; Quérouil *et al*., 2008). They can be classified as negative interactions which are only beneficial to one of the species involved while being detrimental to the other one (such as parasitism for example) or positive interactions that can be beneficial for one of the species involved (commensalism) or for both (mutualism) (Klein & Klein, 1973; Noris & Dohl, 1980; Abrams, 1987; Baraff & Asmutis-Silvia, 1998; Scott & Cattanach, 1998; Quérouil *et al*., 2008; Acevedo-Gutiérrez, 2009; Deakos *et al*., 2010; Koper & Plön, 2016). These interactions have been observed in a wide range of species, such as insects (Denno *et al*., 1995), birds (Sullivan, 1984), fish (Au, 1991; Kordas *et al*., 2011; Milazzo *et al*., 2013), antelopes (Fitzgibbon, 1990) and primates (Klein & Klein, 1973; Struhsaker, 1981; Waser, 1982; Hemelrijk, 1994). In the marine mammal realm, these type of interactions are known for a wide number of marine mammals (see Annex A for a more complete information), such as pinnipeds (Jefferson *et al*., 1991), dolphins (Au & Perryman, 1985; Jefferson et al., 1991; Politi *et al*., 1992; Barlow, 1995; Fertl & Würsig, 1995; Ross & Wilson, 1996; Herzing & Johnson, 1997; Baraff & Asmutis-Silvia, 1998; Clua & Grosvalet, 2001; Cañadas et al., 2002; Herzing *et al*., 2003; Wedekin et al., 2004; Bearzi, 2005; Balance *et al*., 2006; Cañadas & Hammond, 2008; Quérouil et al., 2008; Coscarella & Crespo, 2009; Rossi-Santos et al., 2009; Melillo et al., 2009; Deakos *et al*., 2010; Curé *et al*., 2012; Bearzi *et al*., 2016; Ilangakoon & Alling, 2016; Koper & Plön, 2016; Bacon *et al*., 2017; Pietroluongo *et al*., 2020; Zahn et al., 2020; Braulik *et al*., 2021 de Lima et al., 2021) and whales (Jefferson et al., 1991; Bearzi, 2005; Maze-Foley & Mullin, 2006; Rossi-Santos *et al*., 2009; Deakos *et al*., 2010; Koper & Plön, 2016; Bacon et al., 2017).

Cetaceans are a conspicuous example of known frequent interactions among species, as a result of their social nature, such as bottlenose dolphins (Politi *et al*., 1992; Herzing & Johnson, 1997; Clua & Grosvalet, 2001; Bearzi, 2005; Pietroluongo *et al*., 2020; Zahn *et al*., 2020; de Lima *et al*., 2021), striped dolphins (Barlow, 1995; Clua & Grosvalet, 2001; Cañadas et al., 2002; Frantzis & Herzing, 2002; Bearzi, 2005; Cañadas & Hammond, 2008; Quérouil et al., 2008; Pace et al., 2015; Bearzi *et al*., 2016; Ilangakoon & Alling, 2016; Bacon et al., 2017; Zahn *et al*., 2020; Braulik *et* *al*., 2021; Mussi et., 2021), spinner dolphin (Au & Perryman, 1985; Jefferson *et al*., 1991; Balance *et al*., 2006), common dolphins (Jefferson et al., 1991; Politi et al., 1992; Jefferson et al., 1993; Barlow, 1995; Clua & Grosvalet, 2001; Cañadas et al., 2002; Frantzis & Herzing, 2002; Bearzi, 2005; Cañadas & Hammond, 2008; Quérouil et al., 2008; Frantzis, 2009; Pace et al., 2015; Bearzi *et al*., 2016; Koper & Plön, 2016; Pietroluongo *et al*., 2020, Zahn *et al*., 2020; Braulik *et al*., 2021; de Lima *et al*., 2021; Mussi et al., 2021), Risso's dolphins (Bearzi, 2005; Bearzi *et al*., 2016; Bacon *et al*., 2017; Zahn *et al*., 2020; de Lima *et al*., 2021) Atlantic spotted dolphins (Herzing & Johnson, 1997; Clua & Grosvalet, 2001; Herzing *et al*., 2003; Bearzi, 2005; Maze-Foley & Mullin, 2006; Quérouil *et al*., 2008; Melillo et al., 2009; Bacon et al., 2017; Zahn *et al*., 2020; de Lima *et al*., 2021), sperm whales (Maze-Foley & Mullin, 2006; Zahn *et al*., 2020), false killer whales (Maze-Foley & Mullin, 2006; Zahn *et al*., 2020), orcas (Bearzi, 2005; Curé *et al*., 2012), humpback dolphins (Koper & Plön, 2016), pilot whales (Curé *et al*., 2012; Braulik *et al*., 2021) (see Annex A for more complete information). Interspecific interactions seem to result in benefits for the species involved by: (1) reducing predation risk and increasing protection (Norris & Dohl, 1980; Pook & Pook, 1982; Fitzgibbon, 1990; Stensland *et al*., 2003; Acevedo-Gutiérrez, 2009), (2) gaining social benefits (Stensland *et al*., 2003) and/or (3) improving the foraging activity (Norris & Dohl, 1980; Stensland *et al*., 2003; Acevedo-Gutiérrez, 2009; Koper & Plön, 2016; Bacon *et al*., 2017; Syme *et al*., 2021). These interactions are usually divided in five functional groups: (1) aggression (Ross & Wilson, 1996; Herzing & Johnson, 1997; Herzing *et al*., 2003; Wedekin *et al*., 2004; Coscarella & Crespo, 2009; Deakos *et al*., 2010); (2) epimeletic (Herzing & Johnson, 1997; Deakos *et al*., 2010); (3) playful (Herzing & Johnson, 1997; Deakos *et al*., 2010); (4) communal foraging (Herzing & Johnson, 1997; Acevedo-Gutiérrez, 2009; Deakos *et al*., 2010) and (5) sexual (Dohl *et al*., 1974; Herzing & Johnson, 1997; Deakos *et al*., 2010). However, although the benefits of such interactions are generally known, the drivers and nature of these associations are still poorly studied and unclear (Koper & Plön, 2016).

Cetaceans are well known as one of the most essential groups of the sea as a result of their contribute in vertical and horizontal movements (Moore, 2008; Lavery *et al*., 2012; Roman *et al*., 2014; Gonzalez García, 2018). For that reason, they have also been considered as "umbrella species" meaning that their conservation will have a direct effect on a various number of other species (Gonzalez García, 2018). As a result, association between cetaceans and their importance for the habitat are from a great importance to be studied. In the Azores archipelago, the short-beaked common dolphin (hereafter referred as ‘common dolphin’), the striped dolphin and the Atlantic spotted dolphin (hereafter referred as ‘spotted dolphin’) seem to form these associations sporadically. For dolphins some of these interactions consist on mixing different species in swimming side-by-side while maintaining the limits of their own species sub-group (Frantzis & Herzing, 2002; Kanaji & Miyashita, 2021).

Some of these associations have already been observed in other parts of the world, such as in Hawaii, where it was concluded that for the Pantropical spotted dolphins (*Stenella attenuata*) and Hawaiian spinner dolphins (*Stenella longirostris*) formed mixed-species associations based on social signal and common communication (Au & Perryman, 1985; Psarakos *et al*., 2003), and that for the bottlenose dolphins (*Tursiops truncatus*) and humpback whales (*Megaptera novaeangliae*) the associations where described as being associative, communal foraging, a form of play or involving bow-riding in the front of the whale head allowing the dolphin to save energy during swimming activity (Deakos *et al*., 2010). In a study done in the North Pacific the conclusions where the same as in in Pacific white-sided dolphins and Northern right whale dolphin, where it was established that the species tend to associate as a result of food share (Kanaji & Miyashita, 2021), but in two studies done by Bacon *et al*. (2017) and Clua & Grosvalet (2001) it was concluded that one of the factors that increase the chance for this interactions to occur is the prey and habitat overlap.

The Azorean archipelago, in the middle of the Atlantic Ocean, is known for its cetacean species richness. It harbors 28 different species (Prieto & Silva, 2010; Santos *et al*., 2016), including four resident species – sperm whale (*Physeter macrocephalus*), common dolphin (*Delphinus delphis*), bottlenose dolphin (*Tursiops truncatus*) and the Risso’s dolphin (*Grampus griseus*). This species richness is probably associated to the archipelago dynamic oceanography around the islands and the bathymetry association with the different currents that enhance the primary production (Silva, 2007). Consequently, the whale watching activity has been increasing in the last decade, and so has the availability for opportunistic platforms for data collection.

This study will provide an initial insight into the interactions among the short-beaked common dolphin (*Delphinus delphis*), the striped dolphin (*Stenella coeruleoalba*) and the Atlantic spotted dolphin (*Stenella frontalis*) along seven consecutive years (2012 – 2018) in the surrounding waters of Pico Island, Azores. The main objectives are to understand (1) if the habitat is the key factor promoting these inter-specific associations?; (2) which is the main driver for these associations?; (3) if these associations are species dependent? The results of this study will contribute to help to expand the existent knowledge about these species behaviors and their drivers and nature, but will also contribute for a better understanding and consequently an enhanced and more thoughtful approach for the whale watching boats.

2.3. Material and Methods

2.3.1. Study Area

The Archipelago of the Azores (Portugal), is located in the middle of the warm-temperate waters of the North-East Atlantic Ocean, extends for more than 480 km along with a northwest-southeast trend and crosses the Mid-Atlantic Ridge (MAR) (Silva *et al.*, 2003), between 37° to 40°N and 25° to 32°W. It is located 2000 km from North America and 1500 km from Europe (Gonzales García, 2019) and comprises nine volcanic islands separated by deep waters (> 2000 m), forming three distinct groups Western group (Flores and Corvo), Eastern group (São Miguel and Santa Maria) and Central group (Graciosa, São Jorge, Pico, Faial and Terceira), with Faial, Pico and São Jorge constituting what is called by the Azores Triangle, these are known to be under the influence of the entry of meanders and filaments deriving from the Gulf Stream (Caldeira & Reis, 2017), the archipelago is also influenced by the cold North Atlantic Current and the Azores Current (Silva *et al.*, 2008; Caldeira & Reis, 2017; Gonzales García *et al.*, 2018).

The focal study area was the surrounded waters of one the nine islands of the Archipelago, the south of Pico Island, sometimes spreading until the south coast of São Jorge and/or Faial (Figure 2.1). Pico island has a wide range of marine habitats, with big depths close to the coast and the sea surface temperature (SST) varying from 15 ºC to 25 ºC in winter and summer, respectively. The island also presents a well-defined seasonal cycle for chlorophyll *a* (Chl-*a*), with higher concentrations of Chl-*a* in the spring as a result of the spring bloom (González García *et al.*, 2018). The Chl-*a* and the SST show an inverse pattern, which means that usually when SST is lower, Chl-*a* concentration is higher (Caldeira & Reis, 2017).

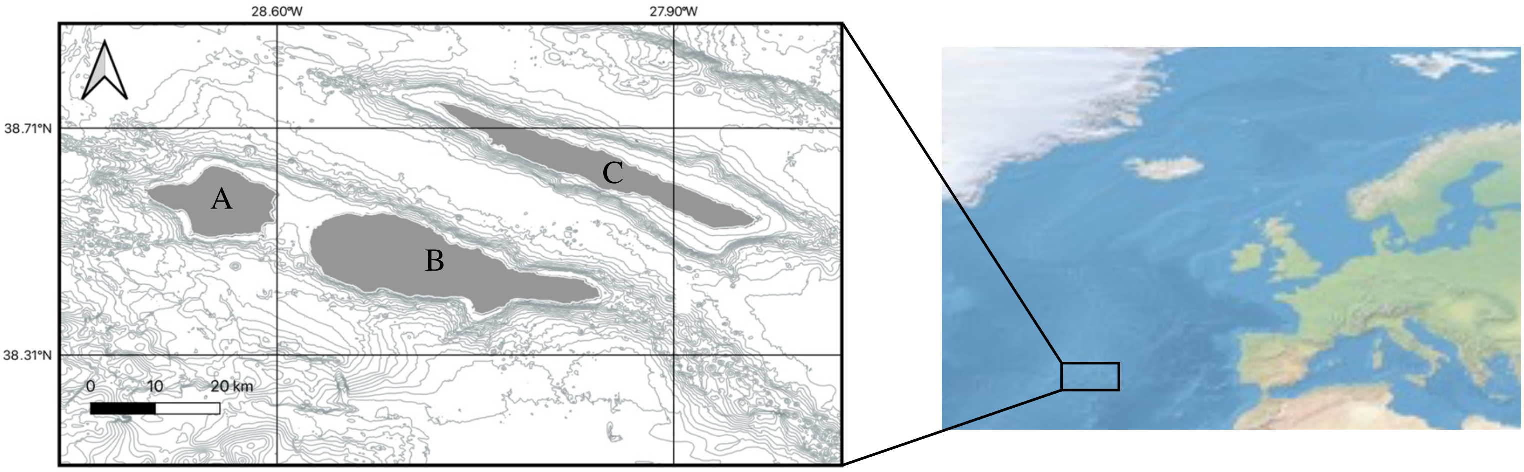

Figure 2.1 – Location of the Azores archipelago (right side) in the North-East Atlantic and the study area, (A) Faial, (B) Pico and (C) São Jorge Islands (called the Azores Triangle), located in the Azores archipelago. Bathymetric lines each 100m.

2.3.2. Data Collection

Cetacean sightings were recorded from 2012 to 2018 during the commercial whale watching trips of two operators Espaço Talassa and Futurismo, both located in Pico Island (Azores). A total of 1452 whale watching trips resulted in an area search effort of 83 786 Km. Experience land observers are in strategic island viewpoints and/or watching towers and find the cetaceans using powerful binoculars. The skippers are then informed of the cetaceans' location. The data collected is therefore opportunistic resulting from non-random way and the observations are not incidental but intentional. Being opportunistic surveys, it means that the data is collected from already existent activities, allowing a more affordable way to do it. The data was collected almost year-round, only excluding the wintertime (as a result of low tourism season, with few whale watching trips and worst weather conditions). For each cetacean encounter the biologists on board observed the animals and registered the species name, time of sighting, location (using a GPS Garmin Etrex20), group size and composition (number of adults, juveniles, calves and newborns and the presence or absence of other species) and behavior of the group individuals. All the observations in the vessel were done visually, as so, the individuals were considered juveniles when they were approximately between 50-75% of the length of a mature adult, calves when they were approximately between 25-50% of the length of a mature adult and newborns (when they still show signs of a recent birth, bend dorsal and presence of light vertical lines on the sides), special attention was given to mixed-species groups (including at least two of the focal species).

2.3.3. Data Analysis

For the statistical analysis the R version 4.1.2 (R Core Team, 2021) was used. The chi-square test was performed to check for normality (p-value < 0.05), after this part checked, the post hoc test by the bonferroni method, was performed to execute multiple comparisons (residuals > 2.0) between the three species, allowing to conclude if the association is with the interaction or not (Beasley & Schumacker, 1995; Agresti, 2007). Both tests were performed for all the variables, including: 1) interaction, 2) behaviors, 3) bathymetry, 4) distance to coast, 5) presence of calves.

The spatial analysis was based on bathymetry and distance to the coast. For each species, based geo-reference presences was extracted bathymetry data that was retrieved from the EMODnet digital bathymetric model released in 2020 (http://portal.emodnet-bathymetry.eu, last access: 15 August 2022). The distance to the coast was recovered using the QGIS-plugin feature NNJoin (QGIS Version 3.16.10, NNJoin Version 3.1.3 by Håvard Tveite, NMBU).

Data obtained was divided into six categories of observed predominant behaviors: (1) Foraging; (2) Socializing, which included socializing, repeatedly individuals interaction, leaping (forward, backward and sideways), bow riding and lob tailing; (3) Travelling, fast (> 6 kn), average (4 – 6 kn) and slow (1 – 4 kn); (4) Resting, which included resting and milling; (5) Others, which included all the behaviors that were not mentioned above; and (6) Non-identified.

2.4. Results

The number of observations with and without species interactions differed considerably (Table 2.1 and Annex C). The total number of observed interspecific interactions was 82, where the most common interspecific interaction was between *D. delphis and S. coeruleoalba* (N = 74). Interactions between *D. delphis* and *S. frontalis, S. coeruleoalba* and *S. frontalis* and the three species were four, two and two, respectively. This means that total interactions per species are 80 for *D. delphis*, 78 for *S. coeruleoalba* and only eight for *S. frontalis*. For the same period and observation effort, single-species observations were much higher 1147 for *D. delphis*, 237 for *S. coeruleoalba* and 463 for *S. frontalis*. The three species were tested for normality with Chi-square test and the three species were normally distributed (p-value < 0.05). Only *S. coeruleoalba* showed a positive association with interaction (p-value = 0.0 and residuals = 12).

Table 2.1 – Number of single species observations and observations with interactions between at least two species and number of observed behaviors for observations with interactions between at least two species and for single species observations (values between parenthesis) for species.

Species	Observations of interactions			Behaviors								
	D. delphis	*S. coeruleoalba*	*S. frontalis*	Bow riding	Foraging	Lob tailing	Leaping	Non-identified	Resting and Milling	Socializing	Traveling	Others
D. delphis	1147	74	4	59 (753)	22 (221)	5 (56)	10 (200)	4 (32)	9 (211)	22 (309)	41(591)	0 (21)
S. coeruleoalba	74	237	2	23 (20)	16 (14)	2 (3)	21 (65)	4 (4)	6 (91)	4 (13)	46 (140)	0 (1)
S. frontalis	4	2	463	1 (147)	5 (392)	4 (313)	1 (67)	3 (91)	1 (143)	1 (17)	0 (36)	0 (8)
D. delphis – S. coeruleoalba- S. frontalis	2	2	2									
Total in interactions	80	78	8									

Observed behaviors in interaction varied from general socializing (*D. delphis*: N = 22; *S. coeruleoalba*: N = 4; *S. frontalis*: N = 1), bow riding (*D. delphis*: N = 59; *S. coeruleoalba*: N = 23; *S. frontalis*: N = 1) and foraging (*D. delphis*: N = 22; *S. coeruleoalba*: N = 16; *S. frontalis*: N = 5). *S. coeruleoalba* most common behavior was travelling fast (N = 46) and leaping (N = 21) was also observed (Table 2.1 and Annex F). The observed behaviors without interactions were mainly bow riding (N = 753) and traveling for *D. delphis* (N = 591), for *S. coeruleoalba* traveling (N = 140) and resting and milling (N = 91) and for *S. frontalis* foraging (N = 392) followed by bow riding and lob tailing (N = 313) (Table 2.1 and Annex F). The behaviors that showed a statistical significance between interactions and single species observations and an association with interaction were all for *S. coeruleoalba* and were foraging (*p*-value = 0.0 and residuals = 11), breaching (*p*-value = 0.0 and residuals = 11), lob tailing (*p*-value = 0.0 and residuals = 5), leaping (*p*-value = 0.0 and residuals = 6) and travelling (*p*-value = 0.0 and residuals = 7).

Observations with interaction for *D. delphis* and *S. coeruleoalba* showed in general a higher abundance between 1300 m and 1800 m (N = 46 and N = 60, respectively), although the common dolphin showed a higher range, being observed between depths of 98 m to 1831 m and the striped dolphin only being observed from 443 to 1824 m. For the *S. frontalis* the depths recorded were from 398 m to 1767 m (with one exception at 98 m), whilst being more abundant at 800 m and 1300 m (N = 4) (Figure 2.2 right side). For the observations where no interactions were detected, *D. delphis* sightings were recorded from depths of 11 to 1835 m, with higher frequency in depths ca. 700 m. However, the species, shows a relatively stable presence at all depths, with a peak at 700 m (N = 70). *S. coeruleoalba* sightings were recorded from depths of 652 to 1855 m. The species was more frequent at the interval between 1200 to 1800m, with its higher frequency at 1600 m (N = 37). *S. frontalis* showed a similar depth range, being observed between 197 to 1824 m, but the interval with the highest frequency was between 700 to 1700 m (Figure 2.2 left side), and the depth with more observations was 1400 m (N = 54). The distance to the coast with or without interaction was not found statistically significant for any of the three species (*p*-value > 0.05).

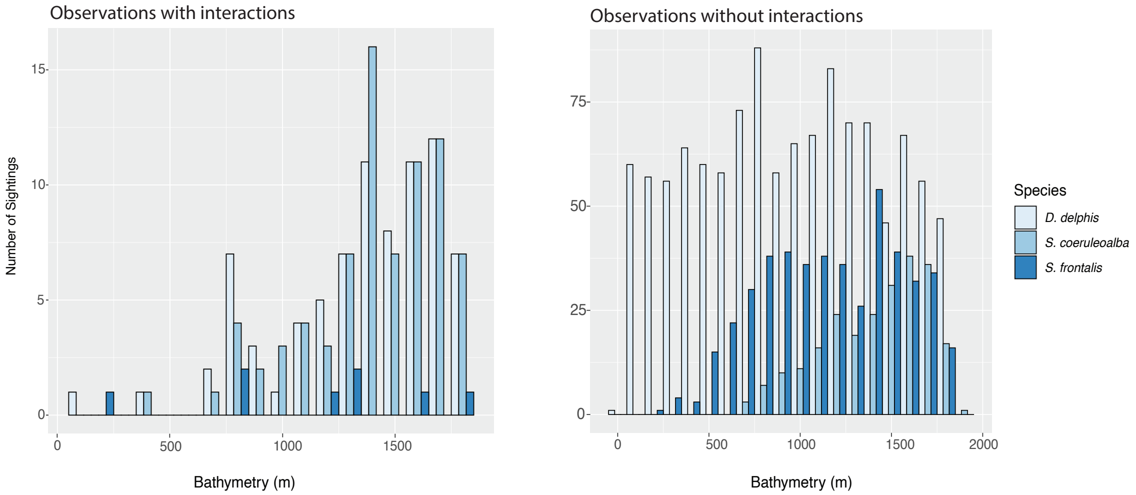

Figure 2.2– Depth range for the three focal species. The X-axis shows the bathymetry in 100m intervals. In the right side there are the observations where interactions between at least two of the target species were sighted and in the left side the observations where no interactions were sighted (single species observations).

Regarding the distance from the coast at which the species were observed with and without interaction, the majority of the sightings with interactions were observed between 0.1 and 10 km from coast (N = 129). Most *D. delphis* sightings occurred between one and eight km (N = 56), with a presence up to 21 km from the shore, *S. coeruleoalba* between two and eleven km (N = 67) being observed up to 22 km from land and *S. frontalis* between one and five km (N = 5) with a maximum presence from the coast of 14 km (Figure 2.3 right side). For the observations without interactions the majority of the sightings were observed between 0.1 and 10 km from shore (N = 1641). With *D. delphis* having about 200 sightings in the first km from the coast and most sightings occurring between one and eight km from the islands (N = 984), being present until 34 km from coast. With *S. coeruleoalba* only appearing first at 2 km from the coast and most sightings occurring in an interval between three and 11 km from coast (N = 196) to 31 km. With *S. frontalis* only appearing after the first km from land and most sightings occurring between two and six km from coast (N = 302) being present until 23 km from shore (Figure 2.3 left side). The bathymetric distribution was statistically significant for all the species between observations with and without interactions, although only for *D. delphis* was associated with interactions (*p*-value = 0.0 and residuals = 9).

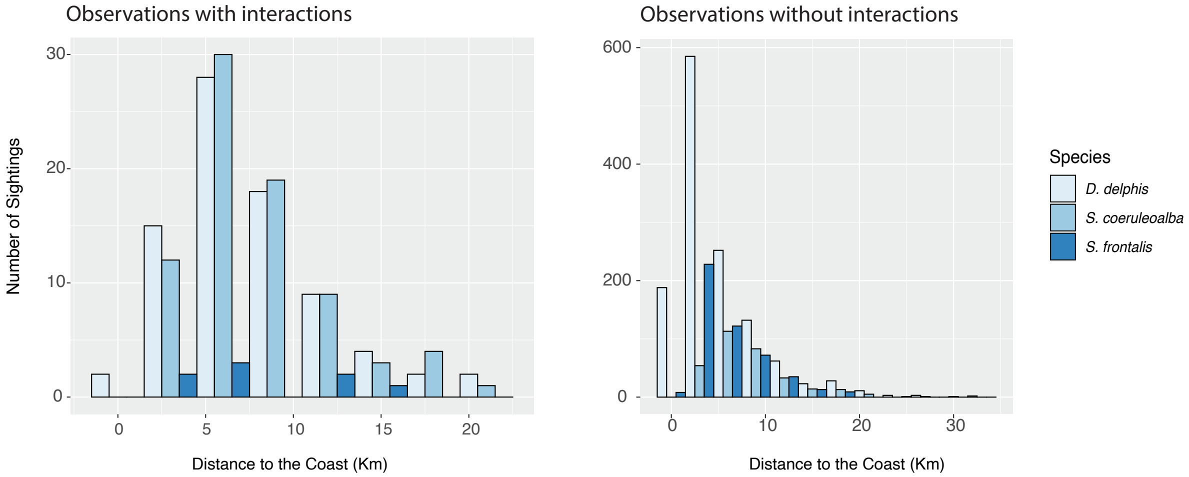

Figure 2.3 - Distance to the coast of observations. In the left side there are the observations where interactions between at least two of the target species were sighted and in the right side the observations where no interactions were sighted (single species observations).

Generally, interactions between *D. delphis* and *S. frontalis* were frequently sighted with calves in the group (*D. delphis* = 41 and *S. frontalis* = 7) with a higher number in the spring. *S. coeruleoalba* was mainly found without calves in the interspecific observations (N = 62). However, the number of calves differed according to the season (Figure 2.4). For *D. delphis* the average number of sightings with calves was lower in the spring and autumn (*D. delphis* = 9 and 6; *S. frontalis* = 1, respectively). While for the *S. coeruleoalba* the presence of calves was similar in the three seasons spring (N = 6) summer and autumn (N = 5) (Figure 4). For the observations with no interactions, generally, *D. delphis* and *S. frontalis* were sighted more frequently with calves in the group (N = 851 and 260, respectively), although *S. coeruleoalba* was mainly found without calves in the group (157. For three species the average number of sightings with calves was higher in the summer (*D. delphis* = 439; *S. coeruleoalba* = 48; *S. frontalis* = 207) when compared with spring and autumn (*D. delphis* = 277 and 135; *S. coeruleoalba* = 18 and 13; *S.*

frontalis = 0 and 53, respectively) (Figure 2.4). For *D. delphis* it is possible to see that, when they are associated with the target species (specially with *S. coeruleoalba*) they are sighted 1.5 less times with calves in the group when compared to when they are in single species groups. In terms of statistical significance just *D. delphis* showed a difference and it was associated with interactions (*p*-value = 0.047 and residuals = 3).

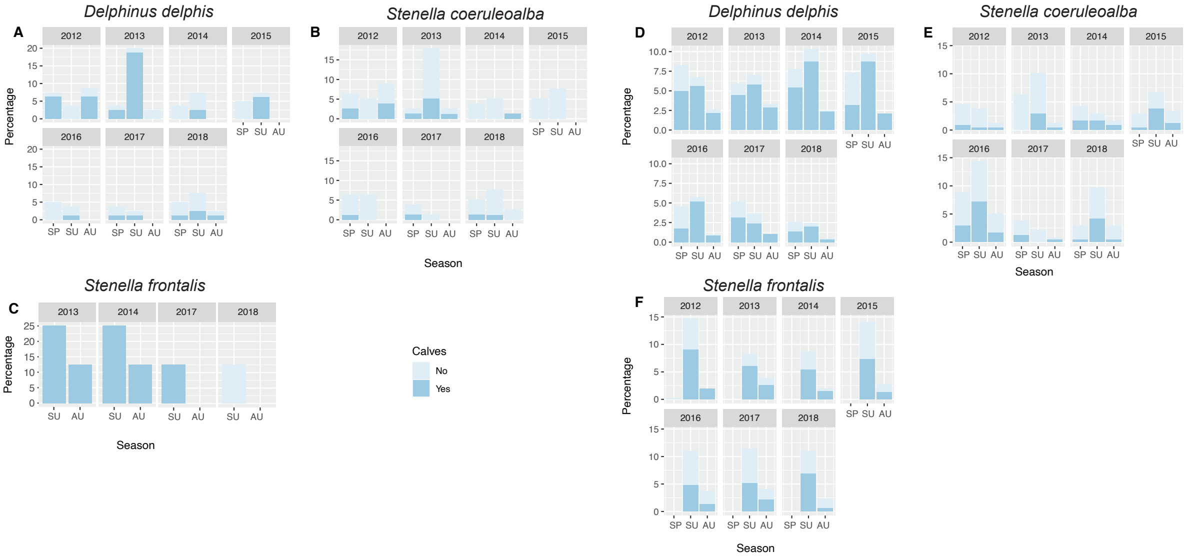

Figure 2.4 - Seasonal percentages of sightings with calves (blue) and without calves (light blue). Panels A, B, C refer to interspecific interactions' observations, and D, E, F, without interactions.

2.5. Discussion

The goal of this study was to access the changes in behavior, depth, distance to coast, and calves' presence for three delphinid species when observed alone or in interspecific association. It was possible to show that the short-beaked common dolphin and the Atlantic spotted dolphin do not tend to associate as much as the striped dolphin and that interspecific association modifies behavior and group composition. Before discussing in detail the results, we will address the caveats of the study. The main limitation of this study is the opportunistic way data was collected which may have influenced the results in several ways: (1) the lookout strategy to detect the individuals influences the species sighted, as some species that are more easily detected than others; (2) the length pre-defined for the whale watching trip (around 2.5 – 3h) can also limit the species sighted, since the whales are always the main focus and because of the time limitation, sometimes it is not possible to go for the area of the dolphins too. Although the act of studying cetaceans also have their own limitations and difficulties, such as the possibility that some individuals are underwater and we are not counting them because they are not in sight (we call them ‘false absences’), resulting in wrong groups sizes countability, surveys only done during good weather conditions and the preference given to whales in comparison to dolphins when doing whale watching trips, as it is possible to observe in the data used, since the total number of observations varied from month to month (Annex 1). And that some behaviors that were and are observed in the dolphin species from the whale watching boats are not the most natural behaviors, since the boat presence has definitely an impact in the individuals, although some of the behaviors observed despite not “natural” are also sometimes observed to happen but with *mysticeti* whales, such the bow riding (Perrin, 2009).

The proportion of mixed-species interactions versus single species observations (with at least two of the target species) was three times higher than the ones calculated in a previous study for the Azores (2%) (Annex B) (Quérouil *et al*., 2008), similar to the values for the Mediterranean Sea (6 – 7%) (Garcia *et al*., 2000; Roussel & Beaubrun, 2000) and lower than the values calculated for the Western South Atlantic (16%) (de Lima *et al*., 2021). The striped dolphin was the most sighted species in interaction (25%), followed by the common dolphin (6%), while the spotted dolphin was rarely seen in association (2%), the rarity of the spotted dolphin interactions is consistent with other studies (Zahn *et al*., 2020; de Lima *et al*., 2021). We posit that because *S. coeruleoalba* is less abundant in the study area if associates more frequently, similar conclusions were obtained in other study about the *D. delphis* in the Mediterranean Sea (Frantzis & Herzing, 2002). These results suggest that despite differences in abundance of the common dolphin in the Mediterranean and in the Azorean waters, the inter-specific interactions seem to have the same importance in both regions.

Consistent with our results, *Delphinus delphis* is the most sighted of the three species being observed all year-round (Silva *et al*., 2003; Quérouil *et al*., 2008; Silva *et al*., 2013; Gonzalez García, 2019; Zahn *et al*., 2020), in the Azorean Archipelago. It is possible that *Stenella coeruleoalba* is also present throughout the year as proposed by previous studies (Silva *et al*. 2013, Gonzalez García, 2019) with an increasing of sightings during the warmer months. In contrast, *Stenella frontalis* is a seasonal species with increased abundances synchronized with the increase of the ocean temperature in the Azores mostly during the summer months (Silva *et al*. 2013;

Najarro, 2020) (Annex D). Although this study span March to November, there were no observations with interactions during March, and *Stenella frontalis* was only observed interacting between July and September, the months of higher species abundance (Annex C and D).

The data showed that the behavior of the common and the Atlantic spotted dolphins is not influenced by the presence of other species. However, the striped dolphin is affected by the presence of other species which play an important influence in the behavior, specially increasing their foraging activity. This suggests that in the Azores, the main driver for the striped dolphin interaction with other cetaceans is food-related, probably to increase the foraging activity, as it was also concluded in other dolphin study (Quérouil *et al.*, 2008) and for dolphins and whales' interaction (Rossi-Santos *et al.*, 2009). In contrast, the interaction between these two species in the Alboran Sea occurs for social reasons and not for feeding purposes (Garcia *et al.*, 2000), although it was not significant the differences between interspecific association and single species socializing behaviors. It is possible that the results observed in the Azores may be due to the abundance of large fish schools, that have already been associated with the formation of mixed-species associations since they favor the cooperative foraging activity (Bearzi 2006; Gowans *et al.*, 2007).

The depth range observed for the observations and without interactions was approximately the same (11 to 1855 m and 98 to 1831 m, respectively), in this study area (the south of the Pico Island) the depth increases rapidly in the first two km from the coast reaching around the 2000 m of depth (Mitchell *et al.*, 2012; Tempera *et al.*, 2012), due to the lack of continental shelf. For the observations without interactions, the common dolphin showed a preference for shallower waters, differently from the striped and Atlantic spotted dolphins (Figure 2.2 and Figure 2.3) (Cañadas *et al.*, 2002; Silva *et al.*, 2003; Quérouil *et al.*, 2008). The preference from the common dolphin for closer to shore waters might be related to the high abundance of fish preys in these locations during nighttime, as a result of the diurnal vertical migrations (Archer & Perrin, 1999; Neumann and Orams, 2005; Archer, 2018) (Annex G), which can suggest that the common dolphin might approach the coast at night to feed (being seen still close to the shore during the day), with this possibly being a form to avoid the food competition with the Atlantic spotted dolphin (food competition already observed and studied (Silva *et al.*, 2013)) that it is known to be a more offshore species (Silva *et al.*, 2003; Quérouil *et al.*, 2008). Although for the observation with interaction (always with the common dolphin), both the striped and the Atlantic spotted dolphins were found more closer to the coast and in shallow waters, these findings are consistence with previous studies (Garcia *et al*., 2000; Quérouil *et al*., 2008), although only for the common dolphin these differences were statistically significant. This suggests that the common dolphin is modifying their habitats to follow the striped dolphin or that they are interacting when coming to coastal waters. In some areas it was concluded that the shallower waters draw cetaceans since they are an area of local upwelling, such as the California Bay (Bearzi, 2006).

The groups of common dolphins for the observations without interactions were considerably smaller than the striped and spotted dolphins' groups and showed a lower presence of calves than the other two species (Annex E). Although when analyzing the observations with interactions, common dolphins were present in much higher numbers than the other two species, also having a higher presence of calves than the other two species, as also seen in other study (Quérouil *et al*., 2008) and in contrast to what it was observed in the Gulf of Corinth (Frantzis and Herzing, 2002). The differences between observations with and without interactions for the presence of calves and the group composition where only statistically significant for the common dolphin, which allows us to assume that for the striped and the spotted dolphin the presence of calves does not seem to have a direct influence in the creation of interactions, our results indicate that differently from what was concluded in a previous study (Quérouil *et al*., 2008) for the common dolphins that can be the main driver for these associations. Allowing us to conclude that in accordance with what was seen in another study (Frantzis & Herzing, 2002) for the common dolphin the driver might be the social benefits that come with the larger group size. Although it has been proven that the common dolphin increases the group size when feeding in a varied type of fish (Gygax, 2002), so the hypothesis of the increase of foraging activity cannot be left aside definitely, however these two species have different diets (Bearzi *et al*., 2016).

In summary, the data indicates that these interactions are rare in the study area, and that when they happen the habitat appears to have a key role in promoting the interactions, with the main driver for the interactions changing from species to species. The common dolphin appears to be driven by social reasons (to increase the group size), the striped dolphin appears to be driven by foraging reasons and the spotted dolphin did not show a tendency to associate at all. This different responses of the three species serve to support and enhance the dolphin's ability to adapt to their environment, that is constantly suffering anthropogenic pressures mainly by overfishing, climate change and ocean acidification. The results also allow us to emphasize that despite the known benefits that these interactions might bring for the species involved, some drawbacks are also a possibility, such as the chance for interspecific sexual interactions that might end in hybridization, that it is known that can have negative impacts in the fitness of the hybrid offspring.

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Annexes

Annex A: Interactions among cetaceans

Table A – Already observed interactions between marine mammals. Adapted from Jefferson et al., 1991.

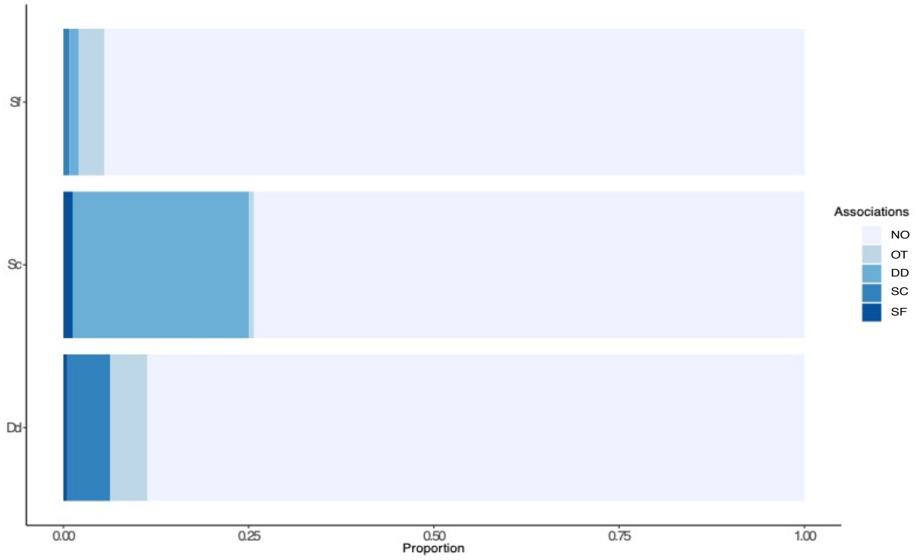
Family	Species	Interactions	References
Delphinidae	Atlantic spotted dolphin (*Stenella frontalis*)	Risso's dolphin; Striped dolphin; Common dolphin; Bottlenose dolphin; Sei whale	Herzing & Johnson, 1997; Clua & Grosvalet, 2001; Herzing *et al*., 2003; Quérouil *et al*., 2008; Melillo *et al*., 2009; Bacon *et al*., 2017; Zahn *et al*., 2020; de Lima *et al*., 2021
	Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	Long-finned pilot whale; Orca	Jefferson *et al*., 1991; Baraff & Asmutis-Silvia, 1998
	Bottlenose dolphin (*Tursiops truncatus*)	Risso's dolphin; Humpback whale; Harbour porpoise; Atlantic spotted dolphin; Estuarine dolphin; Commerson's dolphin; Common dolphin; Orca; Striped dolphin; Long-finned pilot whale; False orca; Rough-toothed dolphin; Melon-headed whale; Minke whale; Short-finned pilot whale; Spinner dolphin; Pantropical spotted dolphin; Dusky dolphin	Jefferson *et al*., 1991; Ross & Wilson, 1996; Herzing & Johnson, 1997; Clua & Grosvalet, 2001; Herzing *et al*., 2003; Wedekin *et al*., 2004; Bearzi, 2005; Quérouil *et al*., 2008; Coscarella & Crespo, 2009; Melillo *et al*., 2009; Rossi-Santos *et al*., 2009; Deakos *et al*., 2010; Bacon *et al*., 2017; Zahn *et al*., 2020; de Lima *et al*., 2021
	Clymene dolphin (*Stenella clymene*)	Pantropical spotted dolphin	Rossi-Santos *et al*., 2009
	Commerson's dolphin (*Cephalorhynchus commersonii*)	Bottlenose dolphin	Coscarella & Crespo, 2009
	Common dolphin (*Delphinus delphis*)	Risso's dolphin; Bottlenose dolphin; Striped dolphin; Orca; Atlantic spotted dolphin; Sperm whale; Long-finned pilot whale	Jefferson *et al*., 1991; Barlow, 1995; Clua & Grosvalet, 2001; Cañadas *et al*., 2002; Frantzis & Herzing, 2002; Cañadas & Hammond, 2008; Quérouil *et al*., 2008; Bearzi *et al*., 2016; Koper & Plön, 2016; Bacon *et al*., 2017; 2021; Zahn *et al*., 2020; Braulik *et al*.*;* de Lima *et al*., 2021
	Dusky dolphin (*Lagenorhynchus obscurus*)	Orca; Bottlenose dolphin; Short-finned pilot whale; Spinner dolphin; Pantropical spotted dolphin	Jefferson *et al*., 1991; Bearzi, 2005
	Estuarine dolphin (*Sotalia guianensis*)	Bottlenose dolphin	Wedekin *et al*., 2004
	False orca (*Pseudorca crassidens*)	Orca; Bottlenose dolphin	Jefferson *et al*., 1991; Zahn *et al*., 2020; de Lima *et al*., 2021
	Indian Ocean humpback dolphin (*Sousa plumbea*)	Bottlenose dolphin; Southern right whale	Koper & Plön, 2016

	Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	Indian Ocean humpback dolphin; Southern right whale	Koper & Plön, 2016
	Indo Pacific humpback dolphin (*Sousa chinensis*)	Orca	Jefferson *et al*.,1991;
	Orca (*Ornicus orca*)	Long-finned pilot whale; Blue whale; Fin whale; Sei whale; Bryde's whale; Minke whale; Humpback whale; Bowhead whale; Northern right whale; Southern right whale; Grey whale; Sperm whale; Arnoux's beaked whale; Northern bottlenose whale; Southern bottlenose whale; Cuvier's beaked whale; Narwhal; White whale; False orca; Risso´s dolphin; Common dolphin; Spinner dolphin; Dusky dolphin; White-beaked dolphin; Atlantic white-sided dolphin; Pacific white-sided dolphin; Bottlenose dolphin; Indo-Pacific humpback dolphin; Dall´s porpoise; Harbour porpoise; Short-finned pilot whale; Pantropical spotted	Jefferson *et al*., 1991; Bearzi, 2005; Curé *et al*., 2012
	Long-finned pilot whale (*Globicephala melas*)	Atlantic white-sided dolphin; Orca	Jefferson *et al*.,1991; Baraff & Asmutis-Silvia, 1998; Cañadas *et al*., 2002; Curé *et al*., 2012; Braulik *et al*., 2021
	Melon-headed whale (*Peponocephala electra*)	Bottlenose dolphin; Rough-toothed dolphin	Rossi-Santos *et al*., 2009
	Pacific-white-sided dolphin (*Lagenorhynchus obliquidens*)	Risso´s dolphin; Orca;	Jefferson *et al*.,1991; Bacon *et al*., 2017
	Pantropical spotted dolphin (*Stenella attenuata*)	Spinner dolphin; Clymene dolphin; Short-finned pilot whale; Bottlenose dolphin; Dusky dolphin; Orca;	Au & Perryman, 1985; Bearzi, 2005; Ballance *et al*., 2006; Rossi-Santos *et al*., 2009; de Lima *et al*., 2021
	Risso´s dolphin (*Grampus griseus*)	California sea lion; Bottlenose dolphin; Common dolphin; Striped dolphin; Orca	Jefferson *et al*.,1991; Cañadas *et al*., 2002; Frantzis & Herzing, 2002; Bearzi *et al*., 2016; Bacon *et al*., 2017; Zahn *et al*., 2020; de Lima *et al*., 2021
	Rough-toothed dolphin (*Steno bredanensis*)	Melon-headed whale; Bottlenose dolphin; Minke whale	Rossi-Santos *et al*., 2009
	Short-finned pilot whale (*Globicephala macrorhynchus*)	Pantropical spotted dolphin	Bearzi, 2005
	Spinner dolphin (*Stenella longirostris*)	Orca; Pantropical spotted dolphin; Botllenose dolphin; Short-finned pilot whale; Dusky dolphin;	Au & Perryman, 1985; Jefferson *et al*., 1991; Bearzi, 2005; Ballance *et al*., 2006; de Lima *et al*., 2021

	Striped dolphin (*Stenella coeruleoalba*)	Risso´s dolphin; Common dolphin; Atlantic spotted dolphin; Bottlenose dolphin	Barlow, 1995; Clua & Grosvalet, 2001; Cañadas *et al*., 2002; Frantzis & Herzing, 2002; Cañadas & Hammond, 2008; Quérouil *et al*.,2008; Bearzi *et al*., 2016; Bacon *et al*.,2017; Zahn *et al*., 2020; Braulik *et al*., 2021
	White-beaked dolphin (*Lagenorhynchus albirostris*)	Orca	Jefferson *et al*.,1991;
Balaenopteridae	Blue whale (*Balaenoptera musculus*)	Risso's dolphin; Orca	Jefferson *et al*.,1991; Bacon *et al*.,2017
	Bryde's whale *(Balaenoptera brydei*)	Orca	Jefferson *et al*.,1991;
	Fin whale (*Balaenoptera physalus*)	Risso's dolphin; Orca	Jefferson *et al*.,1991; Bacon *et al*.,2017
	Humpback whale (*Megaptera novaeangliae*)	Risso´s dolphin; Bottlenose dolphin; Orca	Jefferson *et al*.,1991; Rossi-Santos *et al*., 2009; Deakos *et al*., 2010; Koper & Plön, 2016; Bacon *et al*., 2017
	Minke whale (*Balaenoptera acutorostrata*)	Risso's dolphin; Orca; Bottlenose dolphin; Rough-toothed dolphin;	Jefferson *et al*.,1991; Rossi-Santos *et al*., 2009; Bacon *et al*.,2017;
	Sei whale (*Balaenoptera borealis*)	Orca; Atlantic Spotted dolphin	Jefferson *et al*.,1991; Zahn *et al*., 2020
Balaenidae	Bowhead whale (*Balaena mysticetus*)	Orca	Jefferson *et al*.,1991;
	Northern right whale (*Eubalaena glacialis*)	Orca	Jefferson *et al*.,1991;
	Southern right whale (*Eubalaena australis*)	Indian Oceanbumpback dolphin; Orca	Jefferson *et al*., 1991; Koper & Plön, 2016
Eschrichtiidae	Grey whale (*Eschrichtius robustus*)	Risso's dolphin; Orca	Jefferson *et al*., 1991; Bacon *et al*., 2017
Physeteridae	Sperm whale (*Physeter macrocephalus*)	Risso's dolphin; Orca; Common dolphin	Jefferson *et al*., 1991; Bacon *et al*., 2017; Zahn *et al*., 2020
Ziphiidae	Armour´s beaked whale (*Berardius arnuxii*)	Orca	Jefferson *et al*.,1991;
	Cuvier's beaked whale (*Ziphius cavirostris*)	Orca	Jefferson *et al*.,1991;
	Northern bottlenose whale (*Hyperoodon ampullatus*)	Orca	Jefferson *et al*.,1991;
	Southern bottlenose whale (*Hyperoodon planifrons*)	Orca	Jefferson *et al*.,1991;
Monodontidae	Narwhal (*Monodon monóceros*)	Orca	Jefferson *et al*.,1991;
	White whale (*Delphinapterus leucas*)	Orca	Jefferson *et al*.,1991;
Phocoenidae	Dall's porpoise (*Phocoenoides dalli)*	Orca	Jefferson *et al*.,1991;
	Harbour porpoise (*Phocoena; phocoena*)	Bottlenose dolphin; Orca	Jefferson *et al*.,1991; Ross & Wilson, 1996;

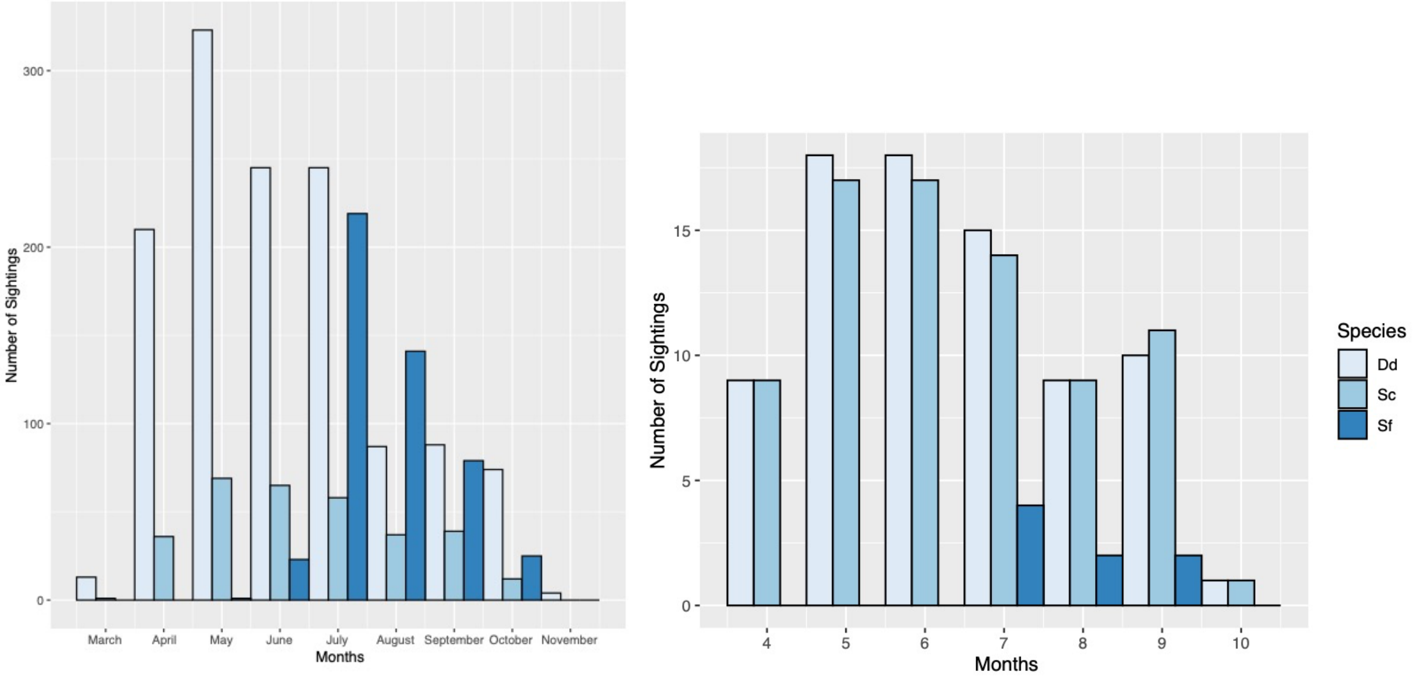
Otariidae	California sea lion (*Zalophus californianus*)	Risso´s dolphin	Bacon *et al*., 2017

Annex B: Associations



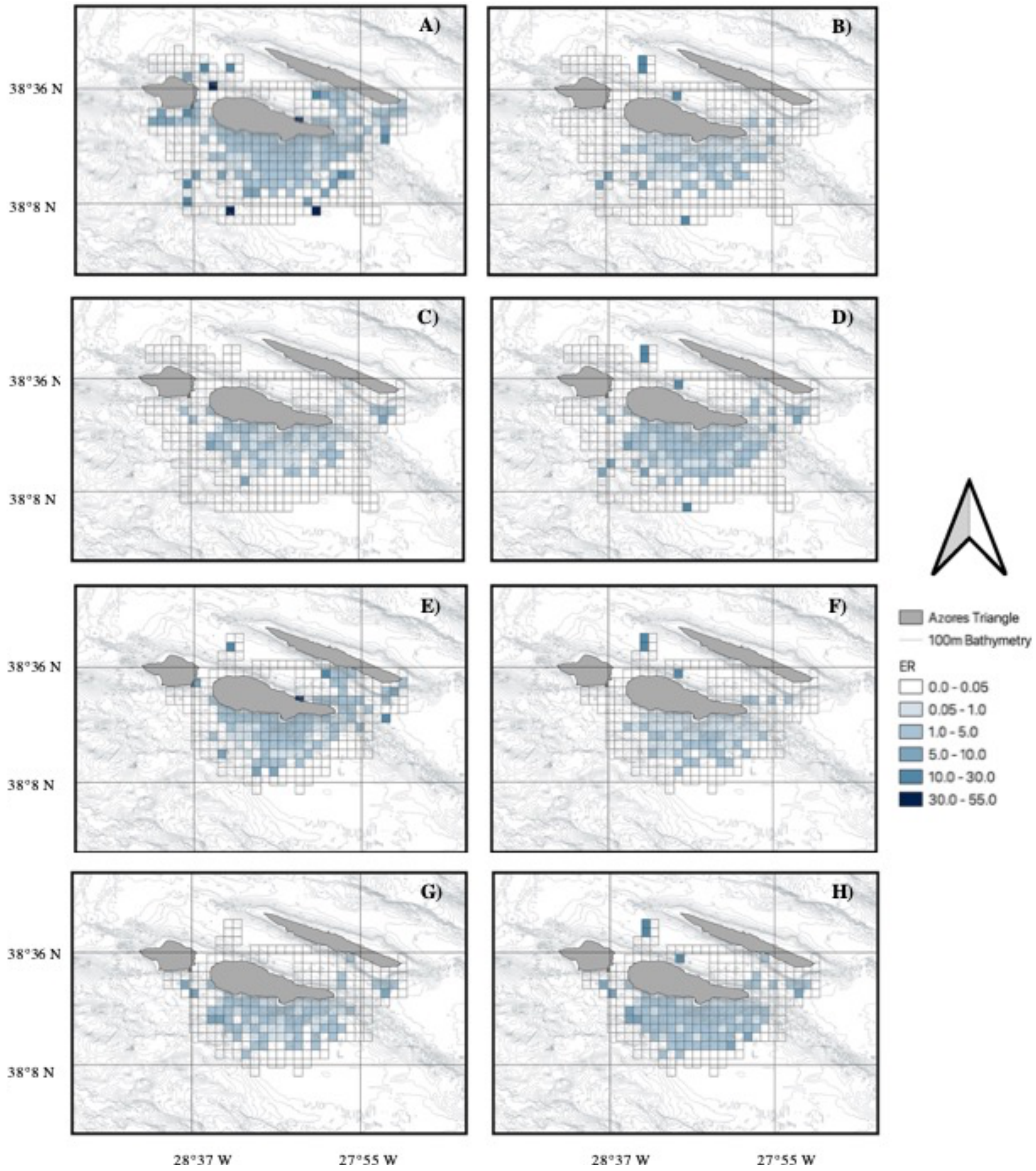
Annex B - Proportion of interactions between the three target species (Sf – *Stenella frontalis*; Sc – *Stenella coeruleoalba*; Dd – *Delphinus delphis*), no interactions (NO) and other species (OT).

Annex C: Sightings



Annex C – Number of monthly sightings during the seven years of study. Dd: *Delphinus delphis;* Sc: *Stenella coeruleoalba;* Sf: *Stenella frontalis*. Right side: Observations without interaction; Left side: Observations with interactions.

Annex D: Encounter Rates



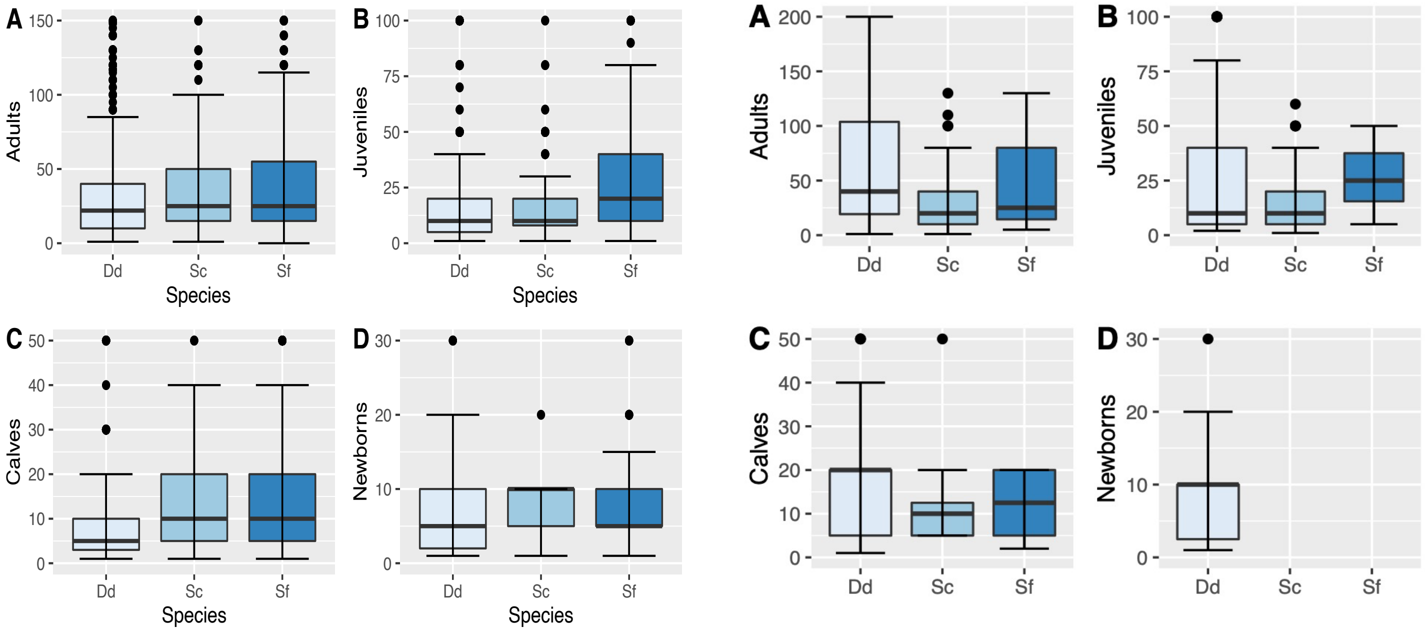
Annex D - Map of the Azores Triangle, which includes some islands from the Central Group, such as Pico, Faial and São Jorge Islands. The bathymetry is represented by an isobath of 100m and the squares in blue tones represent the Encounter Rate (ER) for each species, in A) we have the *Delphinus delphis*, in B) *Stenella coeruleoalba*, in C) *Stenella frontalis,* in D) *Stenella coeruleoalba* and *Stenella frontalis* together, E) *Delphinus delphis* with the data reduced to when the SST was above 19°C, F) *Stenella coeruleoalba* with the data reduced to when the SST was above 19°C, G) *Stenella frontalis* with the data reduced to when the SST was above 19°C and H) *Stenella coeruleoalba* and *Stenella frontalis* with the data reduced to when the SST was above the 19°C.

As a broader perspective of the ER analysis (all effort and sightings and all effort and sightings above 19°C), the ER for each 100 km was calculated, as showed in Table D:

Table D – Number of sightings and estimated encounter rates (ER) for the three focal species. The species encounter rates were calculated through the division of the number of sightings by the survey effort (100 km). ER = N/837.86 and ER (≥ 19°C) = N(≥ 19°C)/570.27

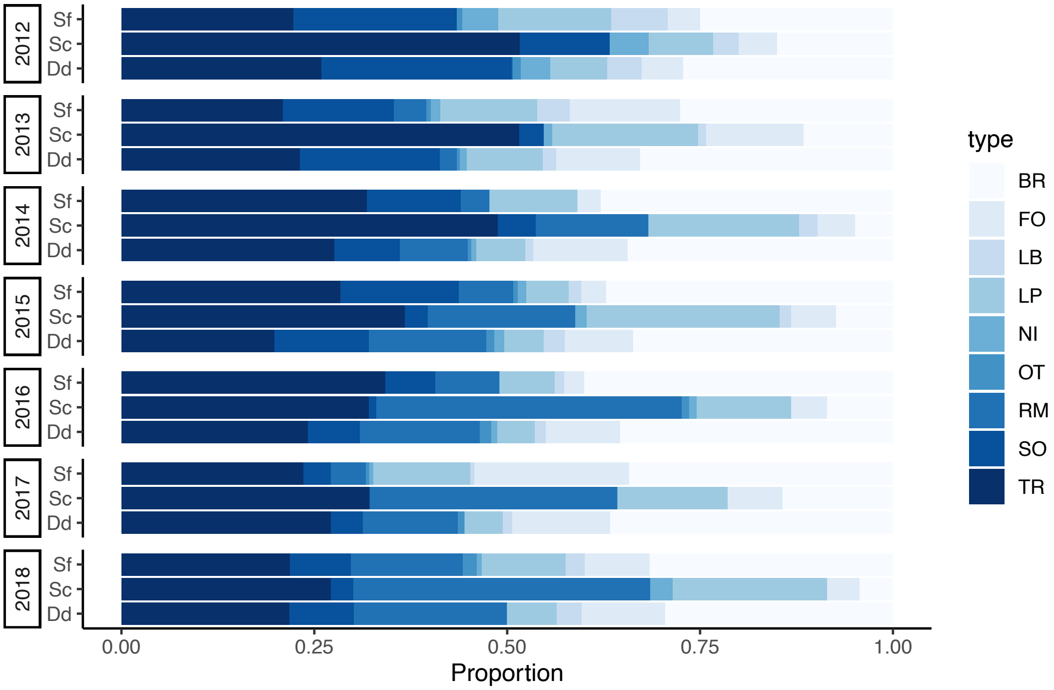
Species	*N*	ER	*N* (≥ 19°C)	ER (≥ 19°C)
Delphinus delphis	1289	1.538	707	1.239
Stenella coeruleoalba	317	0.378	204	0.357
Stenella frontalis	488	0.582	487	0.854
Stenella coeruleoalba + *Stenella frontalis*	805	0.961	691	1.212

Annex E: Group Size and Structure



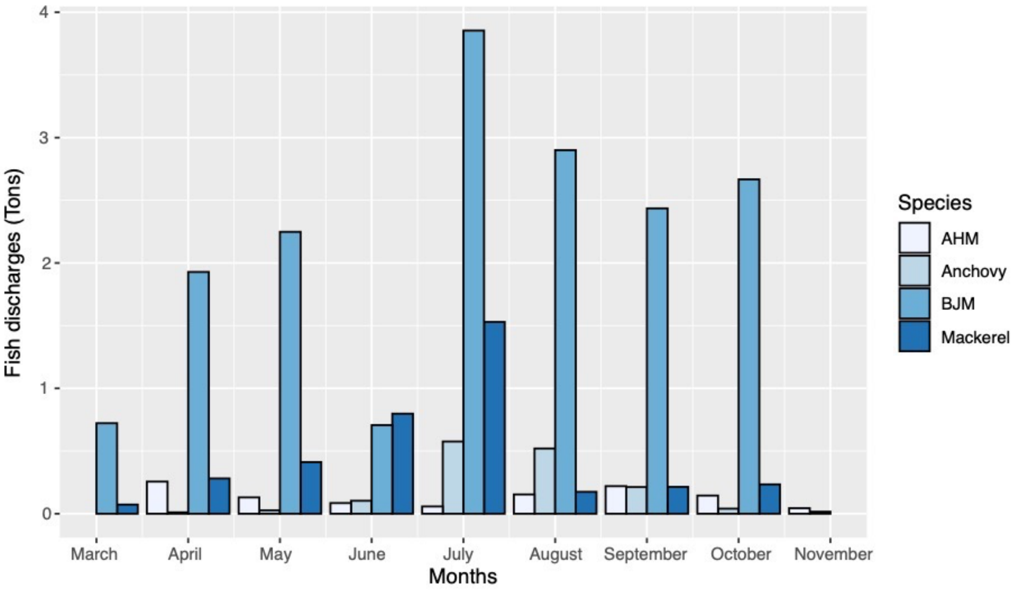
Annex. E – Number of individuals per species group (*Delphinus delphis*, *Stenella coeruleoalba*, *Stenella frontalis*) of each age class: A) adults; B) juveniles; C) calves and D) newborns. Right side: Observations without interaction; Left side: Observations with interactions.

Annex F: Behavior



Annex F – Annual proportions of behaviors for each species, *Stenella frontalis* (Sf), *Stenella coeruleoalba* (Sc) and *Delphinus delphis* (Dd). Bow riding (BR), foraging (FO), lob tailing (LB), leaping (LP), non-identified (NI), others (OT), resting and milling (RM), socializing (SO) and travelling (TR).

Annex G: Diets



Annex G - Mean monthly catches (in tons) for the Pico Island, of the main prey items of the target species. AHM: Atlantic Horse Mackerel, Anchovy, BJM: Blue Jack Mackerel and Mackerel.