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Movements of short-finned pilot whales (*Globicephala macrorhynchus*) in the Macaronesian biogeographical region: a photo-identification analysis

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Declaração de autoria de trabalho

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

____ (Anita Alessandrini)

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ABSTRACT

The short-finned pilot whale, *Globicephala macrorhynchus* Gray (1846), is a marine mammal species from the family Delphinidae. It is a top predator species, with a circumglobal distribution from warm-temperate to tropical regions, at varying distances from shore, including the Macaronesia region (NE Atlantic). Population connectivity can profoundly influence the distribution, persistence and ecological impact of local marine mammal species. Understanding population connectivity and its environmental drivers is critical for effective wildlife conservation and management, namely in a context of increased marine pollution associated to toxic contaminants, ocean noise and disruption of natural food webs. The aim of this study was to compare *Globicephala macrorhynchus* individuals within the Macaronesian' archipelagos. It includes data (digital photographs) from Madeira between 2003 and 2015, from Azores between 1999 and 2015, from the Canary Islands between 1993 and 2015, and from Cape Verde in 2006. This thesis represents the first study comparing individuals from this species within the four archipelagos of the Macaronesia. In this thesis, the method used to study the animals' connectivity was photo-identification, which is based on the analyses of natural markings in dorsal fins. The dorsal fins were cropped from photographs and were matched to available photo-identification catalogues for *G. macrorhynchus* from Madeira and photos from the other archipelagos not catalogued yet. The comparison was made by eyes using image softwares, based on the number of nicks and notches in the dorsal fin of the different individuals. Results showed that 19 short-finned pilot whales were matched, being 11 individuals between Azores and Madeira, and eight individuals between Canaries and Madeira. Of these, 69% were categorized with a residency status of "transient", 26% of "resident", and 5% of "visitors". This thesis supports the importance of the Macaronesia region for this species, and highlights the need for common conservation policies across different archipelagos/countries.

Key words: Photo identification, *Globicephala macrorhynchus*, population connectivity, Macaronesian biogeographical region, individual distribution patterns

RESUMO EXECUTIVO

Os cetáceos (do latim *Cetus* "baleia" e do grego *Ketos* "enorme peixe") incluem 87 espécies de golfinhos, baleias e botos, e com uma grande variabilidade de comprimento, que vai de 1.5 a 33 metros. Os cetáceos marinhos têm dois tipos de aparelho digestivo, barbatanas e dentes: Odontoceti (baleias/golfinhos com dentes) e Mysticeti (baleias com barbas). Neste caso, irei focar-me nos Odontocetes, que normalmente são agregados em grupos, também conhecidos como *pods*, em que a estabilidade da estrutura do grupo é principalmente fornecida por laços entre mães e filhos, e de facto, os grupos são formados principalmente pelas mães e as respetivas crias. Geralmente os mamíferos marinhos são os principais consumidores na maioria dos níveis tróficos: desde zooplâncton a peixes predadores, sendo que alguns deles podem também alimentar-se de outros mamíferos marinhos. Conhecer os mamíferos marinhos é o primeiro passo para a sua conservação, sendo ainda mais importante no caso de algumas espécies que estão em risco de extinção devido à atividade humana (por exemplo, a sobrepesca de presas de cetáceos e a pesca de alguns mamíferos marinhos).

A recente alteração natural e antropogénica do habitat coloca as espécies em risco. Além disso, este clade está em perigo porque se a população começar a diminuir, eles terão dificuldade em recuperar devido à sua maturidade sexual numa idade tardia e ao pequeno número de juvenis que a fêmea pode dar à luz (Perrin et al., 2009). A espécie levada em consideração durante este projeto de tese foi a baleia-piloto-tropical, *Globicephala macrorhynchus* (Gray 1846), que é uma espécie de mamíferos marinhos da família Delphinidae. Pode atingir um comprimento médio de seis metros, com um corpo robusto, uma cauda espessa e uma barbatana dorsal larga. No que diz respeito ao mergulho, pode atingir profundidades entre 1000 e 1300 metros com uma duração de mergulho de 21 a 27 minutos. *Globicephala macrorhynchus* é uma das principais espécies de predadores, com uma distribuição global que vai desde regiões temperadas a regiões tropicais, a diferentes distâncias da costa, incluindo a região biogeográfica da Macaronésia (NE Atlântico), que é conhecida por incluir os quatro arquipélagos vulcânicos, de norte para sul: Açores, Madeira, Canárias e Cabo Verde (Fernández-Palacios et al., 2011). A conectividade em subpopulações geograficamente separadas influência profundamente a distribuição, persistência e impacto ecológico das espécies de mamíferos marinhos locais. Compreender a conectividade da população e as influências ambientais é fundamental para a conservação da vida selvagem e gestão eficazes, devido ao perigo que esta espécie tem passado: perigo vindo da captura direta até aos anos 80 (Kasuya et al., 1984), captura acidental, especialmente durante a pesca do atum e do espadarte (Forney et al., 2007), poluição química, como POPs e DDT que se podem acumular nos músculos e tecidos blubber causando um impacto negativo (Dam et al., 2000). Para além disto, há a poluição sonora e energia acústica, que pode ser ou não intencional, como o sonar e a exploração sísmica e a propulsão do navio, respetivamente (Nowacek et al., 2007). Além disso, o cativeiro tem um impacto importante em *G. macrorhynchus* (Reeves, 1984) e na ruptura das cadeias alimentares naturais. O objetivo deste estudo foi organizar e atualizar um catálogo de foto identificação de *G. macrorhynchus* na Madeira (32 ° 45 'N / 016 ° 57' W), reunindo outras informações de foto-identificação existentes coletadas de diferentes organizações individuais, universidades e empresas de observação de baleias, entre 2003 e 2015 dos Açores (37 ° 44 'N / 025 ° 40' W), entre 1993 e 2015 das Ilhas Canárias (28 ° 17 'N / 016 ° 37' W), e em 2006 de Cabo Verde (14 ° 18'N / 022 ° 26'W). Após um estudo preliminar de foto-identificação de *G. macrorhynchus* efetuado entre as Ilhas Canárias e a Madeira em 2007, esta tese representa o primeiro estudo a comparar indivíduos dos quatro arquipélagos. O estudo dos cetáceos é difícil, uma vez que eles podem movimentar-se rapidamente e passar grande parte do seu tempo debaixo de água (Perrin et al., 2009). Várias técnicas são usadas para estudar a conetividade em populações de cetáceos marinhos, entre as quais, experiências de monitorização de marcação e recaptura, genética de populações e foto-identificação, sendo este último o método utilizado neste projeto. Esta técnica é baseada na análise de marcas naturais em barbatanas dorsais para identificação individual (e.g., incisões, arranhões, cicatrizes, formação de cristas dorsais, padrões de pigmentação e padrões de calosidade), e foi anteriormente aplicada a *G. macrorhynchus* para avaliar a organização social, a estrutura populacional e de residência e os padrões de movimento em vários arquipélagos. Para o presente estudo, as barbatanas dorsais foram analisadas a partir de fotografias obtidas e comparadas com catálogos de foto-identificação disponíveis de *G. macrorhynchus* da Madeira e fotografias não catalogadas dos outros arquipélagos. A comparação das barbatanas destes animais foi feita visualmente, considerando-se o número de cortes, entalhes e arranhões. Os resultados obtidos durante este projecto demostram que indivíduos desta espécie movem-se dentro da área de estudo (baseado em 19 indivíduos identificados em diferentes arquipélagos), em particular entre as Ilhas Canárias e a Madeira (n=8), e entre os Açores e a Madeira (n=11). Embora não tenham sido encontrados movimentos de *G. macrorhynchus* entre os restantes arquipélagos estudados, não podemos ter certeza de que não estiveram presentes naqueles locais pelos seguintes motivos: é possível a presença de erros, em alguns casos os dados eram escassos e devido a um período de comparação pouco longo. Sem essas variáveis, pode haver maior probabilidade de ter *G. macrorhynchus* a corresponder também com outros arquipélagos da área estudada, por isso, seria interessante ter mais dados para comparar e, assim, adquirir um conhecimento completo e um melhor estudo do movimento da *G. macrorhynchus* na área de estudo. Este estudo sobre o movimento de *G. macrorhynchus* pode ajudar no conhecimento das espécies, da sua biologia e gestão da conservação.

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1. INTRODUCTION

1.1 Marine Mammals

Marine mammals include a varied group of aquatic mammals that inhabits the ocean as well as other marine ecosystems. It is divided in three orders: Cetacea and Sirenia, which lives exclusively in an aquatic environment, and Carnivora, which includes species that divides their life between land and water (e.g., polar bears, otters and pinnipeds) (Richardson et al., 2013). Cetaceans include approximately 87 species of dolphins, whales and porpoises (Hoyt, 2012) with a large variability in length, from 1.5 up to 33 meters. They inhabit marine ecosystems, and some species can also live in riverine systems. Like terrestrial mammals, marine cetaceans are air-breathing homeotherms and can live in a wide temperature range, from 2°C to over 30°C (Perrin et al., 2009).

Marine cetaceans have two types of feeding apparatus, baleen and teeth, based on the two suborders divided in: Mysticeti (baleen whales) and Odontoceti (toothed whales) (Milinkovitch et al., 1994). Baleen are used by the biggest whale species to filter prey from the water column, or in some cases from the benthic area, mainly for zooplankton organism's predation, while teeth apparatus is used to directly catch the prey. Depending on the number of the teeth, they can be suction feeders or grasp individual preys (Balance, 2002). The main preys caught by Odontoceti are fishes, mollusks (such as squids and cephalopods), and crustaceans (mainly shrimps). Moreover, cetaceans have physiological adaptations for deep long dives, and this allows the predation of deep sea prey (Bowen et al., 1999). Prey distribution plays a relevant role in the individual's social strategy; many cetaceans are located and associated with prey's abundant and location (Balance, 2002).

Most marine ecosystems are inhabited by cetaceans, but their distribution patterns vary between Families. Baleen whales have been found all around the globe in tropical, polar and temperate waters, while most of toothed whales are distributed in tropical and temperate waters of North and South hemispheres; some subspecies can be found also in the major rivers of India and Pakistan (Perrin et al., 2009).

Odontocetes usually aggregate into groups, also designated pods, and the stability of the group structure is mostly provided by mother-calf bonds; in fact, groups are mainly formed by females with their young (Tyack, 1986). Resource availability also influences the creation of groups and interactions; if the competition for resources between members of the same group is high, then they will probably aggregate into smaller groups (Gowans et al., 2007).

In general, marine mammals are the major consumers at most trophic levels: from zooplankton's organisms to predatory fish and, depending on the size, they can even feed on other marine mammals. The study of these animals, including their behavior, ecology and diet is therefore important because marine mammal can be used to evaluate the impact of their predation on prey populations and community structure (Bowen et al., 1997).

Different marine mammals are at risk of extinction mainly because of human activity (e.g., overfishing of cetacean's prey and harvesting of few marine mammal's species), recent natural and anthropogenic habitat alteration makes species at risk. Moreover marine mammals will have difficulty to recover if the population starts to decrease due to the animal's sexual maturity at a late age and to the low birthing rate (Perrin et al., 2009).

1.2 Population structure and connectivity in cetaceans

A peculiarity of cetaceans is that they are likely to form aggregations for two main reasons: feeding, by helping each other to raise prey's abundance resources, and protection. In fact, pods are necessary to protect members from predation, and also to increase the chance to detect a predator (Perrin et al., 2009). The difference on the spaces used by cetaceans is due to habitat physical characteristics, to risk factors, which can be anthropogenic or natural and also due to other different conditions that can change the distribution of animals (Hauser, 2006). Individuals in a pod travel always together, even though a pod can travel alone or sometimes, with other pods (Hauser et al., 2007). Regarding the interaction between individuals, cetacean's social strategies vary depending on sex and age. For example, adult females usually allocate a lot of energy during the lactation and gestation of the juvenile, so her distribution is often related to high food resources, while males are not involved on parental cares and allocate a large fraction of energy searching for mates (Gowans et al., 2007).

Population connectivity includes different aspects related to dispersal, migration (Baguette et al., 2007), population's genetic structure developed (Kool et al., 2011), and responses to climate change (Munday et al. 2009; Wasserman et al., 2012). Research on the connectivity between populations can define what constitutes a subpopulation or a patch (Kool et al., 2013). The study and understanding of the population connectivity between cetaceans and their environmental drivers is truly important for their conservation and management. An indirect type of threat is the increase of marine pollution, associated to toxic contaminants and ocean noise that can be disruptors of the natural food webs (Reeves and Stewart 2003; Read, 2010). Population connectivity among geographically separated subpopulations profoundly influences the distribution, persistence and ecological impact of local marine mammal species. Knowledge of connection between populations can be useful for the researchers in order to create management actions for the conservation of those cetaceans.

Information about the changing in abundance is important to identify the population and subsequently to choose the best management action that can work on it; information on population structure, their possible decreasing by direct or indirect anthropogenic effect, information on their position and temporal distribution can help research team to predict areas and times of concentration. All those information are relevant to choose a management action, including conservation strategies related to impacts of human activities (Evans et al., 2004).

1.3 Importance of photo-identification for the study of cetaceans' population connectivity

The study of cetaceans is difficult since they move fast and spend most of the time underwater (Perrin et al., 2009). Several useful techniques are used to study marine cetacean population connectivity, and its selection should consider the kind of species and the advantages and disadvantages associated to each technique (Evans et al., 2004). Available direct methods include genetic analysis, telemetry, mark-recapture, and photo- identification (photo-id) (Perrin et al., 2009).

DNA analysis of cetacean skin samples from different individuals of different groups are the basis of genetic analyses. Mitochondrial DNA (mtDNA) is used to know the evolutionary past of both populations and species (Ballard et al., 2004). The procedure consists in the collection of skin samples and using several molecular techniques (e.g., Polymerase Chain Reactions, electrophoresis); it is possible to phylogenetically compare alleles from different individuals (Monteiro, 2014). In fact, the two different sequences of the haplotype have to be analyzed to check if they match. Moreover, individuals are replicated using Microsatellite Tools; the aim of this procedure is to find out possible differentiation between resident individuals and the transient ones (Alves et al., 2013a).

Another method used for studying marine mammal movements is telemetry, a process to obtain data via tag secured to the animal. It can be applied in real time through radio or acoustic tags (Block et al., 2016). The different approaches used in telemetry studies include VHF (Very High Frequency) which allows researchers to follow the movement of individuals, for a period lasting up to 20 days, (Gaskin et al., 1975; Read and Gaskin, 1985; Westgate et al., 1995); beside that, this kind of radio tag can create issues to the animals if researches need long-term studies. The other type of tag is the satellite-linked telemetry; this approach could be more appropriate in case we need to obtain long-term data on the movements and behavior of the individuals tagged, even though the transmitters in some cases are too large (Read et al., 1997). Both of these methods are invasive for the animals.

Mark-recapture method involves the capture of the individuals, marking and release. Using this method, temporal allocation and migration periods have to be considered in order to avoid a loss of individuals. Furthermore, each sampling has to be done in short period of time but long enough to have a high number of captures and recaptures; resampling periods must be done later, in order to give the population sometime to mate. Another aspect is to define the best geographic area to work; the capture and recapture of the samples should be done mostly among the same population. The number of recaptures is important in order to have a better precision of abundance estimation and the probability to capture the same individual has to be counted; it is also important to have a safe natural marking system (Rosel et al., 2011). Initially mark-recapture methods involved physical capture of individuals and application of marks, which could be tags or mutilations and then recaptured or re-sighted without capture. When whaling was still common, more or less until the 70’s, large whales were marked with metal bolts, approximately 30 cm long, placed directly into the blubber of the animal. The whale should be recaptured and the tag recovered when killed by whaling operations. Nowadays a non-invasive method is also used as a mark-recapture method: the photo-id (Perrin et al., 2009).

Photo-id is a method based on the analyses of photographs taken in the field and it requires two important aspects: the quality of the image and the fin distinctiveness (Rosel et al., 2011). The photos of the identified individuals have to be matched, and then it is possible to understand if there are any social groupings and analyze the history of many cetaceans (Mann, 2000). Photo identification studies are fundamental to highlight the population's history parameters, for example the sexual maturity's age, the reproductive and calving intervals (Hammond et al., 1990).

It is fundamental to have information on population size, its evolution history, behavior and ecology and, at the same time, it would be significant to implement conservation strategies (Silva et al., 2009). This technique (photo-id) can be useful for these studies; indeed, it is a good method to identify individuals based on their natural markings (Hammond et al., 1990) (See Fig. 1.1).

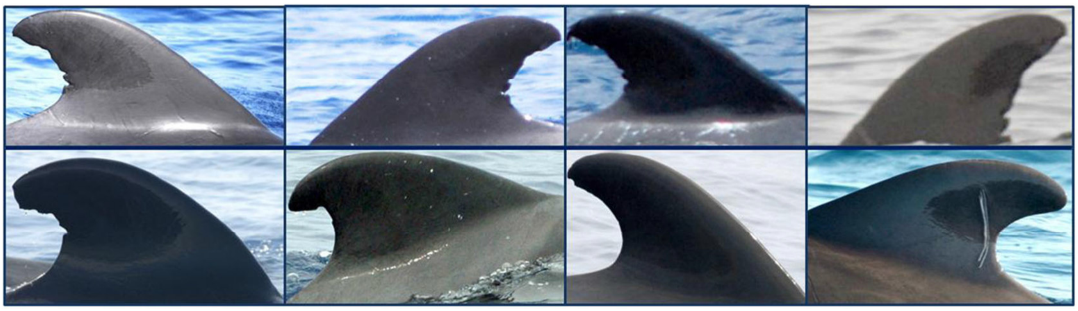


Figure 1.1 - Photographs of dorsal fins from short finned pilot whales (*Globicephala macrorhynchus*) used for individual photo-id (Source: Alves et al., 2013a).

1.4 TARGET SPECIES: *GLOBICEPHALA MACRORHYNCHUS*

The genus *Globicephala* Lesson 1828 is part of the delphinid group (Family Delphinidae) and includes two species, with a small distribution overlap: the short-finned pilot whale, *G. macrorhynchus* Gray (1846) (Van Bree et al., 1971); and the long-finned pilot whale, *G. melas* Traill (1809). The first one is the target species in this study.

Usually pilot whales move in stable pods or schools with more or less 20-90 individuals, and have a close matrilineal hierarchical system. In fact, the name “pilot whale” derives from the theory that a school is piloted by a unique leader. Pilot whales normally grow and spend their life in the same group where they were born. Only occasionally, it has been reported that males make temporary movements between different family groups in order to mate and this peculiarity is unusual within marine mammals (Olson, 2009).

The short-finned pilot whale (see Fig. 1.2) reaches an average length of 6 m and it is mostly distributed in tropical and temperate waters. This species has a stocky body, with a thick tail bulbous melon, the beak is absent (Alves, 2013) and they have a wide dorsal fin: body color of the most pilot whales is dark gray, but we can find also black ones. According to studies undertaken around Hawaii Islands and Canary Islands, individuals are capable to dive to depths between 1000 and 1300 m, during long dives lasting 21 to 27 minutes. Another study in Madeira Island showed that short-finned pilot whales dove to 1000 meters depth with a duration of 20 minutes (Alves et al., 2013b). Cephalopods are the main prey types of short finned pilot whales with suction-feeding, because of their reduced dentition (Abecassis et al., 2014).

Figure 1.2: *Globicephala macrorhynchus* (Source: Nicolau Abreu, CIIMAR-Madeira)

Short finned pilot whale females are sexually mature between 8 to 12 years old. Their breeding capacity end between 29 and 39 years old with a gestation of more than one year, while mature males range is between 15 and 45 years old. Short-finned pilot whales are longlived animals and females live longer than males, respectively 63 and 43 years old (Kasuya et al., 1984). Regarding the size, short-finned pilot whale has sexual dimorphism as males are bigger than females (Olson, 2009); adults reach a size of six meters.

Generally, short-finned pilot whales can be found globally in tropical, subtropical and warm temperate waters (Fig. 1.3) and the southern limit for the Atlantic and Pacific coast of South America has been registered at 25°S of latitude. Regarding the Pacific short-finned pilot whales' range is extended to the north of Japan and the west coast of the United States, while the northern limit of the United State coast (middle Atlantic coast). Short-finned pilot whales were never observed in the Mediterranean (Olson, 2009).

Figure 1.3: Map with yellow color representing the approximate global distribution of *G. macrorhynchus* (Source: http://maps.iucnredlist.org/map.html?id=9249).

Short-finned pilot whales have been threaten by anthropogenic danger for centuries for different reasons: first of all the direct catch where especially in the north Pacific area, in Japan for example, from 1948 and 1980 a huge number of species were caught every year (Kasuya et al., 1984). We have to consider also the incidental catch of short-finned pilot whale by different fishing activities (e.g. trawls, longlines, driftnets) (Servidio, 2014). In Hawaii, 50% of short-finned pilot whales were accidentally caught especially during tuna and swordfish fishing (Forney et al., 2007). Chemical pollution is another threat that can endanger the species: heavy metals as POPs (persistent organic pollutants): e.g. DDT (dichlorodiphenyltrichloroethane) and PCBs (polychlorinated biphenyl)), can be accumulated in their muscles and blubber tissues causing negative impacts on this predator (Dam et al., 2000). Moreover, noise pollution can change the abundance of short-finned pilot whales (e.g. survival and birth rate), acoustic energy can be unintentional, as vessel propulsion, or made on purpose, like the sonar and seismic exploration (Nowacek et al., 2007). Lastly is captivity, which has an important impact on short-finned pilot whale: between 1963 and 1972 several individuals were taken into captivity in Hawaiian waters and southern California (Reeves, 1984).

The distribution area of *G. macrorhynchus* includes the Macaronesian biogeographical region (see Fig. 4). This region, located in the North East Atlantic ocean, includes the archipelagos of Madeira, Azores, Canaries, and Cape Verde. Globally, this region is affected by different current systems (e.g., Portuguese, the Azores and the Canary), and surface waters exhibit high salinity (as from 34.9 ppt to 36.9 ppt), high temperature (from 15°C in Azores to 25°C in Cape Verde) and low concentration of inorganic nutrients (Johnson et al., 2000; Pérez-Rodríguez et al., 2001; Palma et al., 2012). Information on sea surface temperature and salinity off Madeira and Canary Archipelagos is available at http:// oom.arditi.pt/glider/.

There are several studies of short-finned pilot whales in the Macaronesian biogeographical region. For example, off Madeira Island their population structure has been studied using both photo-id method and genetic analysis (Alves et al., 2013a), their dive characteristics (Alves et al., 2013b), and survival and abundance of short-finned pilot whales (Alves et al., 2015); in Canaries Islands, studies of underwater behaviour of short-finned pilot whales (Hoffman et al., 2004) and their distribution, social structure and habitat are also available (Servidio, 2014).

Different residency patterns have been considered in some studies. For example, in Madeira, Alves et al. (2013a) considered residents as individuals that have been captured more than 5 times in 3 years, transients as individuals captured only once, and visitors' or temporary immigrant/emigrants as individuals that stay between these thresholds. According to that study there is no genetic differentiation between resident and transient individuals of this species around Madeira Archipelago. This species was found to move to Madeiran waters for feeding and mating, and statistically there were a higher proportion of mixed groups during the warmer months, and therefore possible for individuals of different residency patterns to breed.

Photo-id analysis carried out by Alves et al. (2013a) showed that the proportions of marked individuals in groups composed by transient were higher than those of residents. As in genetic analysis, groups of individuals with different residency status were observed especially between July and December. Photo-id studies of short-finned pilot whales were also carried out in the Canary Islands and Azores. In the Azores's Archipelago a study from Mendonça (2012) observed 702 short-finned pilot whales individuals between April 1997 and November 2011 with a maximum rate in July and minimum in colder months. For the study of residency pattern, that study showed that 49 individuals have been recaptured, and some in different years.

In Canary Islands, Servidio (2014) affirms that there are a higher number of individuals from this species closer to shore than in offshore waters. She created the largest catalogue of short-finned pilot whales in the Canary Islands, with 3.275 individuals identified, where 1.310 were well-marked individuals with good and excellent quality pictures. Of these, 1.241 were used for the analysis of residency patterns, where: 63% were identified as "transient" animals, 13% as "occasional visitors", and finally the 21% as "resident" and 4% as "core resident".

A preliminary comparison of two catalogues on their early stage from two Archipelagos of Macaronesia (namely Madeira and Canaries) revealed a match of one pod of six individuals that moved between Madeira and Canary Islands in a 20 days-period (Servidio et al., 2007; Alves et al., 2015). Moreover, for that preliminary comparison only a small subset of the data was used, compared to the quantity used in the present study.

1.5 ECOLOGICAL ROLE AND CONSERVATION OF *GLOBICEPHALA MACRORHYNCHUS* IN THE STUDY AREA

Cetaceans, which includes short-finned pilot whales, are important for the ecosystem. Indeed, these are top predators and affect the population of their main prey. During their feeding activities, they can provide food for seabirds by pulling prey on the surface. When they die in the sea, they may sink to the bottom and provide food and habitat for deep-sea water communities (Perrin et al., 2009).

Some of threats for cetaceans can be due to fishery, in fact, fisheries bycatch can kill approximately 125000 marine mammals throughout the world (John et al., 2009) and indirect fishery impact due to competition and therefore causing alteration of the ecosystem (Plagányi and Butterworth, 2005). Other threats include marine noise pollution generated by commercial shipping, military operations and fisheries and aquaculture, which are commonly classified as anthropogenic sound (Hildebrand, 2005); shipping impacts caused by the release of contaminant alien species (Marsh et al., 2003) and marine debris; and even ecotourism, which is an important instrument to support conservation but, at the same time, an overexploitation can transform this resource into a disturbance and a risk for marine mammals (Marsh et al., 2003).

In order to reach the all society, conservation requires specific communication and educational activities which, unfortunately, are not taken into consideration yet. As stated by John et al. (2009), "The question is not whether we will reach a sustainable state, for we will. The question is what will be left when we do".

Marine traffic and fisheries can cause anthropogenic danger for short-finned pilot whales, because of the litter's scatter, which is polluting the marine environment. Direct impact of this has been globally recorded worldwide: several stranded cetaceans died due to fishing gear injury, ship strikes and plastic debris' ingestion. Yet, in Madeira, there is still a lack of studies on the impact of human activities in these species, but it is considered to be of small concern (if compared to other regions) (Cunha, 2013; Nicolau et al., 2014). Off the Canary Islands, there are reports on cases of collision due to increasing of shipping traffic and the high presence of fast vessels (Carillo et al., 2010). Off Azores, many studies reporting the interaction between cetaceans and fisheries were also undertaken. For instance, short-finned pilot whales have been reported as responsible for the damage of the swordfish fishery, while there is a low rate of cetacean captures and there wasn't reported any incidental mortality during nine years of monitoring (Silva et al., 2011). Off Cape Verde, the population of whales decreased due to commercial whaling around the 18th Century; furthermore cetaceans may be vulnerable to anthropogenic activities such as blasting, dredging, the use of high speed boats, and vessel traffic. The rapid increase of whale watching activities could also be detrimental to marine cetaceans (Ryan et al., 2013).

Movements of cetaceans are significant in order to increase the knowledge about species' ecology and conservation biology; furthermore it is important to know more about *G. macrorhynchus,* since they are considered as biological "sink" for many persistent pollutants and good bioindicators of the ocean regarding environmental contamination. In fact this species, as other marine mammals, accumulate some elements due to their position on high trophic level in marine food chain, and have long life spans (Seixas et al., 2009)

Despite a general lack of interest for the majority of marine organisms, it has been positively noticed that, on a global scale, there is an increasing interest in cetaceans' conservation. Indeed cetaceans are generally included into the "charismatic species", given that they usually capture the attention of public and media attention as well as political interest (Hoyt, 2011).

1.6 Objectives

The aim of this study was to assess population connectivity of *G. macrorhynchus* within the Macaronesia biogeographical region using photo identification analysis. This study constitutes the first large assessment of movements of this species in all the four archipelagos comprising the Macaronesia, and it is based on data collected from different organizations between 1993 and 2015. It is expected for this study to increase our knowledge on this species ecology and contribute towards its conservation.

The specific objectives of this study addressed the following questions:

(1) Do short-finned pilot whales move between Macaronesian
archipelagos? And from which specific islands?

(2) Are the individuals moving between the studied archipelagos: transient animals (with larger home ranges: North Atlantic, or Atlantic), or island-associated animals, that visit other archipelagos but regularly return to a specific one?

2. Material and Methods

2.1 Study area

The study area includes the four archipelagos of the Macaronesian biogeographical region (NE Atlantic) (See Fig. 2.1). It is formed by 1700 km belt of volcanism off the Iberian coast and western Africa, Canary, Azores, and Madeira and Cape Verde Archipelagoes, and more than 20 large submarine seamounts (Geldmacher et al., 2000).

2.1.1 Macaronesia Region

The term Macaronesia derives from the classic Greek words "makarios" (happy) and "nessos" (islands). Located off the Iberian Peninsula and North Africa, nowadays the Macaronesian region is known to include the four volcanic archipelagos, from the northern to the southern; Azores, Madeira, Canaries and Cape Verde (Fernández-Palacios et al., 2011). This specific biogeographical region is known for its high variety of endemic biodiversity. This region harbors the highest number of endemic species of Europe, and it can be compared to the endemism level of other archipelagos, such as Hawaii, Galapagos, New Zealand, New Caledonia, and Madagascar (Whittaker et al., 2007).

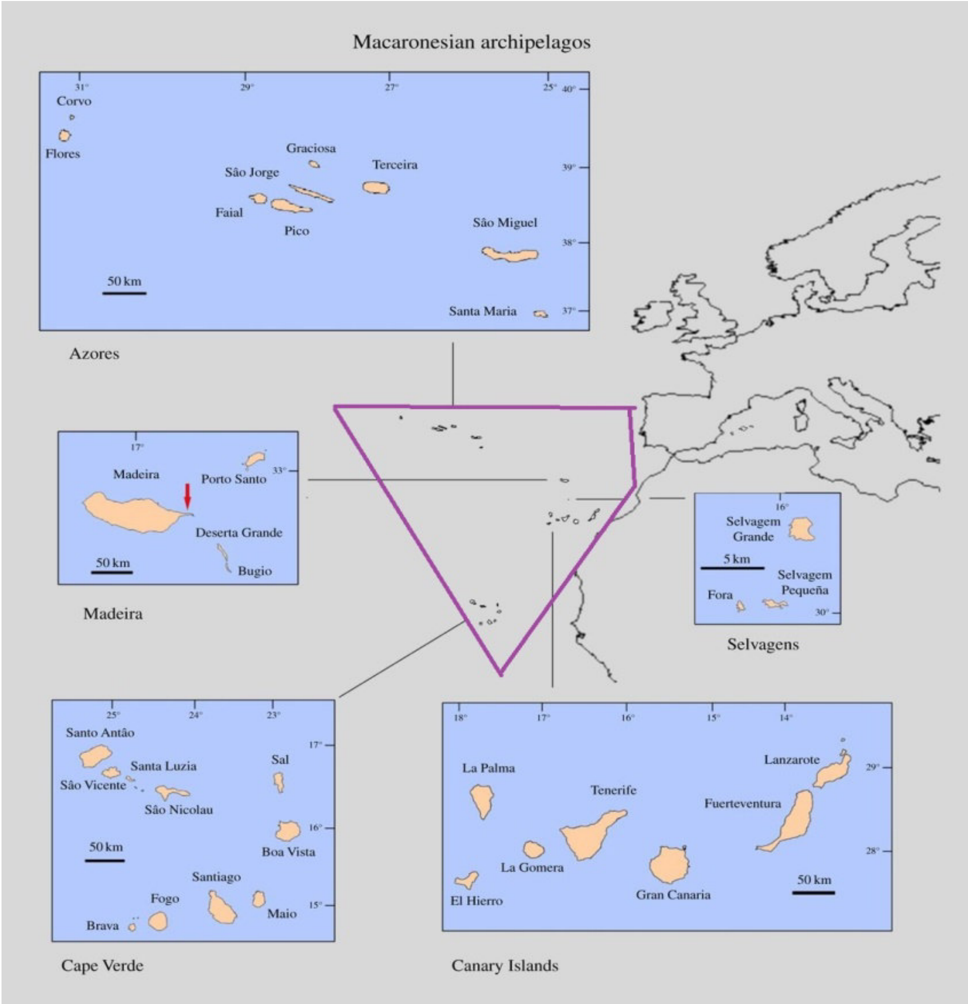


Figure 2.1: Schematic representation of the Macaronesia biogeographical region and associated archipelagos (purple polygon) (source: Rando et al., 2014). In this study Selvagens was considered a sub-archipelago of Madeira and not an independent archipelago.

The presence of seamounts is highly relevant for marine biodiversity, fisheries and conservation (Pitcher et al., 2007). Seamounts are usually considered hotspots of marine life. In fact, they are important because of their capacity to accelerate the water currents (Genin et al., 1986; Boehlert, 1988), and this can make them act as feeding grounds and as an orientation point in large-scale movement patterns (e.g., Holland et al., 1999; Fréon and Dagorn, 2000). Indeed, studies demonstrate that some marine predators, as cetaceans, are related to these mountains rising from the ocean's seafloor, which aggregations of pelagic prey and attract predators and make so this specific habitat a special feeding area for them. Since they are using this special habitat as a feeding area they are attracted by high aggregation of pelagic prey (Morato et al., 2008)

2.1.1.1 Azores Archipelago

The Azores are composed by nine volcanic islands, from the southern to the northern islands, Santa Maria (which is the eldest island with more or less 8 Million years) and São Miguel, Terceira, Graciosa, São Jorge, Pico (Pico is the youngest one with just 0.25 Million years), Faial and the north western islands Flores and Corvo (See Figure 2.1) (França et al., 2005). This Archipelago is located at 37° 74' N and 025° 67' W. These islands have a wet mild climate due to the Gulf Stream' effects (Borges et al., 2005).

2.1.1.2. Madeira Archipelago

This Archipelago is situated at ca. 900 km south west of continental Portugal and 700 km west of the Moroccan coast at approximately 32° 45' N and 016° 57' W; the large hotspot below the eastern Atlantic is the key player in the creation of these volcanic islands. Madeira, the largest one, and Porto Santo are the two main Islands of this Archipelago; Madeira is situated 37 Km North-east of Porto Santo. Three other uninhabited islands, the Desertas Islands, are located16 km southeast from Madeira (See Fig. 2.1).

Usually, in Madeira Archipelago, during the winter season, the wave conditions are more energetic due to the Azorean anticyclone. From November to February the atmospheric circulation can be stronger because of the anticyclone from Morocco, while the large-scale ocean circulation is dominated by the Canary current (Rusu et al., 2008). According to Caldeira et al. (2002), during late spring and early summer winds were strongest and especially from the north.

2.1.1.3. Canary Archipelago

Canary Islands are situated between 27° 37' and 29° 25' N, and 013° 20' and 018° 10' W at the northeast Atlantic Ocean and have been formed by volcanic eruptions almost 20 Milion years ago (See Figure 2.1). From the nearest island (Fuerteventura) to the continent, lies approximately 110 km off the northwest African mainland (Cape Juby) and the farthest Island (La Palma) is situated 110 km off the mainland. The archipelago has seven islands, which are, from the east to the west: Lanzarote, Fuerteventura, Gran Canaria, Tenerife, La

Gomera, La Palma and finally El Hierro. All of them have a sub-tropical climate, indeed temperatures are warm and have little seasonal variation; this climate is influenced by the humid trade winds coming from the northeast (Juan et al., 2000).

2.1.1.4. Cape Verde Archipelago

The Cape Verde Archipelago comprises a horseshoe-shaped cluster of active and inactive volcanic islands, and is located in the Atlantic Ocean, more or less, 500 km west from Africa and 2000 km east from the Mid-Atlantic Ridge and has as coordinates 16°53'N and 023°04' W (see Figure 2.1). Considered to be composed of the oldest rocks in Macaronesia, the islands are ranging in age between 8 Milion years (in the west) to 20 Milion years (in the east part) and the origin, as for the other archipelago, are related to a hot spot, associated to an active volcanism (Pim et al., 2008).

Cape Verde Archipelago is composed by 10 Islands, which are subdivided in two groups: the Windward Islands (Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal, and Boavista), and the Leeward Islands (Maio, Santiago, Fogo, and Brava). Santiago is the largest one, while the smallest and not inhabited island, is Santa Luzia. The climate of this archipelago is influenced by the northeast trade winds and by a wind mass designed Harmattan, which is a dry and dusty north easterly trade from the southern Sahara Desert (Duarte and Romeiras, 2009).

2.2 Data Collection

First step of this thesis was the collection of short-finned pilot whales' photographs taken by different sources/platforms, mainly, whale watching companies (catamaran, sailing boat, and zodiac boat), and research groups from universities, private and governmental organizations. Most of the organizations were contacted in order to obtain either catalogues or raw data (non- identified photographs) of short-finned pilot whales. The collection of data used for this study is a result of a long-term coordinated effort to cover, at least, most of the islands of the Macaronesia region. The aim was to increase the probability of "capturing" (i.e., identifying individuals using photographs) most of the short-finned pilot whale individuals using Macaronesian waters. Moreover, all the collected data from the collaborating organizations have been compiled, organized and compared at the CIIMAR-Madeira (Centro Interdisciplinar de Invstigação Marinha e Ambiental da Madeira) in association with the Oceanic Observatory of Madeira.

Photographs were obtained by experienced researchers/photographers onboard platforms conducting dedicated surveys and in platforms of opportunity such as whale-watching vessels. Photo-id is a non-invasive method that, using analogic or digital cameras with zoom lenses, allowed to collect photographic data, i.e., photographs of both sides of the dorsal fins from all (whenever possible) individuals of a group/sighting of the target species. Research vessels had permits to carry out scientific surveys, and whale-watching vessels followed legislation/licenses of their countries.

2.3 PHOTOGRAPHIC ANALYSIS

The pictures used in this study were accurately chosen for their quality and for the distinctiveness of each individual. Indeed, a photo quality range was assigned to each picture. It goes from 1 to 4 (where 1 was the poor and 4 the best quality) based on the focus, the angle of the dorsal fin captured, or even if the fin was obscured in any way by water or other individuals around. Another important selection of the individual was made by the distinctiveness rating going from 1 to 4 (where 1 was with no distinctiveness and 4 with a high distinctiveness). This evaluation was basically based on the size of dorsal fin notches and on how deep they were, following Alves et al. (2013a) (see Fig. 1.1).

The animals were categorized in folders according to the number of marks (0, 1, 2, 3, 4 and >4). Moreover, during the comparison, only the most-marked animals were considered. This selection was chosen in order to optimize the results (i.e., matches) and the time, since it's a very time-consuming procedure. The comparison of the short-finned pilot whales individuals was made by eye using images software, and by a single researcher (from February to end of July 2016), even though all matches where confirmed by two other experienced researchers in photo-id. It is relevant to report that the accuracy of photo identification depends on photographs quality and on morphological changes suffered by each individual during this relatively long study period (for example the same individual was matched during the study period, but one picture was taken on November 18th 1999 in Azores while the other one on December 11th 2015) (see Figure 2.2).

Figure 2.2: Example of same individuals morphologically changed due to the years passed, on the left OOM_Gma770 from December 11th 2015 (photo by Nicolau Abreu), and on the right the same individual in Azores one 1999-11-18 (photo DOP_063_R)

Based on the individual capture histories, three residency patterns were considered: resident, visitor and transient. "Residents" included individuals, captured more than five times during, at least, a three years and in three different seasons (i.e. spring, summer, autumn and/or winter). "Transient" individuals were captured only once during the study period; and "visitors" were individuals observed with a frequency that range between the transients and residents individuals (Alves, 2013).

2.4 POD AN MATCHES: TERMS USED IN THIS THESIS

During the comparison, as already referred, only well-marked individuals were considered, even though few exceptions occurred when comparing/checking the other individuals of the same pod where the short-finned pilot whale well-marked was. Short-finned pilot whales usually move within groups, designated pods, and, throughout the individual's matching within the study area, this characteristic was taken is consideration. Meaning that, if it was found an individual match, the researcher searched/compared the other mates of the two pod from where the individual match was made.

Throughout this thesis, the following terminology was used: "matches" were considered the two short-finned pilot whales recognized as the same individuals; "individuals" as animals with a unique identity (ID), "pod" as a group of individuals with close matrilineal associations (Amos et al., 1993) and sighted together on several occasions, "captures" as each time an individual is photographically marked, and "picture" which is the cropped image of the dorsal fin of each short-finned pilot whale individual

2.5 Matches analyses

During the comparison, two types of matches were detected and classified: "possible" matches and "sure" matches. When the percentage of match reached 95-99%, they have been named "possible matches" (Fig. 2.3). These could not be added to the final table of matches and consequently could not be found on the results of the study. The only matches that have been included in the results were the "sure matches" with a 100% certainty of being the same individual (Figure 2.4).

The "possible" and "sure" matches were both checked a second time by two other expert researchers.

Figure 2.3: Example of easily false positive or possible match (95-99% sure) between a OOM_Gma94 and GmaA197. Individual from Madeira island (on the left) and from Gran Canary Island (on the right) (Picture on left from R. Marques, and on the right from V. Martin).

Figure 2.4: Positive match (100%) from individual OOM_Gma11; Example of match found (Picture on the left by K. Hartmann Azores, and on the right by R. Marques in Madeira)

3. RESULTS

3.1 PHOTO-IDENTIFICATION EFFORT

The data allowed having precise individuals' number of short-finned pilot whales from Madeira and Cape Verde, thanks to the existence of a catalogue in Madeira and because of the single source of captures from Cape Verde. However, from Canaries and Azores, there is likely an over number of individuals because of the several sources that sent different photos and due to the absence of a main catalogue for each of these Archipelagos, so that some of the individuals from different pictures could be the same. During the present study intra-archipelago comparison was not counted because would not contribute to the main goal of this study and because it is a time-consuming process

Regarding the above-mentioned subject, more than 17,526 photographs were analyzed during the present study addressing the Macaronesia region. Namely, 564 individuals were from Madeira Archipelago, collected between 2003 and 2015; 15,005 captures from Canary Archipelago, between 1993 and 2015. Some individuals could be present in more than one single photograph, so the term "photograph" was preferred over the word "individual". As well as in Azores where 1,949 captures were collected between 1999 and 2015 and finally eight captures (where 4 was the number of individuals: Gma_1; Gma_2; Gma_3 and Gma_4) came from Cape Verde, from the year 2006. Since it's a non-invasive method, the term "captures" represent photographs collected from individuals (Figure 3.1).

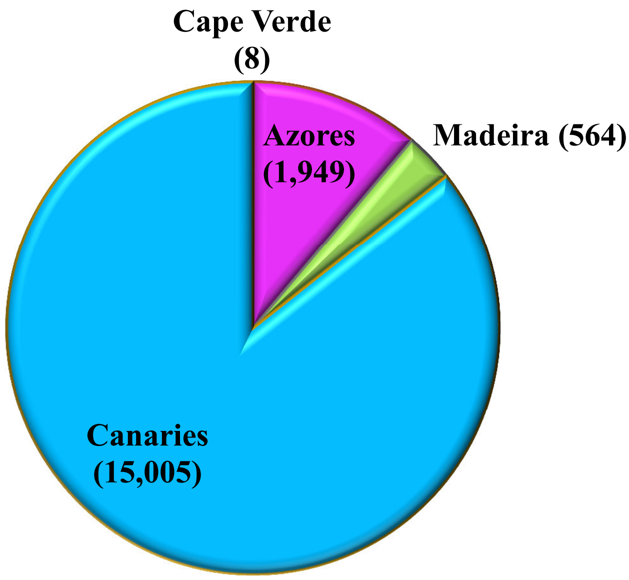


Figure 3.1: Data of *G. macrorhynchus* analysed for each Mararonesian Archipelago, being individuals for Madeira and captures for the remaining archipelagos.

As previously pointed out in 'Material and Methods', it should be considered that only high quality images from well-marked adult individuals were used, which corresponded to approximately 80% of all catalogued individuals. This implies that approximately 80% of the numbers presented below were effectively compared.

The number of photographs (short-finned pilot whales' photographs in the Canaries, Azores, Cape Verde) and the precise number of individuals photo identify (in Madeira) compared between Archipelagos is depicted in Table 3.I.

Table 3.I: Total number of photographs of *G. macrorhynchus* compared between different Macaronesian Archipelagos

ARCHIPELAGOS COMPARED	TOTAL N° PHOTOGRAPHS
Madeira-Canaries	8,462,820
Madeira-Azores	1,099,236
Madeira-Cape Verde	4,512
Canaries-Azores	29,244,745
Canaries-Cape Verde	120,040
Azores-Cape Verde	15,592

Among all images analysed during the study, approximately 1% of the individuals were considered as possible matches. The positive matches are presented in the following section.

3.2 MATCHING OF *GLOBICEPHALA MACRORHYNCHUS* WITHIN MACARONESIA

After the comparison among and between various photo-id's pictures of short-finned pilot whales and after the rejection of poor quality photographs, 19 individual matches were detected between Macaronesian Archipelagos: 11 individuals were matched between Madeira and Azores; and eight individuals were matched between Madeira and Canary Islands (Table 3.II and Figure 3.2).

Figure 3.2 shows all the islands of the short-finned pilot whales matched. Indeed, the arrows on the dashed lines represent the direction of the animals based on the dates of the photographs: it can be from one island to the other or it can represent the movement back and forth in one direction.

The matches between Madeira and Azores showed that the pod 2 (formed by individuals OOM_Gma697, OOM_Gma693 and OOM_Gma696) was sighted on 8th August 2011 in Azores and successively found on 11th December the same year in Madeira; the single individual OOM_Gma528 was captured in Azores on 30th June 2004 and in Madeira on 16th

October 2009, while the individual OOM_Gma770 was captured on 18th November 1999 in Azores and successively in Madeira on 11th of December in the year 2015 and the individual OOM_Gma744 was captured on 11th August 2013 in Azores and 16th July 2015 in Madeira Island.

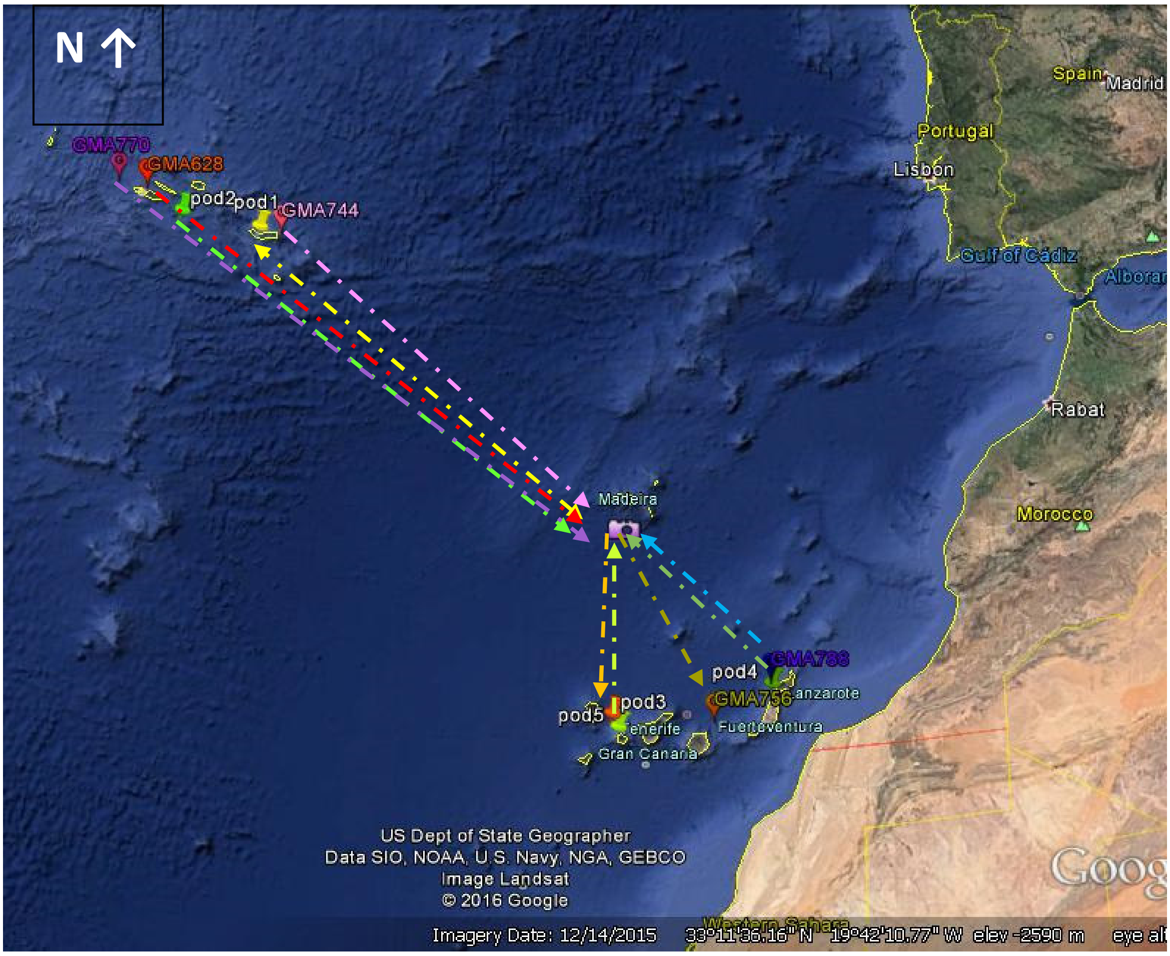
Only one Pod (pod 1: OOM_Gma10, OOM_Gma11, OOM_Gma12, OOM_Gma13, OOM_Gma14), which is known to be resident in Madeira (i.e., sighted several times per yearduring several years, and always together; see below), is confirming movements from Madeira to the Azores and as well from the Azores to Madeira. In fact that pod was captured on 14th of April 2015 in Madeira, on the 2nd of June 2015 in Azores, and was sighted again on 25th of September 2015 in Madeira. Moreover, the individuals from this Pod 1 have been sighted together in Madeira during 50 times between the years 2003-2015.

Regarding the matches found between Madeira and Canary Islands, pod 3 (with individuals OOM_Gma162 and OOM_Gma167) was sighted in Madeira on 8th September 2004 and 20 days after (28th September 2004) in La Gomera Island; pod 4 (OOM_Gma301 and OOM_Gma303) was sighted on 10th June 2007 in Madeira and on 12th April 2010 between Lazarote and Fuerteventura; pod 5 (OOM_Gma713 and OOM_Gma858) was firstly observed off La Gomera on 24th of February 2006 and successively in Madeira on 9th July 2014; as between Madeira and Azores, single individuals were matched even between the archipelagos of Madeira and Canaries. Indeed individuals OOM_Gma756 and OOM_Gma788, were found traveling from Canary Islands to Madeira on the date 16th February 2012 and 12th April 2010 for the former while 25th July 2015 and 6th March 2015 for the latter.

From these data, it can be noted that these species can travel from Madeira to Azores in at least 49 days, and from Madeira to Canaries in at least 20 days; but probably less. It cannot be inferred about these animals route to travel between the archipelagos.

Table 3.II: List of recaptures within the three archipelagos (M=Madeira, C= Canary Island, and A= Azores)

DATE	ISLANDS	ID GMA RECAPTURED																		
		10	11	12	13	14	693	696	697	528	756	744	770	788	162	167	301	303	858	713
18/11/1999	A												X							
30/06/2004	A									X										
08/09/2004	M														X	X				
28/09/2004	C														X	X				
24/02/2006	C																		X	X
10/06/2007	M																X	X		
16/10/2009	M									X										
08/08/2011	A						X	X	X											
11/12/2011	M						X	X	X											
16/02/2012	C										X									
12/04/2012	C													X						
11/08/2013	A											X								
09/07/2014	M																			
06/03/2015	M													X						
14/04/2015	M		X	X	X	X														
02/06/2015	A	X	X	X	X	X														
16/07/2015	M											X								
25/07/2015	M										X									
25/09/2015	M		X	X	X	X														
11/12/2015	M												X							



LEGEND

MADEIRA-AZORES: the individuals sighted in Madeira were photographed approximately at 32°35´N 016°50'W.

POD 1: Gma10, Gma11, Gma12, Gma13, Gma14; position:± 37°44'N 025°40'W;

POD 2: Gma 693, Gma 696 and Gma 697; position:±37°64'N 027°38'W Azores

GMA 744: Located: ±37°44'N 025°40'W Azores

GMA 528: Located: ± 38°37'N 028°30'W Azores

GMA 770: Located:± 38°64' N 028°61'W Azores

MADEIRA-CANARIES: the individuals sighted in Madeira were photographed approximately at 32°35´N 016°50'W.

POD 3: Gma162 and Gma167; Located: ± 28°54'N 017°28'W Canary

POD 4: Gma301 and Gma303; Located: ± 28°48'N 013°53'W Canary

POD 5: Gma858 and Gma713; Located: ± 27°50'N 016°30'W Canary

GMA 788: Located: ± 29°24'N 013°37'W Canary

GMA 756: Located: ± 28°12'N 015°33'W Canary

Fig. 3.2: Map of the study area with location of individual matches.

3.3. RESIDENCY PATTERNS OF *GLOBICEPHALA MACRORHYNCHUS* IN MACARONESIA

After the matching process, the known information about the residency pattern of each individual from Madeira catalogue was checked. Most of the studied animals with matches were transient animals. Sixty nine percent (13 individuals), corresponding to individuals from the four pods (pod2, pod3, pod4, and pod 5) and 4 single individuals (OOM_Gma756, OOM_Gma744, OOM_Gma770, and OOM_Gma788) were transient, 26% (5 individuals) were resident, corresponding to pod 1, and 5% (1 individual, OOM_Gma528) were visitors. This means that these island-associated individuals to Madeira also travel to other archipelago (Figure 3.3).

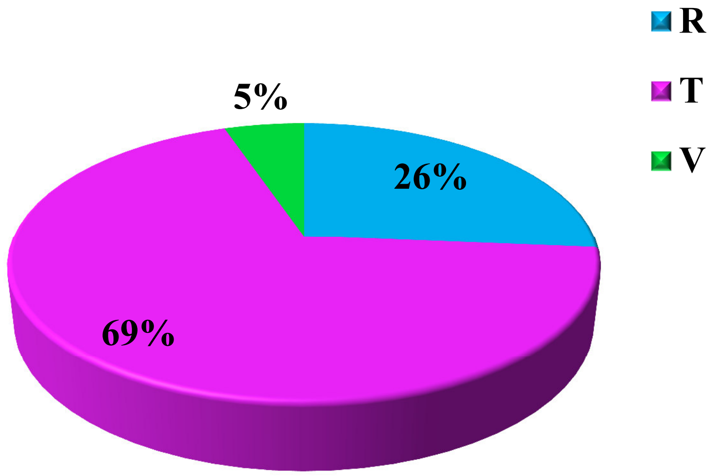


Figure 3.3: Percentage of individuals with matches in Macaronesia according to residency patterns defined in Madeira: Transient (T), Resident (R) and Visitor (V).

4. DISCUSSION

The present study allowed assessing movements of *G. macrorhynchus* in the Macaronesia biogeographical region. The study shows that 19 individual matches were found, indicating that this species travels between archipelagos in the Northeast Atlantic. This is the first study analysing movements of *G. macrorhynchus* in all four archipelagos of the Macaronesia, and, to my best knowledge, the one covering the largest area in this species at a global level. The present research supports that these free-ranging animals are capable of traveling large distances (of hundreds of kilometers) and for long periods of time (weeks), as corroborated by satellite-linked telemetry studies in Florida (Wells et al., 2013) and Hawaii (Abecassis et al., 2015). Also, photo-id studies on *G. macrorhynchus* showed intra-archipelago movements in the Canaries (Servidio 2014) and Hawaii (Mahaffy et al., 2015), and inter-archipelagos movements between Madeira and Canaries (Servidio et al., 2007; Alves et al., 2015). As mentioned in the Introduction, these latter movements revealed a match of one pod of six individuals that moved between Madeira and Canary Islands in 20 days-period.

This study identified 11 individuals travelling between Azores and Madeira, and 8 individuals between Madeira and Canaries. No matches were found between the other archipelagos (i.e., Madeira and Cape Verde; Canaries and Azores; Canaries and Cape Verde, and Azores and Cape Verde). However, it should be expected matches between these archipelagos if more time and data will be invested; in particular from Cape Verde where data were scarce.

One of the specific aims of the present study was related with the residency patterns of the identified/matched individuals. I.e., it would be a point-forward to assess if the individuals moving between these archipelagos were transient animals featuring larger home ranges (e.g., North Atlantic, or Atlantic), or island-associated (residents or regular visitors) animals to a specific island. Although the animals' residency status were known mainly from animals catalogued in Madeira, the results show that with the exception of five individuals from one resident pod and from 1 individual visitor in Madeira, all the remaining matches were from transient animals. Interesting the fact that the resident pod has been considered the 'most resident' pod in Madeira, given that had the highest number of recaptures between 2003-2015 (as observed by Alves et al., 2013a), and that those five individuals were sighted together in most of the times. This study showed that five individuals (OOM_Gma10, OOM_Gma11, OOM_Gma12, OOM_Gma13 and OOM_Gma14) from this pod (defined as Pod 1 in the present study) were sighted also in the Azores (off São Miguel Island). That pod visited Azores and traveled back to Madeira between April and September. Between Madeira and Azores the pod covered at least 1000 km in a maximum of 49 days (see Table 3.II). The fact that this pod is regularly sighted in Madeira throughout the year (50 times between 2003-2015), and that it was only sighted once in Azores supports that Madeira is an important habitat for this particular pod, but also for the species, and that this area plays a major role for vital activities such as feeding and calving, as previously suggested by Alves (2013). Different efforts between these regions could bias some of the results presented here (especially about the animals residency patterns), but should not be the reason for having found this pod only once in Azores given the high number of individuals catalogued/captured from that region.

The individual movements assessed in this thesis were based on photo-id. This technique, which uses natural marks in dorsal fin, proved to be a successful method for the identification of *G. macrorhynchus* over longitudinal studies, as previously described by Miyashita et al. (1990), Shane and McSweeney (1990), and Heimlich-Boran (1993). In this study, the comparison covered photographs from the '90 s to 2015, and several long-term matches were found, including one with 10 years difference and another with 16 years difference. The high proportion of marked individuals and low rate of mark change in this population (Alves et al., 2013a) contributed to long-term matches in this species. This factor combined with an analysis based on well-marked animals (divided in categories according to the numbers of marks in the trailing edge of the dorsal fin) and with the use of high quality photos, encourages further research using this technique in this species. Moreover, it is a non-invasive technique (Hammond et al., 1990) that can be carried out from platforms of opportunity (e.g., whale watching boats) that operate nowadays on a daily basis in almost everywhere (coastlines throughout the world), in order to increase data, as was the case of the present study.

Some factors could affect the matching success in this comparison. As defined in subchapter 1.2, pod is a group of individuals that is bonded together because of several positive reasons. During the matching process, pods were truly important to avoid errors. In fact, after the recognizing of a single individual match (e.g., individual Gma n° 11 of Madeira match with individual Gma n° 003 of Azores), the following step was to search for the other members of that same group from both the islands. This technique has some advantages, like increasing matches' success, but also the disadvantage of influencing matches in more highly cohesive individuals or pods. This should be taken in account in future research.

The results obtained here reinforce the need for combined conservation policies at larger, offshore and international scales, as the north Atlantic. Finally, these findings suggest that this study should be 'only' a first step, and that more photographic data should be used in order to better understand the population connectivity of *G. macrorhynchus* within the study area. This technique should be applied to other species, and in a more expensive approach, satellite-linked tags could also provide very useful information to clarify these animals fine-scale movements.

5. Conclusions

A first preliminary study about movement of short-finned pilot whales between Madeira and the Canary Islands was conducted in 2007 and some positive results came out of that study. However a study of these animals' movements within all the Macaronesia scale has never been done and the confirmation of movements among some of the islands could be considered a great discovery. For this reason further study on short-finned pilot whales is required.

Overexploitation, illegal fishing and pollution, can have an important impact on big marine predators, including the short-finned pilot whale (Seamount of the North east Atlantic, WWF, Susan Gubbay). Analysing their movements can help prove that they are likely to have benefits from all sea mountains in the Macaronesian area and all the possible problems are creating issues for the conservation of animals and can create a waterfall effect affecting all the predators in the region.

The pods of short-finned pilot whales observed moving across the three islands (Canaries, Azores and Madeira) can confirm the strong social structure that characterizes these animals.

This thesis can be a starting point for future studies, and photo-id could be an optimistic approach. Thanks to this technique it is possible to monitor movements of this species and extend the study by tagging the animals and analysing their exact route. These factors are fundamental to help understanding the swim-speed of these animals and other biological characteristics.

This project could be useful for future migration studies, allowing for studies which: scrutinize movement over a longer range, genetic analysis, or determining any possible human impact on these animals. Finally this study could continue and add other organizations in order to create a more holistic catalogue of the consequences, and to gain a better understanding, of their movements.

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7. APPENDIX

Appendix 7.1: MATCHES MADEIRA-AZORES: on the left individuals from Madeira and on the right individuals from Azores.

Appendix 7.1a: POD 1- from the top to the bottom: individuals OOM_Gma10, OOM_Gma11, OOM_Gma12, OOM_Gma13, and OOM_Gma14.

Appendix 7.1b :POD 2-from the top to the bottom: OOM_Gma697, OOM_Gma696, and OOM_Gma693.

Appendix 7.1c: OOM_Gma770.

Appendix 7.1d: OOM_Gma528.

Appendix 7.1e: OOM_Gma744

Appendix 7.2: MATCHES MADEIRA-CANARIES: on the left individuals from Madeira and on the right individuals from Canaries.

Appendix 7.2a: POD3- OOM_Gma162, and OOM_Gma167.

Appendix 7.2b: OOM_Gma756.

Appendix7. 2c: OOM_Gma788

Appendix 7.2d: POD4- OOM_Gma301, and OOM_Gma303.

Appendix 7.2e: POD5- OOM_Gma713, and OOM_Gma858.