



DEPARTAMENTO DE CIÊNCIAS DA VIDA

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE DE COIMBRA

Reproductive biology of an endangered seabird species, the Macaronesian shearwater *Puffinus baroli baroli*



Urtelinda Ramos

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Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de Mestre Em Ecologia, realizada sob a orientação científica do Professor Doutor Jaime Ramos (Universidade de Coimbra) e do Doutor Vitor Paiva (Universidade de Coimbra)

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Abstract

Many seabirds are globally threatened because of impacts both at sea and at their breeding sites, and are now restricted to small islets. Protection of seabird populations has long been an important issue in the development of conservation policies. Management actions have been centred on seabird colonies to reduce impacts as exploitation, predation and disturbance. Macaronesian shearwater *Puffinus baroli* is a burrowing endemic procellariiform from Macaronesia, and is considered a vulnerable species and thought to be affected by the formerly mentioned threats.

At sea, Macaronesian shearwaters are exposed to the potential impacts of overfishing and bycatch. However, researchers believe that the main threat for this species is probably alterations in the breeding colonies (visible in reproductive success), such as exotic mammals and inter-specific competition for breeding borrows.

In this study we compared the breeding ecology of two different populations of Macaronesian shearwaters: in Selvagem Grande and Porto Santo Islands. The following variables were measured in 2011-2013 (some variables were measured only in one or two years) and compared between these two colonies: nest – site characteristics, nest-site fidelity, laying date, egg volume, hatching success, growth of chicks, feeding rate and chick survival. We also collected data to identify the breeding areas and to estimate the current population numbers for Macaronesian shearwater in both islands.

We concluded that apparent declining of this species could be related to problems on nest-site tenacity. The population from both islands appears to be

affected by the climatic fluctuations as well. We also found that the breeding phenology of the species seems to be tightly related with a latitudinal gradient, this meaning that from the Azores to Selvagens archipelagos, all breeding events (e.g. incubation period) are delayed in time.

Resumo

Muitas aves marinhas estão globalmente ameaçadas por causa de impactos tanto no mar como nos seus locais de reprodução, e estão agora restritas a pequenos ilhéus. A protecção das populações de aves marinhas tem sido uma questão importante no desenvolvimento de políticas de conservação. Acções de gestão têm sido centradas em colónias de aves marinhas para reduzir os impactos como a exploração, a predação e perturbação. O pintainho *Puffinus baroli* é uma espécie pertencente à ordem Procellariiformes que faz os ninhos em buracos no solo, é endémica da Macaronésia e considerada uma espécie vulnerável que se pensa estar a ser afectada pelas ameaças anteriormente mencionadas.

No mar, o pintainho está exposto aos potenciais impactos de sobre-pesca e à captura accidental por redes de pesca. No entanto, os pesquisadores acreditam que a principal ameaça para esta espécie provavelmente são alterações nas colónias de reprodução (visível no sucesso reprodutivo), tais como mamíferos exóticos e competição inter-específica por ninhos.

Neste estudo, comparou-se a ecologia de reprodução de duas populações distintas de pintainho: na Selvagem Grande e Porto Santo. As seguintes variáveis foram medidas em 2011-2013 (algumas variáveis foram medidas apenas em um ou dois anos) e comparadas entre as duas colónias: características do ninho, fidelidade ao ninho, data de postura, volume dos ovos, sucesso de eclosão, crescimento das crias, taxa de alimentação e sucesso das crias. Também foram recolhidos dados para identificar as áreas de reprodução e estimar os números populacionais actuais para o pintainho em ambas as ilhas.

Concluiu-se que o aparente declínio desta espécie pode estar relacionado com problemas na tenacidade do ninho. A população de ambas as ilhas parece ser afectada também pelas flutuações climáticas. Descobrimos ainda que a fenologia reprodutiva da espécie parece estar relacionada com um gradiente latitudinal, isto significa que dos Açores para Selvagens, todos os eventos de reprodução (por exemplo, o período de incubação) estão atrasados no tempo.

Keywords: Macaronesian shearwater; population decline; breeding ecology; nest – site characteristics; nest-site fidelity.

Chapter 1 - Introduction

Marine systems

The ocean is one of Earth's most valuable natural resources. The ecological services that the sea provides include land buffering from storms, global nutrient cycle contribution and coastal stabilization, among others (Knox 1994). The diversity and productivity of the world's oceans is a vital interest for humankind. Because of the over exploitation by man, those resources have been declining drastically. The human impacts on marine ecosystems and consequently environmental changes do not just affect the species that live there but it will affect in a short term, the human needs. This is why the conservation of marine biodiversity is very important because only through conservation actions and a sustainable attitude it will be possible to find a balance between human activity and ecological processes.

It has long been recognized that effective conservation and management of marine habitats is many times more difficult than in terrestrial systems. This is particularly true of areas outside national jurisdiction, especially the high seas. Contributing factors to this include the widespread perception that marine resources and systems are inexhaustible, jurisdictional difficulties, lack of effective management and responsibility, lack of data (except on a few harvested species) and lack of understanding of system interactions, especially how effects at one trophic level influence species and habitats at other levels (Croxall, 2008).

Seabirds are marine top predators that may be used as indicators of changes in the marine environment and are useful as flagship species for the conservation of the pelagic marine ecosystems (Knox, 1994). Indices of the abundance and of the spatial and temporal distribution of their fish prey can

potentially be obtained from studies of seabird numbers, distribution, diet, reproductive performance, adult body condition and adult foraging and reproductive behaviour (Monaghan, 1996). The unexpected changes in their numbers, health or breeding success provide an alert for potential problems as food supply or an unknown pollution. In 1996 the study made on the University of Glasgow about the relevance of the behaviour of seabirds to the conservation of marine environments with a study site on Shetland, Monaghan said that “the differences between seabird species in their responses to changes in prey availability can be used to provide information on the abundance, distribution and age structure of the fish far more cheaply than conventional fisheries surveys”.

Conservation of marine seabirds

The importance of seabirds, especially the Procellariiformes (albatrosses, petrels, shearwaters), as top predators has been illustrated in several studies (Croxall *et al.* 1984; Warham, 1990; Connan *et al.* 2010 among others). Many aspects of seabird life history respond to climatic conditions and marine productivity and seabirds can be effective sentinels of changes in the marine environment. For example if the stock of a particular prey fish declines the seabirds, as top, predators will be affected both in terms of reproduction and survival.

Petrel species are long-lived organisms (Warham, 1990) with extreme life-history traits: strong breeding site fidelity, high adult survival rates, low annual reproductive output and deferred maturity (Brooke, 1990; Perrins, 2005; Sandvik *et al.* 2005). Since they are sustained by the sea, immature petrels can go for years

without return to land. The order Procellariiformes comprehends 4 families, Pelecanoididae, Sphenisciformes (penguins) and Pelecaniformes (pelicans) they have highly adaptive sense of smell, possibly connected with food seeking and social interaction (Cramp, 1977). The family procellariidae comprehends about 55 species in 12 genera, 6 of them breeding in western Palearctic. The genera can be divided in 4 groups: fulmars (genus *Macronectes*, *Fulmarus*, *Thalassoica*, *Daption*, *Plagodroma*), prions (genus *Halobaena*, *Pachyptila*), petrels (genus *Pterodroma*, *Bolweria*) and shearwaters (genus *Procellaria*, *Calonectris*, *Puffinus*). Different species nest in different ways: ashore, on sea cliffs, islets, high on slopes or escarpments, on lofty plateau or mountains, sometimes inland. Unlike many open-nesting birds that are largely diurnal, most of hole-nesting species are strictly nocturnal when visiting land, though some shearwaters populations such as the Cory's shearwater *Calonectris diomedea* from Selvagem Grande Island is partially diurnal. The selection of breeding localities is highly selective to guarantee the absence from predators, particularly mammalian predators, and to reduce difficulties in landing and in the access of nest site cavities. Some species, especially larger shearwaters, are long-distance migrants; others mostly stay within feeding range of the colony. Almost all species are colonial breeders, some species moderately territorial and others very aggressive with intruders, and all species are typically gregarious at sea. Food is essentially represented by fish, cephalopods and crustaceans, often as plankton. Regularly, they are long-term monogamous only during the breeding season.

Many seabirds are globally threatened because of impacts both at sea and at their breeding sites (BirdLife International, 2008). They tend to breed in large, dense colonies, at which adults, their eggs, young and droppings have been (and

still are in some areas) heavily exploited for various purposes (Monaghan, 1996). Introduced predators and disturbance may be another reasons contributing to the decline of seabird populations. Protection of seabirds has long been an important issue in the development of conservation policies, particularly in Europe and the United States (Monaghan, 1996). Partly as a consequence of the difficulties in observing seabirds at sea, most basic and applied research on seabirds has been centered on breeding colonies. Conservation measures have also been largely colony-based, concerned with reducing exploitation, predation and disturbance (Monaghan, 1996).

Procellariiformes breed mostly on remote oceanic areas, such as islets and their reproductive biology has particular characteristics. They breed only in areas free from mammalian predators and they have been extinct from many areas following introduction of exotic mammals such as rats. For example, in the Archipelago of Chafarinas Islands on Congreso Island introduced exotic mammals (*Rattus rattus*) were introduced and a rat control campaign was started in October 1999. In the next year, breeding success of Cory's shearwaters *Calonectris diomedea* significantly increased: rat control campaign started in October 1999 with a laying percentage of 27 (n = 180) and the next year the percentage ascended to 70 % (n = 225; Igual *et al.* 2005).

Also, a monitoring on Selvagem Grande Island shown that population of seabirds, especially Cory's shearwaters, has been declining over de years due to problems with rodents (predation and competition for burrows). In 2002 there was an eradication program of house mouse (*Mus musculus*) on the island and three years later the investigators verified a rapid recovery of the entire flora with a probably increasing number of breeding endemic birds (Oliveira *et al.* 2010).

Again, the Case of “Ilhéu da Praia” on Graciosa, Azores Island, where a conservation project removed the invasive alien plants and mammals in 1997. Surveys after restoration work reveal a clear increase in the number of breeding pairs, indicating that the habitat restoration actions have contributed to a significant improvement of breeding conditions for seabirds including species such as *Puffinus baroli baroli*, commonly named as Macaronesian shearwaters (Groz *et al.* 2005). Nearly 40% of seabird species are declining across Europe and many of these widespread declines result from threats to habitats (Groz *et al.* 2005). The historical population trends of seabirds inferred from 16th and 17th century chronicles indicate dramatic declines for most species on the Azores. While the main islands were important breeding places in the past, most seabird populations are now restricted to small islets (Monteiro, *et al.* 1996^b). Current threats to the Azores seabirds and to other seabirds in the Macaronesian Islands (Madeira, Selvagens, Canaries and Cape Verde) are diverse and may differentially affect the various species. They range from predation by introduced mammals, human disturbance and exploitation, habitat loss due to invasive alien plants and overgrazing by rabbits, and, potentially, competition with fisheries (Monteiro, *et al.* 1996^a). Overall, in most Islands, due to predation by introduced mammals, small Procellariiformes such as Macaronesian shearwater they are now mostly restricted to undisturbed rat-free islets (Monteiro *et al.* 1996^a; Groz *et al.* 2005).

Macaronesian Shearwater *Puffinus baroli baroli* (Bonaparte, 1857)

There is a lack of information on feeding ecology and at-sea movements of small shearwaters such as the Macaronesian shearwater. This species is endemic of Macaronesian Islands and currently there are very small populations, restricted to the Azores, Selvagens, Porto Santo and Canary Islands. In Portugal these species is considered vulnerable according to the Portuguese Red Data Book. In 1994/1995 the study made on Selvagem Grande Island by Oliveira & Moniz gives us a statistic between 2050 - 4900 pairs and confirmed that this island is a key site for this species. However, because most Procellariiformes including Macaronesian shearwaters nest in burrows and are only active at the colonies at night, they are very difficult to census (Rodríguez *et al.* 2011). It is necessary to understand the reproductive ecology and habitat selection, on land and at sea, to provide conservation measures for the seabird populations.

The Macaronesian shearwaters appear to stay all year around in the waters of Atlantic Ocean around their colonies (González-Solís *et al.* 2007). During the breeding season the adults return periodically to the ocean to feed themselves and the chicks (Neves *et al.* 2012). When foraging most procellariiformes, including the Macaronesian shearwater, is concentrate in areas with higher primary productivity and with medium or lower sea surface temperature (Fagundes *et al.* 2011; González-Solís *et al.* 2007). When they are at sea these birds are exposed to the impacts of overfishing and bycatch (Fagundes *et al.* 2011; Granadeiro *et al.* 2006). However, researchers still believe that probably the main cause of threat to most species is alterations in the breeding colonies (visible in reproductive success), such exotic mammals and competition for space. To verify this

assumption we need to do more investigation in breeding ecology of the species on land. Our purpose here was to obtain information on breeding ecology about two different populations of Macaronesian shearwaters, on Selvagem Grande and Porto Santo Islands.

Seabird studies on land

Habitat selection

In every generation, the genes of that generation influence the phenotype of that generation. Any individual born, therefore, inherits genes that have succeeded in building a long series of successful phenotypes, for the simple reason that failed phenotypes do not pass on their genes. This is natural selection and explains why organisms are well adapted (Dawkins, 1988).

Procellariiformes are hole - nesting birds, they choose a propitious nest existent on the available habitat, so we can assume that this behaviour of choosing the nest location has a genetic base and influences the fitness of the individuals. The selection of nesting habitat is a crucial decision in many birds' species because characteristics of the nest site can influence adult survival and reproduction success. In long lived seabird species with high fidelity to the nest site, initial selection may be particularly important because it can affect the lifetime reproductive success of a breeding pair (Drummond & Leonard 2010).

Seabirds generally choose among available nest sites based on a combination of physical and social features that can influence reproductive success. For example, individuals may choose nests with physical features such as cover that provide protection against environmental stress or predation. Similarly,

birds may select sites based on proximity to conspecifics, which can enhance vigilance against predators (Birkhead, 1977) or improve foraging ability (Burger, 1997). If habitat selection is adaptive, then birds should select nests sites with features that maximize survival and reproductive success. However, when rapid changes in selective pressures induce a mismatch between previously – evolved cues used for the nest selection and actual nest quality, individuals may choose suboptimal nest sites. Some colonial seabirds with life history traits that limit their behavioral plasticity, such as strong philopatry and site fidelity, may be particularly vulnerable to such apparently maladaptive habitat use (Drummond & Leonard 2010). In the case of Macaronesian shearwater, a colonial seabird, which nests in mixed colonies, physical and social factors are important in the selection of nest sites. And just like for another burrowing procellariiformes, there is some quantitative information on nest-site characteristics, but very little quantitative information on nest-site competition (Ramos *et al.* 1997).

Selection of nesting sites by Macaronesian shearwater

Like other Procellariiformes the Macaronesian shearwater is highly affected by predation of exotic mammals, and it only reproduces on areas without predators, and because such areas are now rare, the competition for appropriate nesting areas may be high. High levels of intraspecific and interspecific interference competition may be a result of alteration of breeding habitats in historical times and competition for nesting sites may play an enhanced role in limiting present seabird populations (Groz *et al.* 2005).

Identical to other Procellariiformes the Macaronesian shearwater is expected to show a strong philopatry and site fidelity so they are particularly vulnerable to maladaptive habitat use. However, there is no data on nest site fidelity for this species. Since the species have marked colony and nest-site tenacity, the competition for burrows can occur intra and interspecifically. A study in the Azores suggests strong intra and inter-specific competition for nest-burrows by Procellariiformes due to the existence of high competition for appropriate nesting areas; fights among Cory's shearwater to secure a burrow; high levels of daytime burrow attendance; sharing of nest sites between species and excavation of nests of smaller petrels by Cory's Shearwaters (Ramos *et al.* 1997).

Since the eradication program implemented on Selvagem Grande Island in 2002 to remove invasive mammals, the colony of Cory's shearwater increased significantly (Zino *et al.* 2008). In the study of Paulo Oliveira and P. Moniz they came to the conclusion that the extremely large colony of Cory's shearwaters in Selvagem Grande Island may be a limiting factor in the increase of the breeding population of Macaronesian shearwater. Due to this increase in numbers of Cory's shearwater colony, the competition for burrows with Macaronesian shearwater is likely to be higher: Macaronesian shearwater is a smaller bird so in fights to secure burrows this species will lose and also burrows excavated and enlarged by Cory's shearwater are not suitable for Macaronesian shearwater, since their nests need to be smaller in order not to be exposed. Reptiles are the most frequent terrestrial vertebrates (regarding native species) on oceanic islands but there have been few studies documenting interactions between reptiles and seabirds (Matias *et al.* 2009). In 2009, a group of researchers made a study about the Wall Lizard (*Teira*

dugesii) and is possible predation of undefended seabird chicks or eggs by this lizard species on Selvagem Grande Island. The species is known on the Selvagens and Madeira for its diverse diet and scavenging habits and predated on eggs from seabirds on Selvagem Grande Island (Matias *et al.* 2009).

Our main goal was to get more information about the parameters of breeding biology in *Puffinus baroli* in Porto Santo and Selvagem Grande Islands: nest – site characteristics; nest-site fidelity; laying date; egg volume; hatching success; growth of chicks; feeding rate and chick survival. For that, we monitored the population in these two islands through regular visits during three years (2011, 2012 and 2013). We also collected data to identify the breeding areas and to estimate the population of Macaronesian shearwater in Porto Santo and Selvagem Grande Islands. Our data was compared between these two islands and with the information available in the literature, in order to discuss the breeding strategies of this species in the Macaronesian Islands. In particular, we attempt to investigate how features of the nest site affected reproductive success of little shearwater by examining the influences of several nest site characteristics, such as nest depth, nest substrate and proximity to conspecifics. Overall, this study should contribute to discuss the possible reasons for the declining of this species in the North Atlantic (Rodríguez & Rodríguez 2009).

Chapter 2 - Material and Methods

Study species

The Macaronesian shearwater *Puffinus baroli baroli* (Bonaparte, 1857) is endemic to the NE Atlantic oceanic islands, breeding in the 4 archipelagos (Madeira (including the Desertas Islands, Porto Santo Island, and the Selvagens Islands), Azores, Canary islands and Cape Verde)) and the *P. b. boydi* subspecies breeding on the Cape Verde islands. The Macaronesian shearwater or Barolo shearwater is restricted to less than 7000 breeding pairs (Neves *et al.* 2012 and Correia-Fagundes & Romano, 2011).

The population of Macaronesian shearwater in Selvagem Grande Island was estimated between 2050 and 4900 breeding pairs (Oliveira & Moniz 1995) and the maximum population estimates in Portugal is around 2,640 to 4,030 breeding pairs (Groz & Pereira. 2005). The Macaronesian shearwater is considered 'Rare' in the Palearctic (BirdLife International 2004) and the Macaronesian shearwater is listed as Vulnerable in the Institute for Nature Conservation (IUCN 2011, Cabral *et al.* 2006).

The Macaronesian shearwater is characterized by crown, hindneck, upper body, flight-feathers and tail are slight-black; sides of face and sites of neck are mottled white and black; under parts, including central under tail coverts, white. The bill is black with blue-gray cast on basal sections of both mandibles. Adults show chalk-blue legs and feet. There are no morphological differences between sexes and is also not possible to distinguish immature adults, but juveniles have interdigital membranes and tarsus with a pinkish hue. Also there are no seasonal differences in plumage of individuals (Cramp *et al.* 1977).

Macaronesian shearwater is a burrowing procellariiform (Correia-Fagundes & Romano, 2011), is sedentary and during the breeding season they form colonies on islands and coastal cliffs (Monteiro *et al.* 1996^a). The nest is usually a chamber excavated in soft soil or a hole between rocks often with a tight entry corridor; it can be found by the couple or it can be dug in soft soil probably by both sexes (Cramp, 1977).

This species presents the typical procellariiform pattern of a single-egg clutch (Warham, 1990) and slow chick development (Hamer & Thompson 1997). At colonies in Azores they breed during the boreal winter and spring and the breeding is less synchronous than in other Procellariiformes, presumably because the species is non-migratory (Booth *et al.* 2000). In the Azores the species presents a breeding period between mid-January and mid-May, the egg – laying occurs from late January, egg - hatching occurs at mid or later March and acquires flight capacity in May, becoming independent 8-11 days later (Monteiro *et al.* 1996^b). The primary regimens are moulted in April and May when most birds are renewing primaries 1 to 4, and the moult of the secondaries occurs towards the end of the non – breeding period (Neves *et al.* 2012). Outside the breeding season the adults returned to their nests regularly or, at least to their vicinity (Monteiro *et al.* 1996^a).

The timing of seabirds breeding cycle correlates and is probably controlled by food availability (Ashmole, 1971; Harris, 1969; Harrison *et al.* 1983). The winter breeding of Macaronesian shearwaters might have been an adaptation to avoid the inter-specific competition for nest-site in spring and summer by larger shearwaters with similar nesting requirements (Monteiro *et al.*, 1996^b). This specie could be easily defeated in fights for nests against other procellariiform species of

the North Atlantic, such as the Cory's shearwater. Interestingly, the chick rearing periods of Procellariiformes with apparently similar ecological niche do not overlap, for either the three shearwater species breeding in the North Atlantic (Macaronesian, Manx *Puffinus puffinus* and Cory's) or small nocturnal feeders (Bulwer's petrel *Bulweria bulweri* and Madeiran storm petrel *Oceanodroma castro*). This is indicative of possible ecological segregation related to partitioning of breeding habitats and food resources (Monteiro *et al.* 1996^b).

The species depends entirely on the oceans for food, their diet consists mainly of fish and cephalopods captured the surface or diving (Monteiro *et al.* 1996^a; Cramp *et al.* 1977). Traditional studies on diet composition, however, are restricted to the breeding period. Nevertheless those studies are very important to determine prey type and size, and especially useful when used in association with others tracers of the feeding ecology which integrate the diet over longer periods, such as carbon and nitrogen stable isotopes. However, in Macaronesian archipelago signatures are often difficult to interpret because we still lack of basic knowledge on diet composition (Neves *et al.* 2012).



Figure 1 – Chick (on left) and adult (on right) of Macaronesian shearwater species in Selvagem Grande Island (Urtelinda Ramos images).

Study sites

For this project data were collected from both study areas during four years (2010, 2011, 2012 and 2013). Since we have a significantly colony of this species in Selvagem Grande Island, our work took place there and also in Porto Santo Island which also has a large population and facilitated access.

Selvagem Grande (30°09'N, 15°52'W) is the largest island of the Portuguese sub-archipelago of the Selvagens with 9455 hectares and lies between Madeira and the Canary Islands in the north-east Atlantic. This archipelago is part of Madeira and is classified as a Nature Reserve because of its richness in flora and fauna (Leitão *et al.* 2005). The island supports one of the most important Atlantic colonies of Cory's shearwaters *Calonectris diomedea borealis* (Granadeiro *et al.* 2006) with approximately 30.000 pairs, also the higher colony of Macaronesian shearwater in Atlantic Ocean and others species as the *Bulweria bulwerii* and *Pelagodroma marina* (Ramírez *et al.* 2008). The foraging of these species is very dependent on the canary – current ecosystem (Fagundes *et al.* 2011).

The birds have been studied intensively since the expedition organized by the Museu Municipal do Funchal (História Natural) in 1963 (Zino, 2008). With the highest percentage of endemic species per unit area, across Macaronesia, these islands exhibit an herbaceous and shrubby flora, with no woody vegetation. The flora has similarities with the Canary, with many endemic species, supporting characteristics of a desert habitat (Leitão *et al.* 2005). These islands are a sanctuary for seabirds, many of them on a vulnerable status (Matias *et al.* 2010, Leitão *et al.* 2005).

Porto Santo Island (33°01'N 16°22'W) is a Portuguese island 43 kilometres (27 mi) northeast of Madeira Island in the North Atlantic Ocean; it is the northernmost and easternmost island of the archipelago of Madeira, located in the Atlantic Ocean west of Europe and Africa. On the island of Porto Santo and islets that surround it, there are small populations of some seabirds such as Cory's Shearwater, *Oceanodroma castro*, *Bulweria bulwerii* and Macaronesian shearwater (Ramírez *et al.* 2008). Data for this study was collected in “Ilhéu de Cima”, a rocky islet with an area of 32 hectares, covered by shrubs and coastal flora of Macaronesia, why is protected by PDM, Natura 2000 and is still an integral part of the Natural Park of Madeira (Boletim Municipal do Porto Santo).

Data was collected from 2010 to 2013 by several researchers both in Selvagem Grande and Porto Santo Islands.

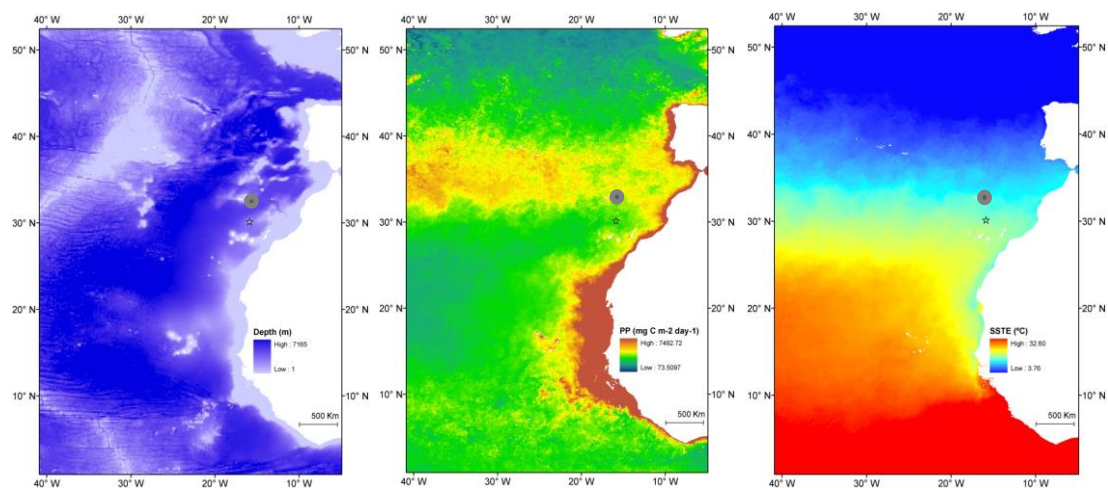


Figure 2 - Oceanographic characteristics of the eastern North Atlantic, where Macaronesian shearwaters breed. (A) Depth, (B) Primary Productivity and, (C) Sea Surface Temperature. The two study colonies are indicated with a star (Selvagem Grande Island) and a point (Porto Santo Island).

Population Estimates

To estimate breeding density we used 44 quadrats of 100m², 34 in Selvagem Grande and 10 in Porto Santo islands, where an intensive search for nests was carried out in different areas of suitable habitat (Oliveira & Moniz 1995). The data was collected at night, during the incubation period. The quadrats were placed on cliffs of the islands because on the plateau the habitat is not appropriate for nesting. The breeding areas recorded in Selvagem Grande Island were “Baía das Cagarras”, “Baía das Galinhas”, “Baía das Pardelas” e “Baía das Quebradas”; in Porto Santo Island were far North, “Rocha do Sol”, “Cabeço das Laranjas” and below the plateau.

Biometrics from adult birds

The adults of Macaronesian shearwater were caught at night when birds may be picked up from the ground by hand (Brooke, 1978). The birds were ringed and the following measurements were taken from adult birds: wing-length, tarsus-length and weight. The wing was straightened and flattened to provide a maximum measurement to the nearest mm (Brooke, 1978). A blood sample was taken from the brachial vein for sexing with molecular methods (because birds do not show sexual dimorphism in terms of size and plumage). During four years we sampled 92 adults in Porto Santo and 200 adults in Selvagem Grande Islands.

Nest-site characterization

The nests of Macaronesian shearwater were characterized after the peak of hatching (mid-March) (Ramos *et al.* 1997). We concentrated our sampling in three habitat types (rock, gravel and sand) where most birds nested (Ramos *et al.* 1997). Data were collected from 79 nest cavities of Macaronesian shearwater, 58 in Selvagem Grande and 21 in Porto Santo islands. For each nest cavity, 8 variables were recorded: 6 continuous and 2 categorical (Table I).

Table I – Variables recorded for each nest cavity in Selvagem Grande and Porto Santo Islands.

Nest-site variable	Description
Entrance Depth	Maximum Depth of entrance (cm)
Entrance height	Maximum height of entrance (cm)
Entrance Width	Maximum Width of entrance (cm)
Cavity Depth	Maximum Depth Cavity (cm)
Cavity Width	Maximum Width Cavity (cm)
Cavity Altitude	Maximum Altitude Cavity (cm)
Sandy Substrate	Sandy Substrate (1)
Rocky Substrate	Rocky Substrate (2)
Orientation of nest entrance	Orientation (South-West, East, south-East, South, West, North)

Nest – site fidelity

Between the years 2010 and 2013 all occupied nests were observed with the purpose to check if the breeding pairs maintained the same nest and mate from year to year. Since the birds are ringed and the new breeding pairs were also ringed, in the end of the three years we could notice the frequency of pairs occupying the same nest or not and the fidelity of their mates.

Reproductive parameters

During the breeding season each nest was marked and checked daily during visits to both islands from February to May. In 79 nests we recorded laying date and success only in 28 nests (22 in Selvagem Grande Island and 6 in Porto Santo Island).

Eggs were measured with callipers and nests were visited through the season, to record whether eggs hatched or not and whether chicks fledged or not. From mid – March when chicks hatched the wing-length and weight were registered. In 2012 chicks were weighed twice a day (at 9:30h and 17:30h) with a Pesola hand-held scale to the nearest gram (Matias *et al.* 2009). Chicks were ringed before fledging. We followed the chicks in 2011 and 2012 with a total of 20 chicks recorded in Selvagem Grande in both years and 16 in Porto Santo, all in 2012.

Statistical analysis

We analysed each year separately and also compared the data between islands when possible.

To estimate the population size we multiplied the mean number of nests in the 100m² plots by the total area of cliffs around each colony (i.e. this would be the area available for burrowing Macaronesian shearwaters). To determine which characteristics of nest-site influenced the laying success and hatching success the cavities were classified as with or without an egg, and successful or unsuccessful resulting in a binary response variable for these two models (Ramos *et al.* 1997). A logistic regression was used to evaluate the effect on hatching and laying success, separately. The nest-site fidelity was analyzed with a chi-square test by counting the number of cases that were faithful to one year to another and pass these values to percentages.

We tested the effect of sex, breeding location and their interaction on Macaronesian shearwaters measurements (weight, wing-length and tarsus-length) using Factorial ANOVA. To calculate egg volume the egg breadth (mm) was squared and an index of volume was calculated through the formula: (Length (mm) * (breadth (mm))²)/1000. We compared egg measurements between islands

with a One-Way ANOVA The effect of egg volume on hatching success was evaluated classifying as successful or unsuccessful each nest with eggs, for both islands, and we also use a one Way ANOVA to compare egg measurements between those that hatched and those that did not hatch. In terms of hatching date, starting on day 1 of January, we counted the days until the day of hatching, this number was used in the database to calculate the hatching date and we compared results between islands and years with a t-test. The effect of year and island in Macaronesian shearwaters success (0, 1) was analyzed with a Logistic Regression (Wald χ^2 test).

To analyze the body mass and wing growth curves for chicks of Selvagem Grande Island Mean Plot graphs were drawn, for body mass and wing-length. Since some chicks died, a growth curve was made for each chick separately. For the linear growth phase (6 - 40 days), we calculated the growth rate for each chick and compared the values between years with a Mann-Whitney U-test, because the sample size was small.

Chapter 3 - Results

Estimating Population size

We can observe that the number of potential burrows was higher in Porto Santo Island and the number of individuals/unit area was also higher. Of 247 potential burrows in Selvagem Grande Island 4 were occupied, while in Porto Santo Island of 125 potential burrows 7 were occupied (Table II). The density of nests per 100m² was 0.7 for Ilhéu de Cima, Porto Santo and 0.22 for Selvagem Grande. The cliff area in Ilhéu de Cima, is about 33500 m², which gives an estimate of 235 nests. The cliff area in Selvagem Grande is about 639500 m², which gives an estimate of 1407 nests.

Table II – Counts of potential and occupied burrows of Macaronesian shearwaters (*Puffinus baroli*) in Porto Santo (2013) and Selvagem Grande Islands (2012 and 2013).

Plot	2012		2013		Plot	2013	
	Potential burrows	Occupied burrows	Potential burrows	Occupied burrows		Potential burrows	Occupied burrows
Selvagem Grande				Porto Santo			
A	9	1	6	0	A	14	0
B	6	0	20	1	B	9	0
C	11	0	16	0	C	15	2
D	0	0	17	0	D	11	1
E	5	0	12	0	E	13	1
F	0	0	13	0	F	11	1
G	0	0	11	0	G	19	1
H	0	0	13	0	H	14	1
I			7	0	I	14	0
J			9	0	J	5	0
K			18	0			
L			7	0			
M			18	1			
N			10	0			
O			7	0			

P		8	1	
Q		11	0	
R		13	0	

Body mass and biometrics of Macaronesian shearwaters breeding in Selvagem Grande and Porto Santo islands

Between 2011 and 2013, 92 adult birds were captured in Porto Santo and 200 in Selvagem Grande Islands. There were no significant differences in the wing-length, tarsus-lengths and body mass of male and female Macaronesian shearwaters. However, adults from Porto Santo had significant higher wing and tarsus lengths and were significantly heavier than birds from Selvagem Grande Island (Tables III and IV).

Table III – Descriptive statistics (mean \pm SD (N)) of wing and tarsus lengths (mm) and body mass (g) of male and female Macaronesian shearwaters (*Puffinus baroli*) breeding on Porto Santo and Selvagem Grande Islands.

Variable	Sex		Island	
	Female	Male	Porto Santo	Selvagem Grande
Wing length (mm)	181.82 3.89 (66)	\pm 181.85 \pm 3.97 (75)	182.63 \pm 3.78 (82)	181.12 \pm 3.93 (162)
Tarsus length (mm)	36.94 \pm 0.93 (66)	36.99 \pm 0.94 (75)	37.28 \pm 0.90 (81)	36.68 \pm 0.86 (159)
Weight (g)	165.76 17.22 (85)	\pm 165.69 \pm 14.33 (95)	168.17 \pm 16.95 (92)	163.98 \pm 14.60 (200)

Table IV – Effect of breeding location, sex and their interaction on Macaronesian shearwaters (*Puffinus baroli*) biometric measurements, using a Factorial ANOVA.

	Sex			Breeding location			Sex * Breeding location		
	DF	F	P	DF	F	p	DF	F	p
Wing length (mm)	1, 139	0.00	0.95	1, 242	9.052	0.003	1, 137	0.882	0.349
Tarsus length (mm)	1, 139	0.07	0.78	1, 238	6.984	0.009	1, 137	0.026	0.872
Weight (g)	1, 178	0.00	0.97	1, 290	4.005	0.046	1, 176	1.860	0.174

The influence of nest characteristics on the laying and hatching success of Macaronesian shearwater

In Selvagem Grande Island, the laying probability increased with the presence of sandy substrate, and when existing nests are orientated towards South-West and decreases when existing nests are orientated towards South-East (Table V). The probability of hatching success increases with deeper nest cavities, with the presence of sandy substrate and when the existing nests are orientated towards South-West (Table VI).

Table V – Logistic regression output of the influence of nest characteristics on Macaronesian shearwaters (*Puffinus baroli*) laying success of breeding in Selvagem Grande Island (2011 and 2012).

Parameter	$\beta \pm SE$	Wald Stat.	p
Intercept	-0.27 \pm 2.9	0.01	0.92
Entrance Depth	-0.01 \pm 0.02	0.42	0.52
Entrance Altitude	-0.05 \pm 0.06	0.82	0.36
Entrance Width	0.09 \pm 0.06	2.26	0.13
Cavity Depth	-0.07 \pm 0.08	0.73	0.39
Cavity Width	-0.04 \pm 0.04	0.78	0.38

Cavity			
Altitude	0.01 ± 0.06	0.01	0.9
Sandy	18.53 ±		<
Substrate	1.67	122.6	0.001
Rocky			
Substrate	0.26 ± 1.86	0.02	0.89
Orientation			<
SW	3.25 ± 1.20	7.26	0.001
Orientation E	2.27 ± 1.82	1.55	0.21
Orientation	-14.65 ±		<
SE	1.96	55.85	0.001

Table VI – Logistic regression output of the influence of nest characteristics on Macaronesian shearwaters (*Puffinus baroli*) hatching success of breeding in Selvagem Grande Island (2011 and 2012).

Parameter	$\beta \pm SE$	Wald Stat.	p
Intercept	1.56 ± 1.44	0.88	0.36
	-0.14 ±		
Entrance Depth	0.17	0.74	0.39
Entrance	-0.78 ±		
Altitude	1.87	0.66	0.57
Entrance Width	0.88 ± 1.56	0.56	0.77
Cavity Depth	3.25 ± 0.66	6.73	0.001
Cavity Width	0.89 ± 1.22	0.44	0.23
Cavity Altitude	0.97 ± 1.82	1.57	0.25
Sandy Substrate	5.23 ± 0.87	5.99	0.001
	-1.23 ±		
Rocky Substrate	1.99	0.78	0.44
Orientation S	1.45 ± 0.91	0.76	0.39
	-1.09 ±		
Orientation W	0.23	0.96	0.1
			<
Orientation SW	3.18 ± 1.09	7.42	0.001
	-0.23 ±		
Orientation E	1.56	0.87	0.15

In Porto Santo Island, the probability of laying success by Macaronesian shearwaters increases with longer borrow entrances, with the presence of sandy substrate and when nests exists are orientated towards South-East. In opposite,

probability of laying success decreases when existing nests are orientated towards North (Table VII).

Table VII – Logistic regression output of the influence of nest characteristics on Macaronesian shearwaters (*Puffinus baroli*) laying success of breeding in Porto Santo Island (2011 and 2012).

Parameter	$\beta \pm SE$	Wald Stat.	p
Intercept	-0.67 ± 0.15	0.85	0.45
Entrance Depth	3.18 ± 1.08	2.23	0.001
Entrance			
Altitude	-0.78 ± 0.45	0.45	0.34
Entrance Width	1.56 ± 0.67	0.56	0.38
Cavity Depth	-0.70 ± 0.51	0.89	0.40
Cavity Width	-0.54 ± 0.12	0.77	0.56
Cavity Altitude	1.59 ± 0.33	0.91	0.09
Sandy Substrate	2.99 ± 0.13	2.1	0.01
Rocky Substrate	-0.23 ± 1.67	0.78	0.88
Orientation S	0.78 ± 0.34	0.89	0.21
	-3.56 ±		
Orientation N	0.56	2.67	0.01
Orientation SW	-1.01 ± 1.05	0.55	0.41
Orientation SE	4.87 ± 0.14	6.69	0.001

Nest site fidelity

Between 2010 and 2013, birds breeding in Selvagem Grande Island had higher one-year nest site fidelity than birds breeding in Porto Santo Island, but lower 2-year nest site fidelity than breeders from Porto Santo Island. In Selvagem Grande Island, just 7.3% of the individuals appeared at the same borrow during 3 consecutive years (Table VIII).

Table VIII – Nest site fidelity (in percentage) of individual Macaronesian shearwaters breeding in Selvagem Grande and Porto Santo, between 2010 and 2013.

Breeding location	1 year	2 years	3 years
Selvagem Grande (N = 100)	75.3	17.4	7.3
Porto Santo (N = 37)	60.9	39.1	—

Reproductive parameters

Eggs measurements

Eggs from Porto Santo Island seem to be slightly longer, larger and overall with more volume than eggs from Selvagem Grande Island (Table IX). However, there were no significant differences in egg measures between islands.

Table IX – Comparison of Mean (\pm S.D.) of Macaronesian shearwater (*Puffinus baroli*) egg length (mm) and breadth (mm) and volume (cm³) between Porto Santo and Selvagem Grande Islands. Data was assembled from 2012 and 2013. Samples sizes are given in brackets.

Egg measurements	Breeding location		Statistic		
	Selvagem Grande	Porto Santo	DF	F	p
Length (mm)	48.13 \pm 1.90 (25)	48.81 \pm 3.01 (20)		0.84	0.364
Breadth (mm)	33.71 \pm 1.28 (25)	34.14 \pm 2.46 (20)	1, 43	0.58	0.452
Volume (cm³)	54.80 \pm 4.88 (25)	57.53 \pm 9.17 (20)		1.65	0.206

Hatching success

Length, Breadth and volume of successful eggs (i.e. those eggs that hatch) were similar to those of unsuccessful eggs (Table X).

Table X – Comparison of egg measurements (mean \pm S.D., with sample sizes indicated between brackets) of Macaronesian shearwater (*Puffinus baroli*) between eggs that hatched and eggs that did not hatch in 2012.

Egg measurements	Hatching success		Statistic		
	Success (1)	No success (0)	DF	F	p
Length (mm)	48.84 \pm 2.65 (7)	48.29 \pm 1.69 (10)	1, 15	0.28	0.606
Breadth (mm)	33.46 \pm 2.01 (7)	34.47 \pm 0.92 (10)		1.99	0.179
Volume (cm³)	54.98 \pm 8.28 (7)	57.42 \pm 3.71 (10)		0.69	0.420

Hatching date in Porto Santo 2011 e 2012

It was possible to study this variable only in Porto Santo, where eggs hatched significantly earlier in 2012 (n=8) than in 2011 (n=6) (respectively, 97.3 \pm 1.36 days vs 74.6 \pm 3.2 days after 1 January; $t_{12} = 16.16$; $p < 0.005$; Fig.2).

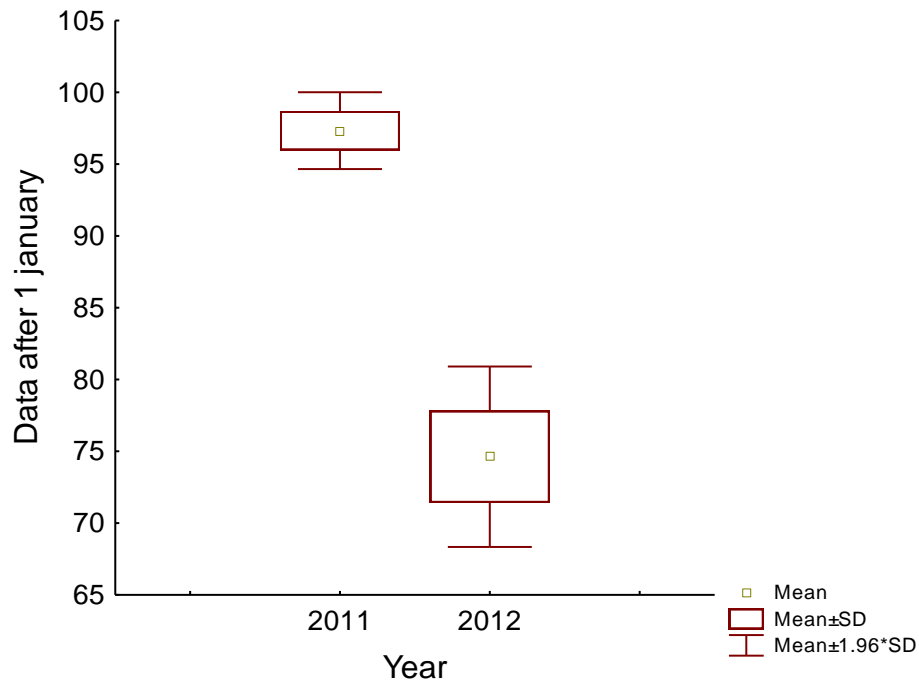


Figure 3 – Egg hatching dates in Porto Santo since January 1 for the breeding seasons of 2011 (n=6) and 2012 (n=8).

Effect of island and year on Macaronesian shearwaters hatching success in Porto Santo and Selvagem Grande Islands in 2011 and 2012

During 2011 and 2012, 68 nests of Macaronesian shearwaters were followed throughout the breeding seasons in Porto Santo (n= 31) and Selvagem Grande (n= 37) Islands. We did not find any statistical differences on the hatching success between islands, study year and the interaction of both variables (Table XI).

Table XI – Effect of breeding location and year on Macaronesian shearwater (*Puffinus baroli*) nest' success in Porto Santo and Selvagem Grande Islands in 2011 (n= 31) and 2012 (n= 37).

Effect	Wald test	p
Island	$\chi^2_1 = 2.33$	0.126
Year	$\chi^2_2 = 1.07$	0.302
Year *Island	$\chi^2_3 = 0.18$	0.674

Chick's growth on Selvagem Grande Island in 2011 and 2012

There were a total of 17 chicks registered in the two years, and we can notice that the wing-length chick growth was higher in 2012 (n= 13) than in 2011 (n=4). The increase of growth in the wing was mostly noticeable until 30 days followed by a decrease in the growth rate (Fig.3).

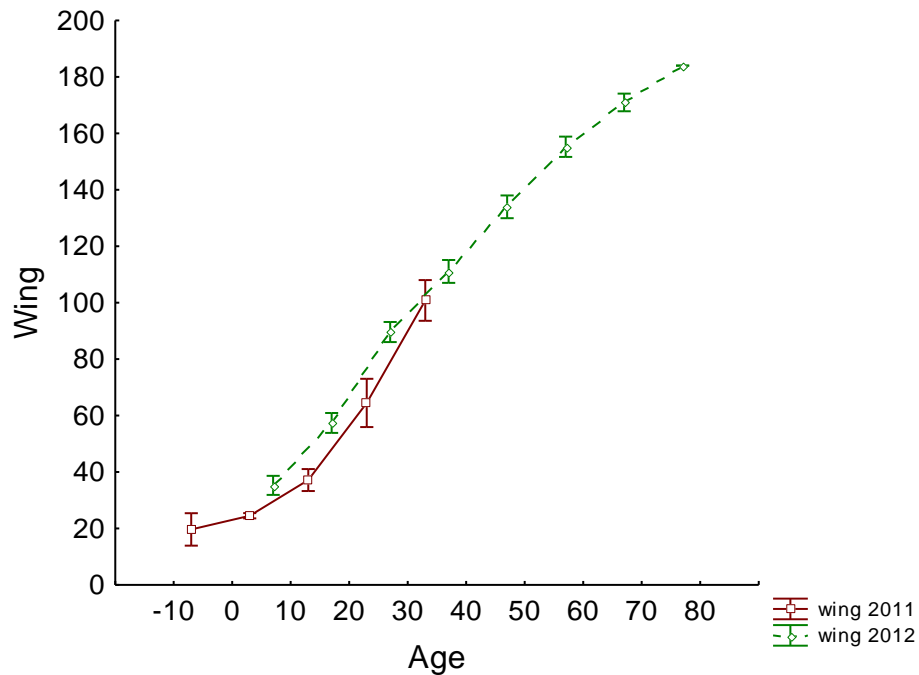


Figure 4 - Wing-length growth of Macaronesian shearwaters chicks in Selvagem Island in 2011 (n= 4) and 2012 (n= 13). Values are mean \pm SD.

In relation to the growth curve in terms of body mass (Fig. 4), there was an increment of weight more uniform and continuous in 2012 (n=13) than in 2011 (n=4). Similarly to the wing-length growth, the growth rate was higher until 30 days of life, followed by a stabilization and a decrease before fledging.

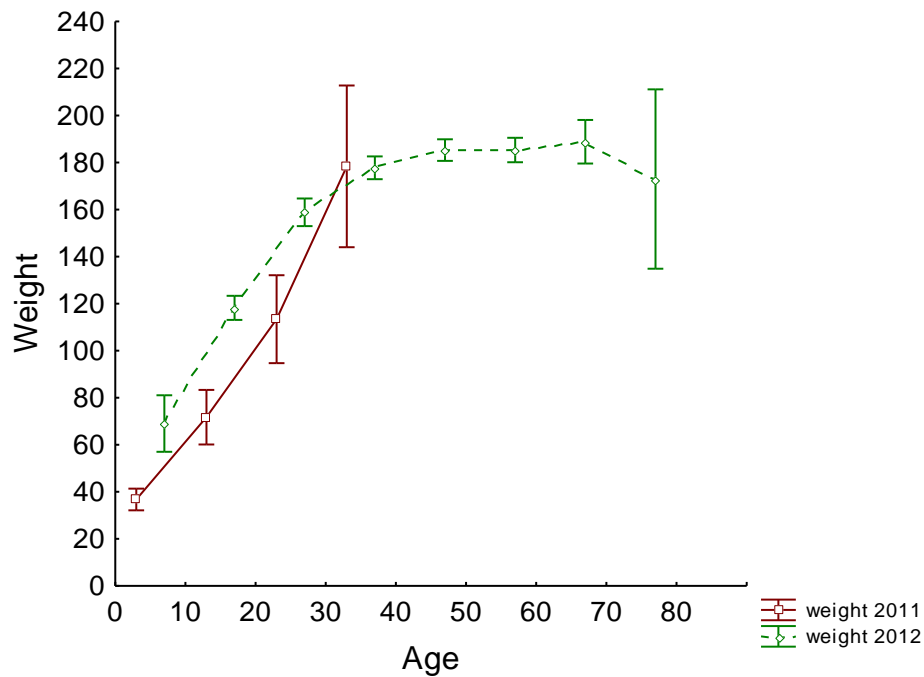


Figure 5 – Body mass growth of Macaronesian shearwaters chicks in Selvagem Island in 2011 (n= 4) and 2012 (n= 13). Values are mean \pm SD.

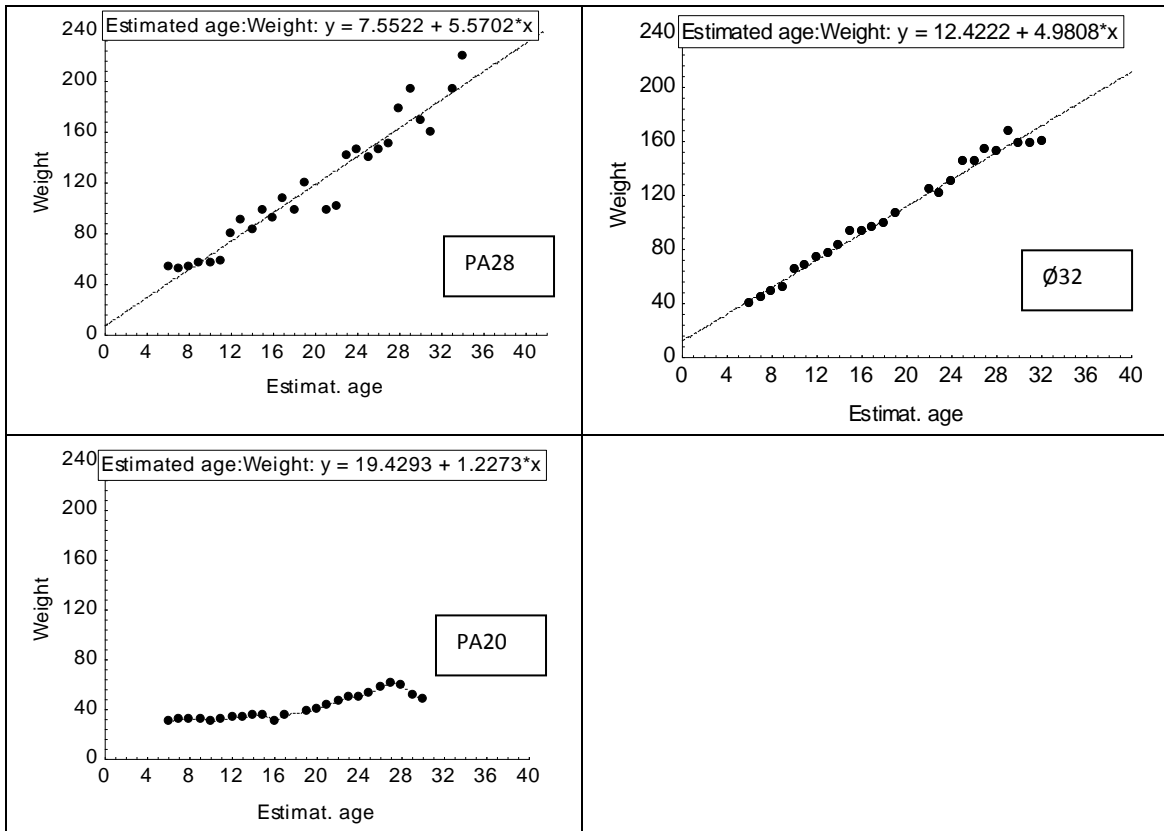
Body mass growth of Macaronesian shearwater chicks of Selvagem Grande Island in 2011 and 2012 during the linear growth phase.

For the linear growth phase the chick growth, in terms of weight, was followed from day 6 to day 40. Three chicks in 2011 and 6 chicks in 2012 were analyzed (Fig. 5). Because some chicks died, a growth curve was made for each chick, separately. The chicks are represented by the classification of their nests: In 2011, on PA28 and Ø32 nests the growth of Macaronesian shearwater chicks was rather uniform and continuous from which we consider that both birds had fledged. On the other hand, on PA20 the growth of the offspring was irregular and weak so we considered that the bird died (Fig.5).

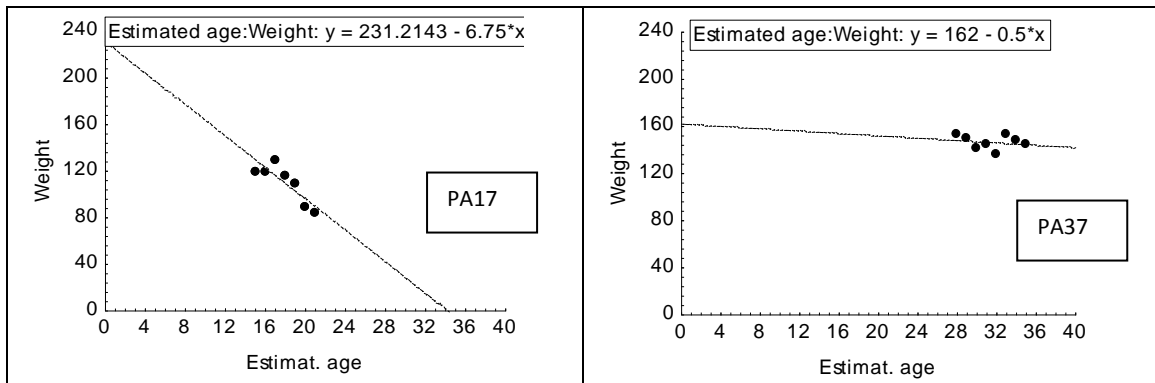
In 2012, the first two nests analysed, PA17 and PA37, the growth of chicks appears to be negative. In fact, the chick of PA17 suffered a weight decline and died which justify this result. Still, in the case of PA37 nest the chick succeeded and fledged. For the remaining nests all chicks were successful and it is easily

observable in the graphs that growth rate was more or less uniform and continuous (Fig.5).

2011



2012



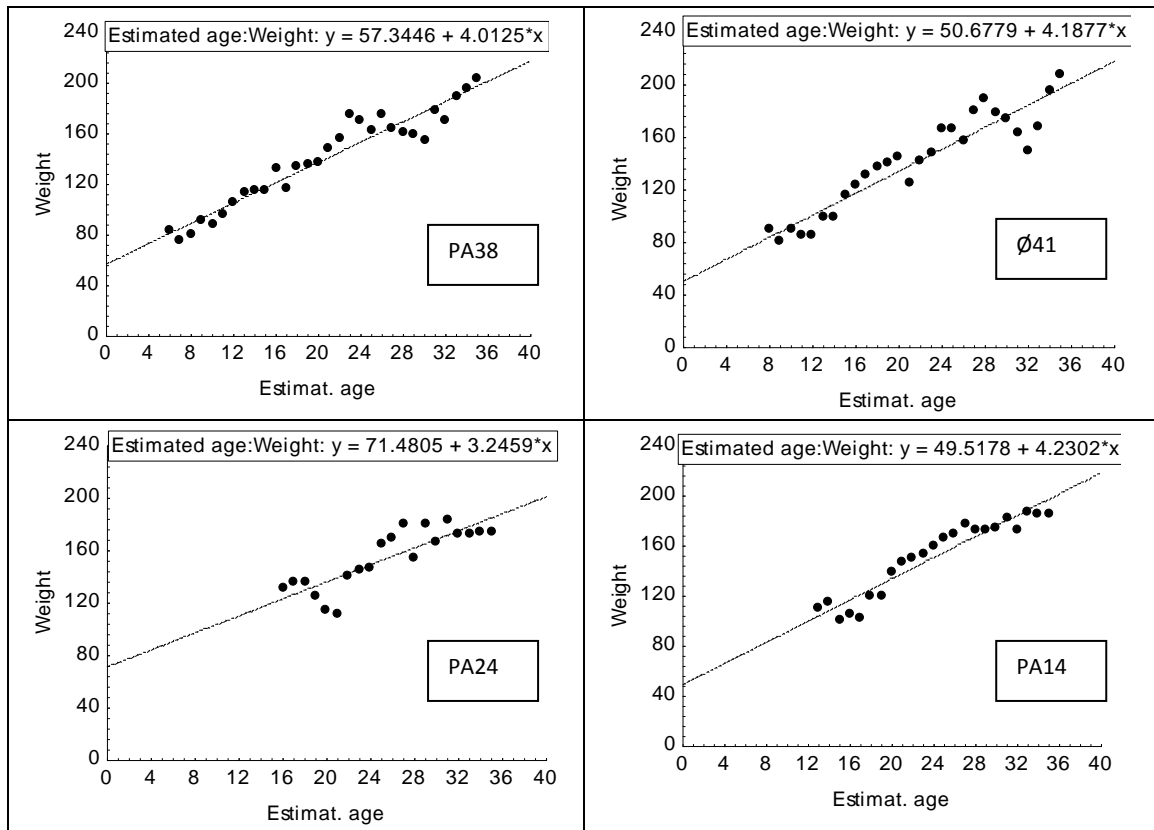


Figure 6 – Growth of Macaronesian shearwater chicks in Selvagem Grande Island in 2011 and 2012.

Overall, the linear growth rate of chicks was significantly higher in 2012 ($n=6$) than in 2011 ($n=3$; Mann – Whitney U test: $Z = -2.32379$, $p = 0.024$) (Fig.6).

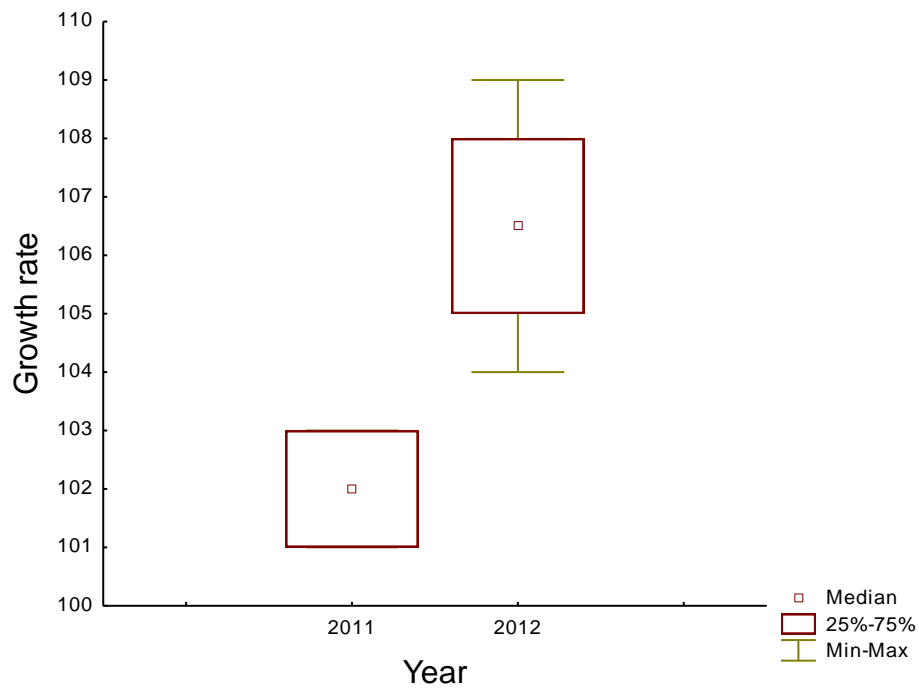


Figure 7 – Growth rate of Macaronesian shearwaters chicks during the linear growth phase (from 6 to 40 days of age) in Selvagem Island in 2011 (n= 3) and 2012 (n= 6).

Daily Weight increment of the Macaronesian shearwater offspring in 2012 in Selvagem Grande Island.

In 2012, 11 chicks were followed to register their daily weight increment in Selvagem Grande Island. Weight increment had a mean value of around 10 g/day until chicks were about 30 days old, after that there was a slow decrease up to 56, 57 days and finally a higher decrease in the weight increment until birds reached 67, 68 days, the time of their fledging (Fig.7).

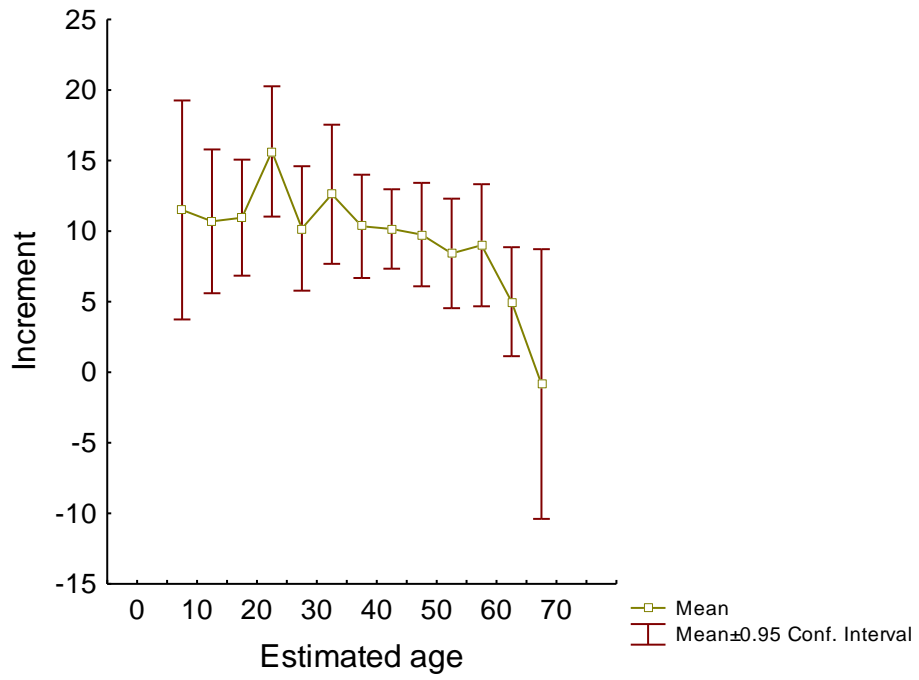


Figure 8 – Weight increase of the Macaronesian shearwater offspring in 2012 (n= 11) in Selvagem Grande Island.

Chapter 4 - Discussion

Population Estimate

This study presents the first description of reproductive biology of Macaronesian shearwaters breeding in Selvagem Grande and Porto Santo Islands allowing a comparison between both islands. This is of particular importance given the fact that this species is restricted to the Macaronesian islands and previously there was no information about the reproductive biology of this species for these two islands. Moreover, the population estimates for Selvagem Grande Island in the 1990's was about 2050 pairs (Oliveira & Moniz. 1995), and given the fact that the total European population is estimated at 3040-4430 breeding pairs (Table XII, Groz *et al.* 2005), this suggests that Selvagem Grande Island holds a potentially large colony of Macaronesian shearwater. However, these estimates were based on extrapolations from census of only a few areas and new estimates are urgently needed.

Table XII – Total population estimates of Macaronesian shearwaters *Puffinus baroli* breeding pairs in Europe, Portugal, Selvagem Grande Island, Azores and Canary Islands.

	Europe	Portugal	Selvagem Grande	Azores	Canary Islands
Breeding pairs	3,040 4,430	– 2,640 4,030	– 2050 4900	- 840 – 1,530	400
References	Groz & Pereira 2005	Groz & Pereira 2005	Oliveira & Moniz 1995	Groz & Pereira 2005	Rodríguez & Rodríguez 2009

Estimating population numbers of most procellariiform species is particularly difficult because most shearwaters and petrels are nocturnal, nest in underground burrows that are difficult to count and often occupy inaccessible, remote nesting sites. Consequently, the size of most colonies is poorly known (Perrins, 2005; Rodríguez *et al.* 2011). In this study we try to get more data on the

population of Macaronesian shearwaters in Selvagem Grande and Porto Santo islands. Our estimates should be over-estimates because there may be high variation in the number of occupied burrows among different areas. According to our data, there seems to be a drop in the population numbers of Macaronesian shearwaters in Selvagens to ~1407 breeding pairs (considering the former estimate of 2050 breeding pairs) This is in accordance with the reported declining of this species since the 1990's (Rodríguez & Rodríguez. 2009). Moreover, studies performed in Canary Islands show mortality rates on Tenerife, higher enough to have severe effects on the population dynamics of the species. The decline in the number of rescued fledglings (a program implemented by the La Tahonilla Wildlife Rehabilitation Centre where the sampling effort is rather constant among years) seems to indicate a decline in the breeding population and/ or a decline in breeding success sustained over several consecutive years (Fig.8). Population decline has also been suggested by limited field observations (Madroño *et al.* 2004; Lorenzo, 2007; Rodríguez & Rodríguez, 2009; Rodríguez *et al.* 2011).

Despite all ideas discussed before, we suggest that to gather more reliable population number estimates for this species, the census should be made over several years at the time of reproduction, in order to get a realistic value, by buffering the inter-annual asynchronous breeding behaviour of this species. Moreover, we believe such future census would gather more representative data if they are made with the Brooke method (1978), which relies on a tape-recording of a male shearwater call, played down on a sample of burrows during the incubation period to detect any reply from inside the potential nesting borrows (Perrins, 2005).

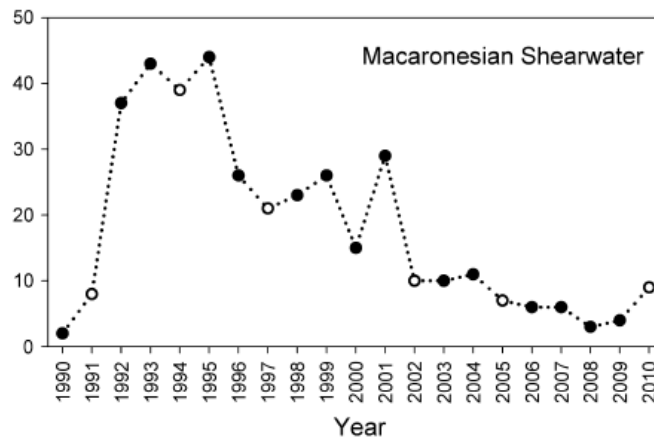


Figure 9 – Number of rescued fledglings of Macaronesian shearwater collected by the rescue campaigns on Tenerife (Canary Islands) (adapted from Rodríguez *et al.* 2011)

Many petrels have suffered substantial declines in recent times; more than 50% of the species from this group are threatened, mostly due to the presence of introduced predators in their breeding grounds (Jones *et al.* 2008) and the impact of commercial fisheries at sea (Rodríguez & Rodríguez, 2009; Ellis, 2005). The introduction of exotic mammals has contributed to high levels of competition for nest cavities (Igual *et al.* 2005). Also high levels of intraspecific and interspecific interference competition may be a result of alteration of breeding habitats in historical times and competition for nesting sites may play a more important role in limiting present seabird populations (Groz & Pereira. 2005).

In Selvagem Grande Island, the end of the exploitation of Cory's shearwater by humans (i.e. until 1974 chicks were killed yearly at the Island) and the eradication of terrestrial mammals mice (*Mus musculus*) and rabbits (*Oryctolagus cuniculus*), in 2002, from the Selvagem Grande increased the Cory's shearwaters population substantially (Granadeiro *et al.* 2006; Zino *et al.* 2008). This event may lead to a higher competition for nest cavities (Ramos *et al.* 1997). The increase of the Cory's shearwater population and another factors occurring in breeding colonies such as habitat selection (Jones, 2001; Tieleman *et al.* 2007) justifies the large proportion of nest site sharing between species (Monteiro *et al.* 1996^a). In 2011 and 2012 the following events were observed in Selvagem Grande island: 1) presence of *Bulweria bulwerii* on six active nests of Macaronesian Shearwater; 2) one occupied nest of Macaronesian Shearwater excavated by Cory's Shearwater; 3)

five unoccupied nests excavated by Cory's Shearwater; 4) from 61 nests of Macaronesian shearwater found, 16 were occupied by them; 31 were occupied by *Bulweria bulwerii*; 4 by Cory's Shearwater and 1 by *Bulweria bulwerii* and Cory's Shearwater; 5) the two species (*Bulweria bulwerii* and Macaronesian shearwater) share the nest, even one of them having a chick on development. This kind of events suggests high levels of intra and interspecific competition.

Another threat to Macaronesian shearwaters is the possible predation by Madeiran Wall Lizards *Teira dugesii* present in the Madeira, Desertas and Selvagens archipelagos. During 2006 and 2007, Matias *et al* (2009), performed a study to understand the impact of this reptile in the Cory's shearwaters performance. A sample of 231 Cory's Shearwater nests was studied in Selvagem Grande. Forty cases of Cory's Shearwater chicks killed by lizards were recorded. In 2006, the overall breeding success of Cory's Shearwaters was reduced by 5.1% and, in 2007, was reduced by 5.2% (Matias *et al.* 2009). The same study also reported the killing of smaller procellariiform species by lizard species. Namely, four Bulwer's Petrel chicks, one Madeiran Storm-petrel chick and one White-faced Storm-petrel chick were likely killed by lizards (Matias *et al.* 2009). Small petrels are highly vulnerable to predators attacks (Tomkins 1985), therefore the Madeiran Wall lizard may represent a big threat to Macaronesian shearwaters, making the assessment of potential impacts on small crevice-nesting birds a priority on Selvagem Grande Island and elsewhere in the world.

Body mass and biometrics of the Macaronesian Shearwaters of Selvagem Grande and Porto Santo islands

The body mass and biometric measures of Macaronesian shearwaters from both islands showed that birds from Porto Santo Island are larger than those from Selvagem Grande Island. Moreover, Macaronesian shearwaters breeding in the Azores are even slightly bigger than their relatives from Porto Santo Island (Monteiro *et al.* 1996^b). Such pattern is in accordance with the general theory that birds get bigger towards higher latitudes (table XIII).

Table XIII – Reproductive parameters in Atlantic Islands where Macaronesian shearwaters is present. Wing and tarsus lengths (mm) and body mass (g) of Macaronesian shearwaters (*Puffinus baroli*) breeding on Azores, Porto Santo and Selvagem Grande Islands (mean \pm SD (N)); l=length, b=breadth.

Parameters	Azores	Porto santo (this study)	Selvagens (this study)	Canary Islands	Bibliography
	49.69 /	48.81 /	48.13 /		
Egg volume	34.18 (l/b)	34.14 (l/b)	33.71 (l/b)	-	Monteiro <i>et al.</i> (1996 ^b)
Laying period	Late January	January	Late January	Late January	Monteiro <i>et al.</i> (1996 ^b); Rodríguez & Rodríguez, 2009
Hatching date	Mid-later March	Later March/April	Later March/April	April/May	Monteiro <i>et al.</i> (1996 ^b); Rodríguez & Rodríguez, 2009
Fledging date	Mid-later May	-	Mid-later May	May	Monteiro <i>et al.</i> (1996 ^b); Rodríguez & Rodríguez, 2009
Body mass (g)	171.8 \pm 13.3 (157)	168.17 \pm 16.95 (92)	163.98 \pm 14.60 (200)	-	Ramos <i>et al.</i> (1997), Monteiro <i>et al.</i> (1996 ^b)
Wing length (mm)	182.6 \pm 4.01 (133)	182.63 \pm 3.78 (82)	181.12 \pm 3.93 (162)	-	Monteiro <i>et al.</i> (1996 ^b)
Tarsus length (mm)	37.77 \pm 1.03 (93)	37.28 \pm 0.90 (81)	36.68 \pm 0.86 (159)	-	Monteiro <i>et al.</i> (1996 ^b)

Nest-site characteristics analysis

In Selvagem Grande and in Porto Santo Islands it seems that laying probability increases with the presence of sandy substrate which could mean the need of security for the eggs, indeed in rocky substrate is easier to tumble or breaking the eggs. There is also the fact that soil burrows had more stable nest temperatures than rocky crevices (Drummond & Leonard 2010).

In Selvagem Grande the laying probability and the hatching success increases when nests are orientated towards South-West and decreases when existing nests are orientated towards South-East. In Porto Santo the laying probability increases when nests are orientated towards South-East. On opposite, laying success decreases when nest are orientated towards North. This may be due to the fact that in the Atlantic, in our study area, the prevailing winds and harshest weather conditions come from the North. Probably in an opposed direction in relation to the North, nests are more protected from wind, rain and colder weather (Ramos *et al.* 1997). Both in Selvagem Grande and Porto Santo Islands the probability of laying success increases with deeper nest cavities and longer borrow entrances, respectively. We believe that the selection of such characteristics is related with the protection from possible flooding (Brooke, 1990) and perhaps protection from predation (other birds such as gulls (Matias *et al.* 2009)). Characteristics of the nest site can influence reproductive success and adult survival. In long-lived seabird species with high fidelity to the nest site, initial selection may be particularly important because it can affect the lifetime reproductive success of a breeding pair (Drummond & Leonard 2010). Small petrels focus on fairly sheltered cavities because they need greater protection against rainfall, drainage and wind (Ramos *et al.* 1997).

Nest site fidelity

Nest-site tenacity and mate fidelity are relatively high in Procellariiformes comparing with other seabirds (Warham, 1990). The maintenance of the same nest and mate from year to year has potential advantages as save time at the start of the breeding season and it may improve breeding success because of the better

coordination between the parents (Thibault, 1994). Macaronesian shearwaters breeding in Selvagem Grande Island had higher one-year nest site fidelity than birds breeding in Porto Santo, but lower 2-year nest site fidelity than breeders from Porto Santo Island. In Selvagem Grande Island, just 7.3% of the individuals appeared at the same borrow during 3 consecutive years. Despite this really low value of nest site fidelity, birds from Selvagem Grande Island exhibited a higher nest-site tenacity (Mougin *et al.* 1987) and with higher nest-site tenacity increases the mate fidelity (Thibault, 1994). According Bradley *et al.* (1990) mate retention is associated with high survival rates, which means that the apparent declining of the specie could be related to problems on nest-site tenacity, consequently associated with maladaptive habitat use.

Reproductive parameters

In relation to egg measurements, our data from Porto Santo and Selvagem Grande suggests that birds from these two islands lay smaller eggs than those from the Azores and the measurements from Selvagem Grande are the smallest ones (Azores: length = 49.69 ± 1.72 and breadth = 34.18 ± 1.18 (17) (Monteiro *et al.* 1996 ^b); Porto Santo: length = 48.81 ± 3.01 and breadth = 34.14 ± 2.46 (20); Selvagem Grande: length = 48.13 ± 1.90 and breadth = 33.71 ± 1.28 (25) (the measures are in mm). This is consistent with the results of body mass, i.e. larger females lay larger eggs.

In our study it seems that the size and shape of eggs did not have a significant influence on the hatching success, which is a result in accordance with previous studies in other procellariiform species (Warham, 1990). The size of the egg should reflect the age and also the quality of the female (Brooke, 1990; Monaghan 1996), but other factors such as the quality of the nest-site will influence whether the eggs breaks during the incubation period or not (Birkhead & Nettleship. 1987). In our study most of the eggs that did not hatch were abandoned by birds during the incubating, suggesting that environmental factors related with food availability could have played a role in explaining such egg abandonment events (Birkhead & Nettleship 1987).

In Porto Santo Island, eggs hatched much earlier in 2012 than in 2011, meaning that laying date was also earlier in 2012. Presumably the different environmental conditions in both years contributed to explain such difference in laying dates. The species has high survival and low fecundity, which make it especially vulnerable from environmental changes because even small decreases in survival will potentially have huge effects on the lifetime reproductive success of individuals (Stenseth *et al.* 2002; Sandvik & Erikstad 2008). Another explanation could be the presence of a higher proportion of young birds in the colony which are expected to laid at later dates (Warham *et al.* 1982), meaning that the younger and inexperienced females have a higher variation in laying date (Brooke, 1978). Little shearwater *Puffinus assimillis haurakiensis* breeding in New Zealand also showed asynchronous laying and Booth *et al.* (2000) pointed out that this might be due to the non-migratory behaviour of the species, whereas migratory procellariiforms usually lay synchronously. The little shearwater is a sedentary species with relatively short incubation and chick periods, and may be under less selection pressure to lay synchronously (Booth *et al.* 2000), which we assume that also happens with Macaronesian shearwater.

In 2011, the laying dates in Selvagem Grande and Porto Santo Islands were similar since eggs hatched between 30th of March 30 and 9th of April. In Azores, it seems that this period occurs a bit earlier on Azores, with chick-rearing starting in the middle of March (Monteiro *et al.* 1996^b), and both in Porto Santo and Selvagem Grande Islands the hatching seems to extend until beginnings of April. On the other hand in Canary Islands, laying and hatching date occurs later than in Selvagem Grande Island (April/May). There seems to be a clear latitudinal pattern on the breeding phenology of the species, related with the geographical location of there breeding colonies. This meaning that, timing of breeding events are anticipated with increasing latitude of the breeding colonies location.

In relation to hatching success we did not find an effect of Island, Year or interaction in explaining hatching success of this species. It is necessary to keep monitoring these populations and have a larger sample size in order to have more confidence in our results. The cases of failure of the Macaronesian shearwater chicks in 2011 were solely egg abandonment. In 2012, the majority of deaths occurred mainly due to a heavy storm (eggs were flooded). Reasons for such an

abandonment of those chicks that died could be related with adults having difficulties in finding food at sea (having to prioritize their own survival in detriment of the chick's survival).

Chick provisioning and foraging ecology

The adults feed chicks through regurgitated food in the cross-billed manner typical of procellariiform species. By weighing chicks twice a day (in the morning and at end of the day) we can record the increase of weight in that night and check if the chicks were visited and feed. The results for wing-length chick growth and body mass growth curves of the offspring from Selvagem Grande Island were higher in 2012 than in 2011. This difference could be related with different climatic/environmental conditions between years. The growth rate of the linear phase was significantly higher in 2012 than in 2011, which again agrees with this line of reasoning. However we must stress that our data is based on a small sample size and this could affect our results

Analysing the graph results, in 2011, it was verified that the weight of Macaronesian shearwaters offspring increases daily for the firsts 5 – 6 days, we cannot analyse this for 2012 because all the chicks were found with a later age. In both years, the weight fluctuates around an asymptote of 80 - 200 g, finalizing with a decrease of weight before the chicks fledge. The reasons for this should be related with parents feeding their offspring at least once a day during the first days of life, and then increasing the duration of their foraging journeys. An explanation for decrease in body weight before fledging can be interpreted as an impulse for the chicks to start their own foraging excursions at sea. The Macaronesian shearwaters should follow the provisioning strategies of other procellariiform species, with provisioning shifts between parents (Booth *et al.* 2000).

In general, the daily weight increment in Selvagem Grande Island suggests the same theory, as it was verified, weight increment had a mean value of around 10 g daily until chicks were about 30 days old, after that the weight decreases up to 56, 57 days and finally a higher decrease until birds reached 67, 68 days, the time of their fledging. At this time most of the birds have the average weight adults of the species. With similar results, the study performed in the North Island of New Zealand with Little shearwaters show that up to 45 days old, chicks had an

overnight weight increase on 93% (n = 155 observations) of the days that they were weighed. This frequent feeding of chicks does not support the theory that large fat deposits in the Procellariiformes are an adaptation to poor feeding conditions, when the frequency of meals delivered to the chick may decrease. Rates of chick feeding may differ between breeding seasons, so it is necessary to monitor chick provisioning for several years in order to confirm the regularity of chick feeding in the Macaronesian shearwaters.

Conservation issues

Conservation and management programs for seabirds are quite recent and still have a lot to improve in efficiency, but since the current population numbers of Macaronesian shearwaters remains poorly known and perhaps in a possible declining trend over all islands of the Macaronesia this requests for a management plan. Such a plan was required by the Spanish law and should be based on three key points: (1) control of cats and rats at colonies; (2) enhancement of the rescue campaign during the fledging months to improve citizens' awareness and improve rehabilitation procedures to reduce the mortality of rescued birds by providing food and liquid, and test waterproof properties of plumage; and (3) execution of a detailed survey program on the distribution, population size and breeding parameters to evaluate its demographic dynamics (Rodríguez *et al.* 2011).

The population of Macaronesian shearwaters breeding in Selvagem Grande Island depends highly on the Canary Current system to forage for food. This ecosystem is also highly used by industrial fisheries, which means a possible impact of overfishing and bycatch on the species survival (Fagundes *et al.* 2011). This would need further investigations at sea (e.g. at-sea census surveys and individual tracking studies) to understand the importance of those impacts on the species' survival. The movements, foraging areas and diet of the smallest and most secretive shearwater of the subtropical Atlantic remain largely unknown. Therefore, it is essential to evaluate the factors that may alter the current and future dynamics of its populations as well as help identify important conservation areas at sea (Neves *et al.* 2012). Besides this, it would be important to create more management actions of educational programs (e.g. leaflets, posters, rescue

campaigns, radio and TV spots) (Groz *et al.* 2005) and even to convert this species into a Flagship species for the general public.

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