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## **BREEDING BIOLOGY AND NEST-SITE CHARACTERISTICS OF THE LITTLE SHEARWATER (*Puffinus assimilis*) NESTING ON NORTH-EAST ATLANTIC ISLANDS**

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## ABSTRACT

The most delicate periods in the life of a bird are certainly at the egg and chick stage: the life in the nest. This is a very dangerous period because eggs and, in most species, also the chicks are totally armless and dependent on their parents. The happy ending of the story of the nestlings depends on the parental ability to find a good nest-site, and on their ability to defend it and to feed the chick. These capability vary according to their condition and experience. Using a multivariate logistic regression we found that some nest-site characteristics are associated with the nest-site selection process by the parents and that other characteristics probably influence the hatching success in two colonies of Little Shearwater (*Puffinus assimilis*) nesting in Selvagem Grande Island and Porto Santo Island (Madeira, Portugal). In this study we also compared some differences in some breeding parameters between the two colonies, in particular hatching date and hatching success. These differences are probably due to different habitats and different interactions with the other breeding species nesting in the same place. Although this is the first study of this type conducted on the Little Shearwater, our results are comparable with those obtained in other closely related species. The Little Shearwater is considered a good indicator of the conservation of the marine habitat, and the data we collected on nest-site selection can be exploited for conservation policy, like the construction of artificial nests, as already experienced for other species, whereas the knowledge on the breeding biology can be used for the fishing management of the areas where the species lives.

## RIASSUNTO

Le fasi più delicate nella vita di un uccello sono sicuramente quella di uovo e quella di pulcino: la vita nel nido. È un periodo molto pericoloso durante il quale l'uovo e, in molte specie, anche il pulcino sono totalmente indifesi e dipendenti dai loro genitori. Il lieto fine della storia di un pulcino dipende quindi dall'abilità dei genitori di trovare un buon sito per la nidificazione, di saperlo difendere e di nutrire il pulcino. Queste capacità variano a seconda delle loro condizioni fisiche e alla loro esperienza. Utilizzando una regressione logistica multivariata abbiamo trovato che alcune caratteristiche del nido sono associate alla scelta del nido stesso da parte del genitore e che altre potrebbero influenzare il successo della schiusa delle uova di due colonie di *Puffinus assimilis* nidificanti nelle isole di Selvagem Grande e Porto Santo (Madeira, Portogallo). In questo studio abbiamo inoltre confrontato alcune differenze nei parametri della biologia riproduttiva tra le due colonie, in particolare le date di schiusa delle uova e i successi della schiusa. Queste differenze sono probabilmente dovute a differenti ambienti e a differenti interazioni con altre specie che nidificano nello stesso posto. Anche se questo è il primo lavoro di questo tipo condotto sul *P. assimilis*, i nostri risultati sono comparabili con quelli ottenuti per altre specie simili. Questa specie è considerata un buon indicatore per la conservazione dell'ambiente marino e i dati raccolti sulla scelta del nido possono essere utilizzati per interventi di conservazione della specie per esempio con la costruzione di nidi artificiali, già sperimentati per altre specie, considerato che la conoscenza della biologia riproduttiva può essere sfruttata per la gestione della pesca nelle aree in cui vive questa specie.

## INTRODUCTION

### Natural selection

Natural selection is an evolutionary mechanism that allows to an individual with certain heritable characteristics to have an higher fitness among another one of the same species that does not have got them, in the same habitat in the same time. This theory, exposed by Darwin in *Origin of Species* in 1859, is one of the basis of the most accepted modern evolutionary theory: the modern synthesis (Mayr, 2002). This is one of the most powerful tool to understand and to study the life history of the specie.

### The extend phenotype concept

Dawkins proposed, in 1982 in *The Extended Phenotype*, an extension of the classic natural selection theory: in the same way that there are demonstrably genes for a physical characteristic, there must be genes whose phenotypic expression is apparent, for example, in the architecture of a web of a spider or a nest. However, we know all too little about phenotypic variation in animal-built structures or in its genetic bases. If we suppose that the number of radii in the orb web of the garden spider, *Araneus diadematus*, has a genetic bases, than it follows that, if web variants with more radii were more successful than those with fewer, than spiders with a genotype for many radii would increase in the population at the expense of those with the phenotype for fewer radii (Hansell, 2000). Another context in which the concept of extende phenotype can be applied is certainly that of nest-building birds. There is a incredible interspecific variation is size and shape of the structures that birds use to lay the eggs and raise the nestlings and certainly part of this variation has an adaptive value (Hansell, 2000). However, there is substantial variation also at the intraspecific level. Whether this variation has a genetic basis and it is associated with variation in fitness, however, is largely unexplored.



Fig.1: a classic web of a garden spider *Araneus diadematus*.

The concept of extended phenotype is not limited to nest-building birds, however. In case of species that do not directly built their nest, but rather they choose these, like some hole-nesting birds, we can consider that the choice of the nest location itself has certainly a genetic base and is likely to have strong fitness consequences.

### Nest-site

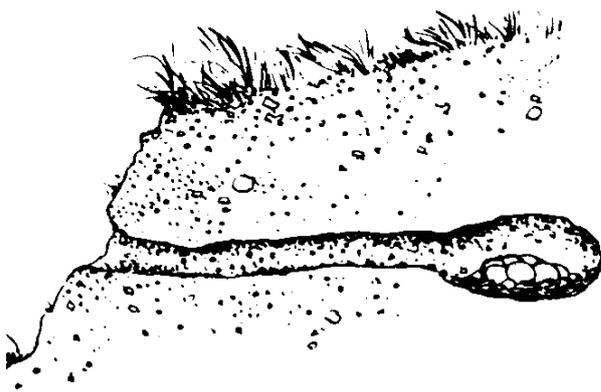
For all bird species, the stage of development, from the fertilization of the egg to the young development, is certainly the most delicate stage throughout the entire life of the individual. This is even more true in species like flying birds: normally an adult can escape rapidly from a danger to a safety place. Contrariwise, egg and nestlings stage are extremely armless and they can be easy victims of predator and weathering. The parent has so to choose a proper nest-site for the best develop of its offspring and it has also to defend the nest from intruders of both same and other species.

In the class Aves we can find various nesting methods, from the simple ashore laying of the ostrich *Struthio camelus* (Cramp, 1977), to the more elaborate and complex common-nest of the sociable weaver *Philetairus socius* (Bartholomew et al, 1976). All these methods are very different and they respond to different selective pressures of different habitats in which the different species live, but are all likely to be selected: to give the offspring the better place where to develop.



Fig.2: a huge common-nest of Sociable Weavers *Philetairus socius*.

Nesting on branches of a high tree is a common practice for many birds of different families, as this nest location give the eggs and the nestlings a safety place far from non-flying and non-climbing predators. However, this nesting methods also involves some risks: the fallen of an egg or a chick leads to a certain loss of offspring for the breeders, and therefore the nest must be build properly, with an investment of time and resources by the parents. Another problem associated with this kind of nesting method is represented by the limitation of the available nesting sites: trees do not grow anywhere and this involves a limit to the geographic expansion of the population and the rising of the intra-specific competition for the nest-sites available.



a.



b.



c.



d.



e.

Fig.3: different kinds of ashore nests: section of Kingfisher burrow (a), Shelduck standing on the entry of its burrow (b), a pair of Ostriches and their ground-nest (c), an adult and two chicks of Magellanic Penguin in their burrow (d), incubating Coot in its floating nest (e).

The species nesting in inaccessible place probably do this to avoid the predation on the offspring, that ashore is more intense (Ricklefs, 1969); obviously this general rule finds its exceptions according to the habitat where the species live (Martin, 1993; Matessi & Bogliani, 1994). Several species nest ashore, albeit in different ways: the Coot (gen. *Fulica*) builds platforms among the reeds to avoid the drawing of the eggs (Cramp, 1977), the female of Pheasant (*Phasianus colchicus*) erects a little slope and covers it with vegetal material before laying its eggs (Cramp, 1977), while other species like Shelducks (gen. *Tadorna*), Magellanic Penguins (*Spheniscus magellanicus*) and common Kingfishers (*Alcedo atthis*) nest in borrows excavated by themselves or abandoned by individuals of the same or other bird or non-bird species (Stokes & Boersma, 1991; Cramp, 1977; Robertson et al, 2007).

Ashore nesting is observed especially in non-flying birds, like ratites, and also in species living in places with no ground predators, like species nesting on oceanic islands. In the latter case the weathering can play a very important selective role because intense rainfalls can happen, also frequently, causing floods in poorly designed or clumsy nests (Stokes & Boersma, 1991). Furthermore in these isolated habitats, both parents must leave the nest for long periods (from many hours to few days) (Monteiro et al, 1996) abandoning the offspring unprotected against predators and adverse climate.

The ability of the parents to choose nest-sites is really important, especially for borrow-nesting species that do not dig themselves their borrows in order that the offspring can reach the age of fledging, another very delicate stage in the life of a bird.

According to the high importance of the nest, many species evolved a selectivity for the nest-site that sometimes is so rigorous that the intra- and inter-specific competition for the site turns out to be very important (Monteiro et al, 1996). This rule must be even more strong in non-digging cavity-nesting birds that in consequence are limited in the choice.

Therefore the very important function of the nest is the defense of the offspring, as well of the parents, from the weathering and from predation. According to the species and the habitat, the nest-site can be subject to different selective pressure. The Greater Hoopoe-lark (*Alaemon alaudipes*), a passerine nesting in hot desert areas, must accept a compromise between the risk of nest predation and the risk of nest overheating nesting in more exposed sites for an easier ventilation or in more hidden sites to avoid predators (Tieleman et al, 2008); the White-crowned Sparrow (*Zonotrichia leucophrys*) is a species that apparently regulates nest temperature by selecting a suitable pattern of overhead

vegetation (Walsberg & King, 1978). Otherwise for species nesting in burrows, a serious danger is represented by rainfalls that can flood or destroy borrows killing offspring and adults, even if those phenomena are sporadic. This is the case of Humboldt (*Spheniscus humboldti*) and Magellanic (*S. magellanicus*) Penguins that carefully choose the digging area according to the soil conformation (Paredes & Zavalaga, 2001; Stokes & Boersma, 1991).

Not only the nest itself, also the territory has to support the needs of the individual, whether territorial or colonial: when nest-sites are provided experimentally, they are often occupied, leading to an immediate rise in breeding density but in future years this increment will level off. This implies that other limiting factor come into play at this higher level (Newton, 1998).

### **Parents**

Not only the nest, but also parental quality and experience play a fundamental role in the growth and in the development of the offspring. Parents with a good ability of finding food for themselves, probably are in excellent health and they are easily able to supply the nutritional needs of their chicks. Contrariwise, parents who are struggling to find food for themselves it is almost certainly that they cannot take care of their offspring. This rule is applied for several species (Amat et al, 2000; Whittingham & Robertson, 1994).

If the parent is able to learn, the experience could be an advantage especially in long life species (Sanz-Aguilar, 2008): if the parent make a mistake that has an immediate impact on its offspring, probably it will not repeat the same error during its next breeding season.

The defense of the nest, especially in high-density colonial breeders, is a primary duty for the parents; the risks for the parents are not only the loss of the nest-site, but also of the partner, of the offspring (if egg has already been laid) and of its life itself (Tryjanowski P & Goławski A, 2004; Jäntti et al, 2007; Griggio et al, 2003).

### **Aim of the work**

With this work we want to study the nest-site of *Puffinus assimilis* nesting on the oceanic islands of Selvagem Grande and Porto Santo. We want to analyze, using statistical methods, if and how nest-site characteristics are important in the parental choice of the nest site itself and which characteristics affect the hatching success and the chick growth. Habitat selection is likely to be adaptive because, in most species, the choice of a place to live or reproduce can have marked consequences on survival and breeding success (Birkhead et al, 1985).

Habitat preferences and the adaptive significance of such preferences have been demonstrated in a number of species (Partridge, 1978). If selection of breeding habitats is adaptive, habitat quality is likely to be reflected in breeding success (Birkhead et al, 1985).

Many other authors made this kind of study for other bird species like Humboldt and magellanic penguin (Paredes & Zavalaga, 2001; Stokes & Boersma, 1991), the Manx shearwater *P. puffinus* (Thompson, 1987), the Cory's Shearwater *Calonectris diomedea* (Werner, 2010), the Northern Fulmar *Fulmarus glacialis* (Mallory & Forbes, 2010) and other Procellariiformes (Ramos et al, 1997), but never for the Little Shearwater *P. assimilis*. Researches like these ones can help to comprehend the biology of species that can serve as good health indicators of the marine areas used for fishing. These researches can also improve the conservational policy of the species for example building artificial nests (Bolton et al, 2004) custom-made for the species of interest, therefore more effective.

Some species have an economic importance for the mankind. Monitoring and controlling this species is very hard especially on fishing because the extension of the seas and the complexity of marine ecology. An easier way to overcome these problems is using other species economically uninteresting, but tightly linked to the other ones, like indicators of the good state of the ecosystem in which they live together. The most susceptible species under this point of view are predators: a decline of predators could be an effect of a prey pauperization or of a prey pollution and these facts often can have economical repercussions on fishing (Boersma, 1986; Foster et al, 2010; Colabuono et al, 2009; Colabuono et al, 2010). As regard the marine environment, in particular for fished species, birds are important predators. A good biology and life history knowledge of these birds can be very useful for a conscious management of the fishing resources in certain places (Furness & Camphuysen, 1997).

## Materials and methods

### Study area

Macaronesia is a region in the north-east Atlantic Ocean that comprehend several groups of islands: Azores (Portugal), Madeira, including Porto Santo Island and the Desertas Islands (Portugal), Selvagens Islands (Portugal), Canary Islands (Spain), Cape Verde Islands (Cape Verde). Macaronesian islands, but Azores, belong to a geological complex extended from Capo Verde to the coast of Portugal, about parallel to the middle-Atlantic dorsal (Carvalho & Brandão, 1991). Our study areas were on Selvagem Grande (Selvagens Islands) and Porto Santo Island (Madeira).



Fig.6: Macaronesian islands. Arrows indicate Porto Santo and Selvagem Grande.

### Selvagem Grande

Selvagem Grande (30°04'N 15°56'W) is the biggest island in the Archipelago of Savages Islands. It belongs to Autonomous Region of Madeira, Portugal, in the North-East Atlantic Ocean. The island is located 165 km north off the coast of Tenerife (Canary Islands, Spain) and 250 km south off Madeira (Portugal). The entire Archipelago of Savages has got an area of 2,73 km<sup>2</sup>, mostly occupied by Selvagem Grande. The archipelago comprehends two other islands: Selvagem Pequena and Ilhéu de Fora, off about 1 km south the biggest one, and many reefs. The only stable human presence on the archipelago is a team of two rangers of the Madeira Natural Park.

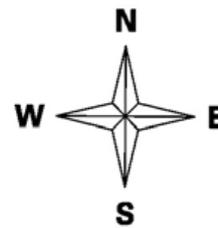
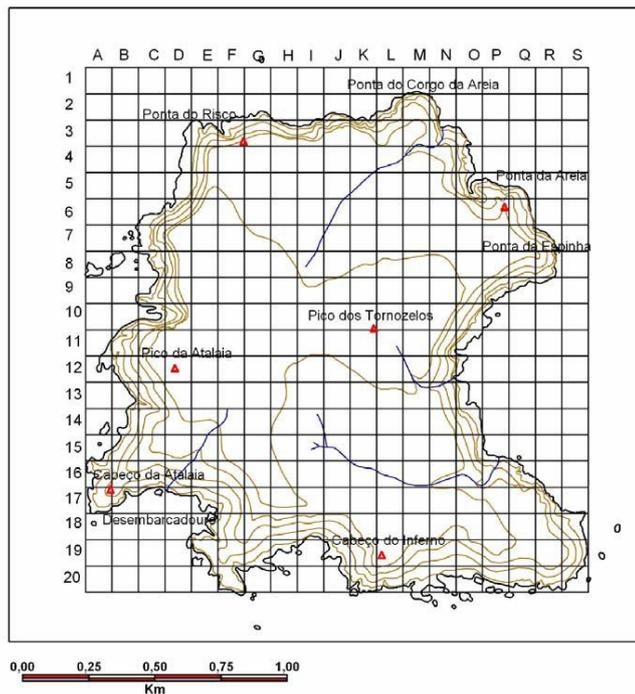


Fig.7: topography of Selvagem Grande.

All the islands of the archipelago have a volcanic origin, formed between 24 and 27 mya and from a geological point of view are more similar to the Canary Islands than to the islands of the Madeiran archipelago (Carvalho & Brandão, 1991). Like the other. The climate is desert with less than 500 mm of rain per year, mostly concentrated in the winter season with heavy rainfalls. The Selvagens group of islands provides an habitat for 111 xerophytic plant species, including 11 that are endemic to the islands (Press & Short, 1994). This flora was undergoing in a decline due to the introduction of rabbits and rats. A campaign for the complete eradication of the rodents from Selvagem Grande started in 2002, ended 3 years after causing a rapid recovery of the entire flora (Oliveira et al, 2010).

In this archipelago 5 species of the Procellariidae Family nest stably, 3 Laridae and only one species of Motacillidae Family. Among Procellariiformes are *C. diomedea borealis* (30.000 pairs), *Pelagodroma marina hypoleuca* (36.000 pairs), *Bulweria bulwerii* (4.000 pairs), *P. assimilis baroli* (2.700 pairs) and *Oceanodroma castro* (1.500 pairs). In addition nest *Sterna dougalli*, with a small number of pairs in Ilhéu de Fora, *Anthus bertheloti bertheloti* (100 pairs) and *Falco tinnunculus canariensis* with a small number of individuals (Mougin et al, 2000; Menezes et al, 2004; Oliveira & Moniz, 1995; Oliveira et al, 2010; Granadeiro et al, 2006; Campos & Granadeiro, 1999).

The study area was limited in the two more accessible bays of the island: Baía das Cagarras and Baía das Galinhas (respectively A14 – G19 and F18 – K20 in fig.7).

## Porto Santo

Porto Santo Island (33°07'N, 16°35'W) is located in the Archipelago of Madeira and belongs to Autonomous Region of Madeira, Portugal, in the North-East Atlantic Ocean. It is located 43 km North-East off the coast of Madeira Island. It occupies an area of 42,17 km<sup>2</sup>. The island, formed 18-13,5 mya, belongs to a volcanic complex formed by an hotspot that stopped its subaerial activity about 8 mya, but that is still active under the sea (Carvalho & Brandão, 1991). There are two types of coast in the island: mountainous with cliffs on the north and a 9 km long sandy beach on the south (Carvalho & Brandão, 1991). The landscape looks like semi-arid with very low precipitations (about 400 mm per year) concentrated in January and the average annual temperature fluctuates between 13-25°C (Carvalho & Brandão, 1991). The human population, about 4500 people, is concentrated to the southern zone that is more exploited by the touristic industry than the northern one.

## Study species

Most of the information about the study species is based on *The Birds of the Western Palearctic* by Cramp (1977).

## Procellariiformes

The order Procellariiformes comprehends 4 families, all but Pelecanoididae represented in west Palearctic. It is a clearly defined order, not closely related to any other, but with affinities to Sphenisciformes (penguins) and Pelecaniformes (pelicans) suggested by some morphological and biochemical characters. The individuals are strictly marine and they come to land only to breed. The nasal olfactory organ is better developed than in most birds, including all other seabirds, indicating an highly adaptive sense of smell, possibly connected with food seeking and social interaction.

## Procellariidae

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 (genera *Macronectes*, *Fulmarus*, *Thalassoica*, *Daption*, *Pagodroma*), prions (genera *Halobaena*, *Pachyptila*), petrels (genera *Pterodroma*, *Bolweria*) and shearwaters (genera *Procellaria*, *Calonectris*, *Puffinus*). The flight is low and it glides on stiff wings; shearwaters also use the wings for underwater propulsion. Sexes are similar in plumage, but male is usually larger than female.

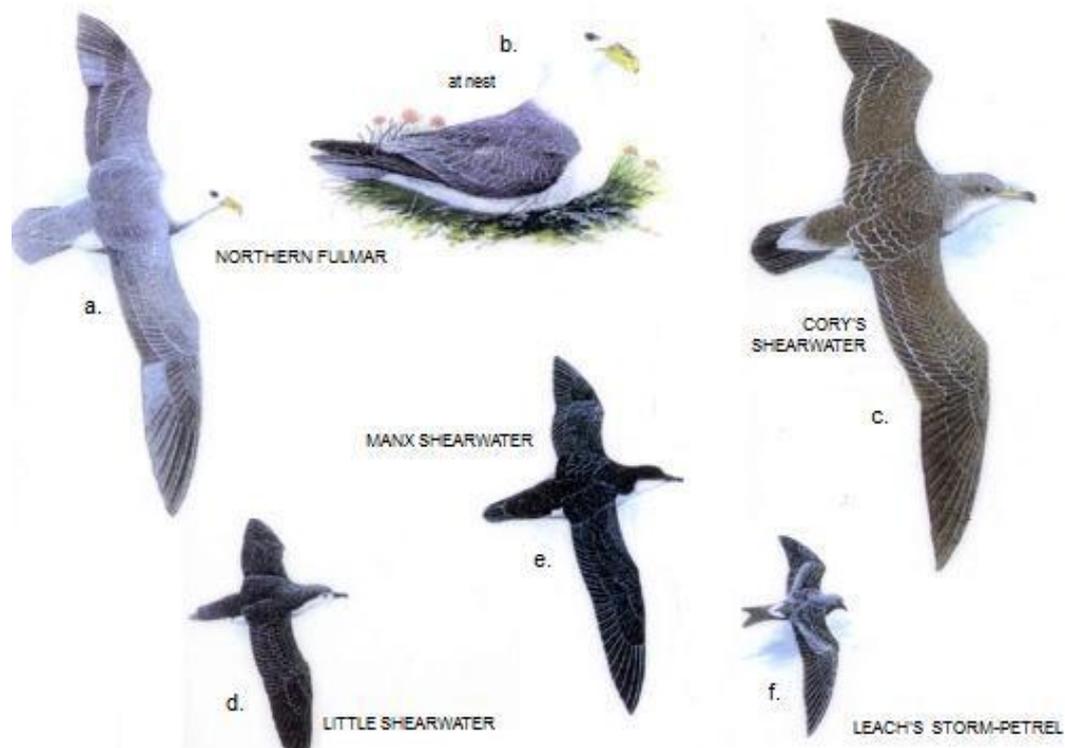


Fig.4: some Procellariiformes nesting in north-west Palearctic: *Fulmarus glacialis* (a and b), *C. diomedea* (c), *P. assimilis* (d), *P. puffinus* (e), *Oceanodroma leucorhoa* (f).

The family occurs in all oceans. All species are essentially pelagic and they are highly adapted for living far from land. Different species nest in different ways: ashore, on sea cliffs, high on slopes or escarpments, or lofty plateau or mountains, sometimes inland. Clumsy and feeble on land, they avoid open ground as much as possible. Unlike many open-nesting birds that are largely diurnal, most of hole-nesting species are strictly nocturnal when visiting land, though *C. diomedea* is partially diurnal in some populations (like in Selvagem Grande). The selection of breeding localities is highly selective to guarantee immunity from predators and to reduce difficulties of landing and in the access. Some species, especially larger shearwaters, are long-distance migrants, others mostly stay within feeding range of the colony. Birds are mostly gregarious at sea. Food is chiefly represented by fish, cephalopods and crustaceans, often as plankton. They are colonial breeders, some species moderately territorial and others very aggressive with intruders. They are mostly long-term monogamous only during the breeding season. Copulation takes place ashore, on the ground or in the nest-hole. Loud, complex and individually variable calls are given largely during the approach in darkness and within borrows.

In west Palearctic, the family has a relatively restricted laying period, that depends on the species and on the latitude of the breeding area. Nests are often enriched with vegetal material and plumage from the body of the parents. For

the nest-hole species, the borrow can be both natural or excavated by both sexes up to 1 meter long. Eggs are ovate, white and not glossy. The clutch size is always one. All the species have a single brood per season and no replacements has been recorded. The incubation period is long (45-55 days). Sexes take roughly equal shares in spells of 1-11 days. After the hatching, eggshells are always left in the nest. Young are cared and fed through incomplete regurgitation, by both parents. Rarely the chick stays alone for the firsts 1-2 weeks, than it is fed only at night (hole nesters) or during day (cliff-ledge nesters). The young reach the age of maturity not before an age of 3-4 years and not after 6-12 years old.

### Little Shearwater

**Field characters.** The Little Shearwater (*P. assimilis* Gould, 1838) is a 25-30 cm long bird, with a wingspan of 58-67 cm. The bill is short and small. Sexes are alike. We can distinguish some subspecies in the west Palearctic: Madeiran Little Shearwater (*P. assimilis baroli* Bonaparte, 1857) is the subject of this article. This subspecies is characterized by crown, hindneck, upper body, flight-feathers and tail are slaty-black; sides of face and sites of neck are mottled white and black; underparts, including central undertail coverts, white. The bill is black with blue-gray cast on basal sections of both mandibles. Adults show chalk-blue legs and feet.

**Habitat.** Unlike other shearwaters, *P. assimilis* is confined to tropical, subtropical and other relatively warm waters close to the breeding islands; it is not a migratory species. It keeps normally to lowest airspace over sea, flying fast and diving adroitly; seldom it needs to ride out storms. The subspecies *baroli* is largely distributed on the Macaronesian Islands (Azores, Madeira, Canary Islands) except Cape Verde Islands (Correia-Fagundes & Romano, 2011).

**Food.** Here the information are limited. The stomachs of *P. assimilis* analyzed in the past contained small fish, beaks of squids and crustaceans (Monteiro et al, 1996; Bourne, 1955; Palmer, 1962).

**Behaviour.** *P.assimilis* is a gregarious species, both ashore and at sea where individuals form small flocks. It pays frequent visits outside breeding period to nesting sites, unlike other pelagic birds, especially during nighttime (Bannerman & Bannerman, 1968). Mating system is generally a strict monogamy that links partners together and with their nest-site, which are the same every breeding season (Bried et al, 2003). The reproductive cycle normally comprehends a short exodus of females, and sometimes males, from the breeding colony just before one-egg laying (Bried et al, 2003).



Fig.5: adult of Little Shearwater.

**Breeding.** Egg laying takes place from late February to early March, in the northern hemisphere; for this reason Little Shearwater is a winter breeder. Fledging period starts from September to October (Monteiro et al, 1996). Relating to time, the Little Shearwater is the first breeder, in North Atlantic colonies, within the Procellariiformes family (Monteiro et al, 1996). This precocity might be selected to overlap the maximum food availability with the breeding season (Ashmole, 1971; Harris, 1969; Harrison et al, 1983) or to avoid the inter-specific competition for the nest-site (Monteiro et al, 1996) with other Procellariiformes nesting in similar burrows. As a matter of fact that Little Shearwater could be easily defeated in a fight for the nest against another species because it is the smaller Procellariiformes in North Atlantic. For this reason the Little Shearwater could be subjected to a stronger selective pressure compared to other Procellariiformes (Monteiro et al, 1996).

The nest is usually a chamber excavated in soft soil or an 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.

Eggs are white and not glossy; dimensions are about 50 mm long and 35 mm broad, with a mean volume of about  $30 \text{ cm}^3$  (Monteiro et al, 1996).

#### **Measure of the nest-site characteristics**

From March 11<sup>th</sup> to April 15<sup>th</sup> 2011, we monitored 54 nests of *P. assimilis* in Selvagem Grande Island, 3 of them discovered during the fieldwork and 51 already marked in previous years. In Porto Santo Island we monitored 17 nests in April.

The breeding habitat comprises not only the physical features, but also the social ones, so we collect measures of different kind of variables in Selvagem Grande (Tab.1).

We obtained the length measurements with a retractable aluminum-made carpenter tape ( $\pm 1$  mm) for measurements up to 3 m, and with a glass fiber ( $\pm 1$  mm) for sizes up to 10m. For longer lengths we used a GPS receiver Garmin eTrex Legend® C ( $\pm 4$  m). With the same tool we also obtained the measurements of altitude. We obtained the entrance area extension by taking a digital photo with a Kodak EasyShare DX6490 camera (4Mpixel resolution) and analyzing the image with the UTHSCSA Image Tool program. We obtained the measurements of orientation with a compass. We measured the inclinations with an inclinometer. We used six loggers of two different brands for measuring the relative humidity and the temperature inside the nests: Dostmann LOG32 Temperature/Humidity USB Logger (temperature range:  $-40$  to  $+70^{\circ}\text{C}$ ; humidity range: 0 to 99%rH; resolution:  $0,1^{\circ}\text{C}/0,1\%r\text{H}$ ; accuracy:  $\pm 1,0^{\circ}\text{C}(-20$  to  $50^{\circ}\text{C})/\pm 3\%r\text{H}$ ) and Temperature and Humidity USB Data Logger HT71\_E20091203\_R00 (temperature range:  $-35$  to  $+80^{\circ}\text{C}$ ; humidity range: 0 to 100%rH; resolution:  $0,1^{\circ}\text{C}/0,5\%r\text{H}$ ; accuracy:  $\pm 1^{\circ}\text{C}/\pm 3,5\%r\text{H}$  (20 to 80%rH)/ $\pm 5\%r\text{H}$  (0 to 100%rH)).

Characteristic	Code	Unit of measurement
<b>Bay</b>	BAY	Baía das Cagarras (BdC); Baía das Galinhas (BdG); Porto Santo (PS)
<b>Entry length</b>	EL	cm
<b>Entry width</b>	EW	cm
<b>Entry slope</b>	ES	degree
<b>Entry area</b>	EA	cm <sup>2</sup>
<b>Sea entry orientation</b>	SEO	degree
<b>Hillside entry orientation</b>	HEO	degree
<b>Entry tortuosity</b>	ET	0;1
<b>Vegetation cover</b>	VC	0;1;2;3;4
<b>Chamber length</b>	CL	cm
<b>Chamber width</b>	CW	cm
<b>Chamber height</b>	CH	cm
<b>Chamber relative humidity</b>	rH	%rH
<b>Chamber temperature</b>	T	$^{\circ}\text{C}$
<b>Chamber substrate</b>	Sub	S(sand);G(gravel);R(rock)
<b>Altitude</b>	Alt	m
<b>Extra nest material</b>	ENM	0;1
<b>Distance from another Little Shearwater nest</b>	DLS	m
<b>Distance from Cory's Shearwater nest</b>	DCS	m
<b>Number of neighbor</b>	nLS	n <sup>o</sup>
<b>Number of Cory's Shearwater</b>	nCS	n <sup>o</sup>

Tab.1: nest-site characteristics variables collected during the fieldwork.

The characteristics are defined as follows:

- Bay: bay in which the nest is located
- Entry length: from the opening of the entry corridor to the point where it widens to become the incubating chamber
- Entry width: average width of the entry opening
- Slope entry: slope at the beginning of the entry corridor
- Entry Area: area of entrance
- Sea orientation: difference in degrees between the entry opening line and the perpendicular line to the coastline nearest to the nest
- Hillside orientation: difference in degrees between the entry opening line and the hillside line
- Entry tortuosity: number of curves greater than 45° in the entry corridor
- Vegetation cover: number of plants that cover the entry even partially
- Chamber length: distance from the chamber opening at the deepest point of the chamber following the line of the entry corridor
- Chamber width: maximum length of the line perpendicular to the length of the chamber and parallel to the ground
- Chamber height: maximum length of the line perpendicular to the chamber length and to the ground
- Chamber Relative Humidity: we obtained different measures with data provided by the loggers for a period of at least 48 consecutive hours:
  - AvrH: average relative humidity throughout the period of activity
  - MaxrH: maximum relative humidity recorded
  - minrH: minimum relative humidity recorded
  - MaxrH - minrH: difference between maximum and minimum relative humidity recorded
  - AvrHd: average relative humidity during dawn-dusk period\*
  - AvrHn: average relative humidity during dusk-dawn period\*
  - MaxrHd: maximum relative humidity during dawn-dusk period\*
  - MaxrHn: maximum relative humidity during dusk-dawn period\*
  - minrHd: minimum relative humidity during dawn-dusk period\*
  - minrHn: minimum relative humidity during dusk-dawn period\*
- Chamber temperature: for temperature we extrapolated the same data as we did for relative humidity
- Chamber substrate: type of chamber substrate. This could have different values ordered according the hardness:

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\* We have considered the times of sunrise and sunset according to the official twilight (zenith 90° 50').

- 0 = rock
  - 1 = rock and gravel
  - 2 = rock and sand
  - 3 = gravel
  - 4 = gravel and sand
  - 5 = sand
- Altitude: altitude of the nest above sea level
  - Extra nest material: presence of plumage or vegetable material inside the chamber
  - Distance from another Little Shearwater nest: the distance from the nearest nest of another Little Shearwater measured from the center of the entry opening with a tape, or via GPS
  - Distance from Cory's Shearwater nest: distance from the nearest Cory's Shearwater's nest by measuring from the center of the entry opening
  - Number of neighbors: the number of Little Shearwater nests whose entrance is located within a radius of 3 m from the nest in question<sup>†</sup>
  - Number of Cory's Shearwater: number of Cory's Shearwater nests whose entrance is located within a radius of 3m from the nest in question<sup>†</sup>

For the nests in Porto Santo colony we took the measures of: width, length and tortuosity of the entrance, and vegetation cover (n = 12), the size of the chamber (n = 9), type of substrate and nearest Little Shearwater nest (n = 8).



Fig.8: burrow with an incubating Little Shearwater.

<sup>†</sup> The measure of 3 meters is arbitrary, but it was already used by Ramos et al. (1997).

We considered as “occupied” only nests containing an egg. In Selvagem Grande island, we defined as “deserted” nests containing an intact egg but where the parent has never been found in daily visits for at least 17 consecutive days. We considered as “unoccupied” nests without eggs up to April 1<sup>st</sup>, even though in them we found a couple of adults. When we found a nests containing a broken egg and later abandoned by parents, we not considered it as “abandoned”, but as “containing a broken egg”.

In this work we used the laying success as an indicator of the parental nest-site choice. We do not interpreted the simple presence of an individual or a couple inside a borrow like a nest choice because this species often frequent the colony without breeding (Cramp, 1977), furthermore breeding pairs could be present in a certain borrow only for visit it and, after, they could make another choice. Therefore we consider “occupied” by a breeding pair only nests with an egg. We also used the hatching success as an indicator of the fitness (Bradley & Meathrel, 2006) because this species is hard to study: Little Shearwater is a long-life species, its dispersal area is very vast and there are few recognizable individuals (in the two studied colonies chicks were never ringed, but only few adults).

#### **Measure of the parental body condition**

During nocturnal inspections we caught 27 adults in Selvagem Grande, 15 nesting in 12 monitored borrows, and 31 adults in Porto Santo, 8 nesting in 7 monitored nests. We weighted all of them and we also took the measures of wing and tarsus lengths.

Body condition index (BCI) was obtained from the residuals of the linear regression of body mass on tarsus length (Hochachka & Smith, 1991; Brown, 1996) both for Selvagem Grande and Porto Santo according to the formula:

$$BCI = 1 - \frac{res}{pred}$$

Where *BCI* is the body condition index, *res* is the non-standardized residuals of the linear regression of weight on tarsus length and *pred* is the predicted values by linear regression of weight on tarsus length.

Body condition index is therefore a measure of mass corrected for size and is considered an indication of nutrient stores (Blem & Blem 1990, Brown 1996), mostly fat, which was found to be the most important contributor to the mass of passerines (Gosler et al. 1998). It has been reported to predict well lipid reserves (Blem & Blem, 1990). The nutrient stores (fat, muscle) can be used in productive

activities and in stressful events before starvation. This approach distinguishes these reserves from non-utilizable structural components.

### **Offspring monitoring**

We measured the length (EggL), breadth (EggB); if the egg was laid during the breeding season 2011, weight (EggW) of all the eggs we found in nests. We weighed all the chicks born in Selvagem Grande (n = 5) (ChickW) and we measured their wing length (ChickWL) and tarsus length (ChickTL) daily, from the day of the birth (March 30<sup>th</sup>/April 1<sup>st</sup>) until the end of the expedition (May 2<sup>nd</sup>) or until the chick death. Our monitoring took place everyday in the same time period: in the afternoon from 2pm to 4pm to avoid as much as possible the parental visits. Chicks never regurgitated food while being handled. With this data we can obtain a growth curve and gauge the frequency whereby the chicks are fed by their parents.

We weighed eggs, chicks and adults with a set of Pesola® spring scales with a maximum of 50g ( $\pm 0,5$  g), 100g ( $\pm 1$  g) and 300g ( $\pm 2$  g) according to the weight of the subject. We took the spatial measures of egg, tarsus and wing of chicks and adults with a vernier caliper ( $\pm 0,1$  mm).



Fig.9: 25 days old chick of Little Shearwater outside the nest.

### **Statistical analysis**

We used the program SPSS (v13) to perform all statistical analysis.

For the analysis about laying and hatching success in Selvagem Grande, we also integrate data of the previous breeding season (2010).

## Comparison of the breeding biology between Selvagem Grande and Porto Santo

In this paper we compared some features of breeding ecology of the two Little Shearwater colonies nesting on Selvagem Grande and Porto Santo during the breeding season 2011. The comparison is based on:

- Date of hatching by comparing the averages of the two colonies with a Student t-test
- Hatching success of the colony by comparing the two colonies with a  $\chi^2$  test
- Causes of hatching failure in the two colonies with another  $\chi^2$  test
- Parental body condition by comparing the averages with a Student t-test

The causes of hatching failure may be of various kinds: nest desertion by parents, egg break (also by the researchers), lizard predation, addled egg or egg ejection from the nest (Matias et al. 2009).

### Analysis for the nest-site characteristics

#### *Logistic regression*

We analyzed 66 nests of *P. assimilis* and we identified 39 variables which could influence the parental choice of the nest-site (laying success) or the hatching success. We divided data in 4 clusters:

- Laying success in Selvagem Grande
- Hatching success in Selvagem Grande
- Laying success in Porto Santo
- Hatching success in Porto Santo

We analyzed these groups separately, but with the same statistical method. The logistic regression is presented in the following form:

$$y = \ln \frac{P}{1 - P} = a + b_1x_1 + b_2x_2 + \dots + b_nx_n$$

where  $a$  is constant and  $b_1, b_2, \dots, b_n$  are the coefficients of the independent variables  $x_1, x_2, \dots, x_n$ , and represent the effect of these ones on the dependent variable,  $P$  is the probability, between 0 and 1, of the nest occupation/egg hatching, and  $y$  is the logistic regression model (Hosmer & Lemeshow, 2000).

The specific form of the logistic regression model we used is:

$$P = \frac{e^y}{1 + e^y}$$

We also divided the independent variables in two groups:

- Continuous: Measurements of length, orientation, temperature, relative humidity, altitude, count of individuals
- Categorical: presence/absence, type of substrate, vegetation cover, location (bay)

Some continuous variables are transformed into 4 categorical variables using 3 cut-points based on quartiles of distribution (25, 50, 75%) of the variable. We do this the SPSS calculation was more robust and reliable.

If some variables in table had got empty cells (gaps due to data loss or non-harvesting) there we fill the empty cells with the average of the variable.

Zero cells count could cause problems in the modeling stage of the analysis so we could collapse the categories of the variable in a meaningful way to eliminate it, eliminate the category all together or, if the variable is at least ordinal scaled, treat it as continuous (Hosmer & Lemeshow, 2000). In this paper we always choose the first option. We “design” all categorical variables included in the model according to the method of *reference cell coding* which is to define the category with the lowest odds ratio as a reference to which other categories are compared (Hosmer & Lemeshow, 2000).

For the hatching success we considered three additional variables like egg dimensions and parental body condition index (BCI).

<b>Characteristic</b>	<b>Code</b>	<b>Unit of measurement</b>
<b>Egg breadth</b>	EBh	mm
<b>Egg length</b>	ELh	mm
<b>Parental body condition</b>	BCI	-

Tab.2: three additional variables used in the analysis for the hatching success.

We considered reproductive failing nests, nests had an egg abandoned in previous years and never reoccupied, because those nests are still part of the group of nests that have not given rise to an hatching, although not in the breeding season 2011.

### *Univariate analysis*

We carried out the construction of the logistic regression model according the Hosmer & Lemeshow model. The first step is the univariate analysis of all independent variables in order to measure their degree of association with the dependent variable, according to the results of Wald tests and likelihood ratio test (Franco et al, 2000; Franco & Sutherland, 2004). We enter all the variables

which gave, in the Wald test, a  $P < 0.25$  into the multivariate model (Hosmer & Lemeshow, 2000).

#### *Analysis of possible interactions between independent variables*

To avoid introducing highly correlated variables in the model, we made a Spearman correlation matrix (Zar, 1999; Dytham, 2003). When two variables correlate with an  $r > 0.7$ , we eliminated the variable with the minor  $P$  in the likelihood test (Tabachnick & Fidell, 2007).

#### *Adjusting multivariate model*

We analyzed the importance of each independent variable with the Wald test and the likelihood test between models (to assess whether a model with a certain variable can fit better than a model without that variable). To do this we used the stepwise forward method. This method adds the independent variables one by one until obtaining the final model. To further prevent to not find a relationship when it exists, the statistical significance criterion for inclusion ( $P$  value of the Wald test) was set to 0.20 (Bendell & Afifi, 1977). The stepwise method for the logistic regression is used especially for analysis about hypothesis in study areas with a little knowledge (Menard, 2001). We further tested the excluded variables in the model one by one to identify the variables that not showed significance, but could be significant in presence of other variables in the model (Paiva, 2005).

#### *Significance tests of the model*

We used two methods to assess the degree of fitting of the model to observed data:

- Hosmer-Lemeshow test of goodness-of-fit: tests the null hypothesis that the observed data do not differ from the values predicted by the model;
- Area Under the Receiver Operating Characteristic (AUC or area under the ROC): a measure of the overall fit of the model which produces a measure to discriminate between two possible outcomes of the response variable (0, 1). We interpreted the results according to table 3. This analysis allows to determine the precision of the model in predicting the success/fail of the occupation/hatching. It is based on the estimated area under the ROC curve (Zweig & Campbell 1993), the AUC, which is a measure of overall fit of the model. This measure can vary between 0,5 (model performance is due to chance) and 1 (perfect fit) (Osborne et al, 2001). In this way the test shows the sensitivity (fraction of correctly predicted successes) of a model,  $y$  axis, in relation to its specificity

(fraction of correctly predicted fails), x axis. In this way, a model that has a high value of AUC, has a high relative accuracy (Pinilla, 2002).

	<i>Characteristics Curve AUC</i>	<b>Interpretation</b>
Tab.3: interpretation of the model according to the Area Under the ROC curve (AUC).	0.5	No discrimination
	0.7-0.8	Acceptable discrimination
	0.8-0.9	Very good discrimination
	$\geq 0.9$	Excelent discrimination

### *Interpretation of the model*

After obtaining the final model, we analyzed the coefficients  $\beta$  in order to understand the relationship between the independent and dependent variables. Coefficients represent the influence of the independent variables on the dependent variable (tab.4).

<b>Coefficient B</b>	<b>Interpretation</b>
= 0	When the independent variable has no effect on the dependent variable.
> 0	When an increase in the independent variable is associated with an increase of the probability that the dependent variable will 1 (laying/hatching success).
< 0	When an increase in the independent variable is associated with an increase of the probability that the dependent variable will 0 (laying/hatching failure).

Tab. 4: interpretation of the coefficients *B* in the logistic regression model.

## Results

### Comparison of the breeding biology between Selvagem Grande and Porto Santo colonies

#### Hatching date

In the 2011 breeding season we observed 14 broods of *P. assimilis*, 5 in the colony of Selvagem Grande and 6 in Porto Santo.

We used a student t-test to compare the mean hatching date between the two colonies and found a significant difference between them ( $t = 9.50$ , 8 df,  $P < 0.01$ ).

#### Hatching success

In the two colonies we found 25 nests with eggs laid in the 2011 breeding season, 13 on Selvagem Grande and 12 on Porto Santo. The frequencies of hatching success and failure are shown in table 5B.

With a  $\chi^2$  test to compare the frequencies hatching between of the two colonies, we obtain value of  $\chi^2 = 2.06$ , 1 df,  $P = 0.15$  with Yates correction. This means there were no significant differences in hatching success between the two colonies.

#### Causes of failure

In the two colonies we observed just 2 causes of failure: broken egg ( $n = 7$ ) and desertion ( $n = 3$ ). In one case it was not possible to verify the cause of failure (table 7).

With a  $\chi^2$  test to compare the frequencies of failure between the two colonies, we obtain a value of  $\chi^2 = 2.357$ , 2 df,  $P = 0.31$ . This means that the differences between the two colonies were not statistically different.

#### Parental body condition

During the nocturnal surveys in Selvagem Grande, 27 adults were captured, 15 of them breeding in 12 of the nests monitored. In the island of Porto Santo we captured 31 adults, 8 of them breeding in 7 of the nests monitored.

We compared the body condition of parent birds between Selvagem Grande and Porto Santo with a Student-t test and obtained a value of  $t = 1,2115$ , 56 df,  $P = 0.23$ . Therefore, parents birds have similar body condition between the two islands.

A

	Broken egg	Desertion	Unknown	TOT
<b>Selvagem Grande</b>	4 (50%)	3 (38%)	1 (12%)	8
<b>Porto Santo</b>	3 (100%)	0	0	3
<b>TOT</b>	7 (64%)	3 (27%)	1 (9%)	11

B

	Success	Failure	TOT
<b>Selvagem Grande</b>	5 (38%)	8 (62%)	13
<b>Porto Santo</b>	9 (75%)	3 (25%)	12
<b>TOT</b>	14 (56%)	11 (44%)	25

C

	Selvagem Grande	Porto Santo
	March 30 <sup>th</sup>	April 6 <sup>th</sup>
	March 30 <sup>th</sup>	April 6 <sup>th</sup>
	March 31 <sup>th</sup>	April 7 <sup>th</sup>
	April 1 <sup>st</sup>	April 7 <sup>th</sup>
	April 1 <sup>st</sup>	April 9 <sup>th</sup>
		April 9 <sup>th</sup>
<b>Mean ± SD</b>	March 31 <sup>th</sup> ± 1 day	April 7 <sup>th</sup> ± 1,4 days

Tab.5: frequencies of the hatching failure causes in Selvagem Grande and Porto Santo during the breeding season 2011 (A); frequencies of hatching success and failure in Selvagem Grande and Porto Santo during the breeding season 2011 (B); Table 5: hatching date in Selvagem Grande (n=5) and in Porto Santo (n=6) during the breeding season 2011 (C).

### Offspring monitoring in Selvagem Grande

After the hatch, we weighted and measured all the chicks daily for a period of 34 days. With this data we obtained the growth curves according to weight, to tarsus length and to wing length (graph.1).

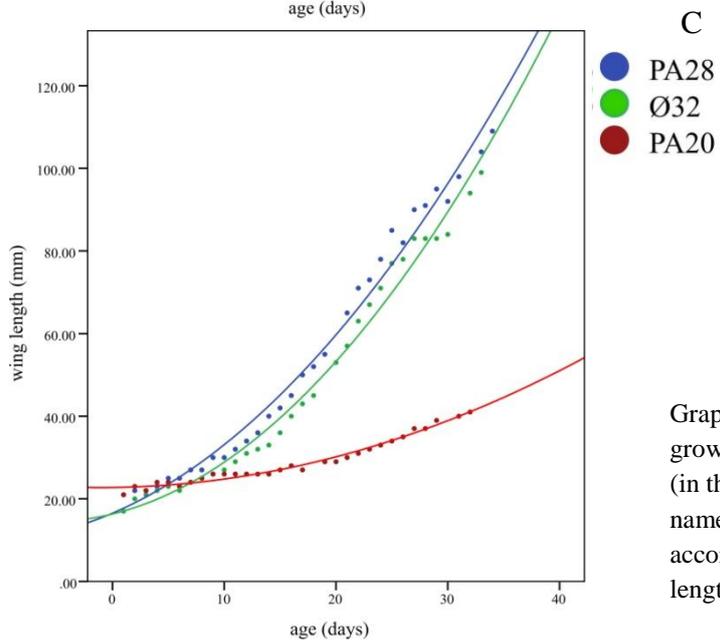
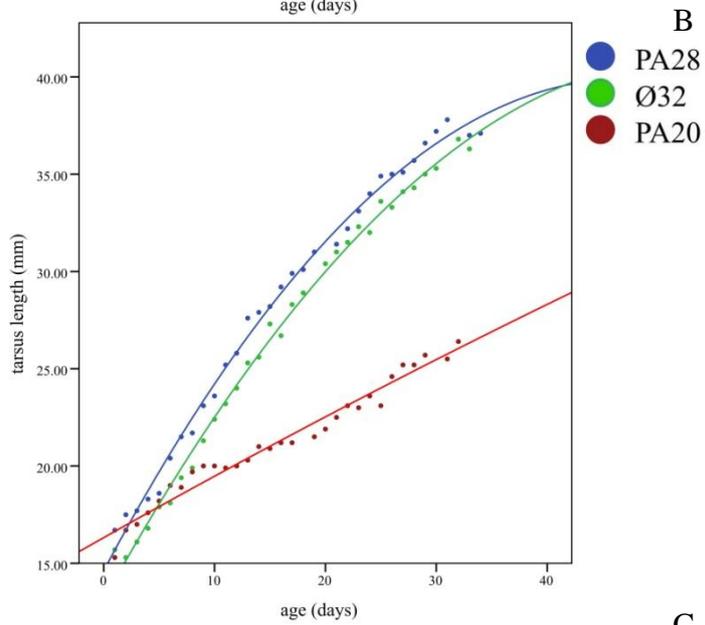
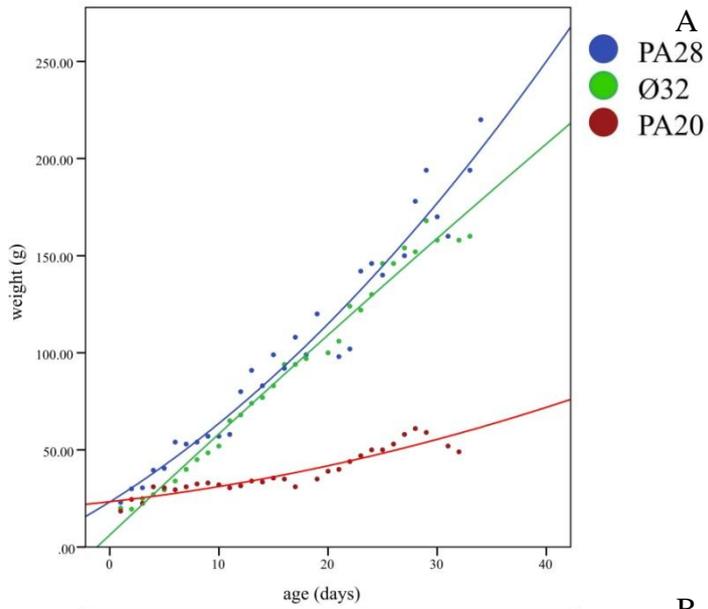
The individual weigh graphics show a daily growth in weigh during the firsts days of life, but after 25 days the weigh seems to vary, in one case even daily, fluctuating near the growth curve.

### Nest-site characteristics

As expected all the nests of *P. assimilis* were in cavities under rocks or small burrows with roof and walls made of small and large stones, almost all of them with an entry corridor. The nests appeared to be distributed in relation to the availability of areas with rocks and cavities within them.

Selvagem Grande		Porto Santo	
<i>Ring number</i>	<i>Body condition index</i>	<i>Ring number</i>	<i>Body condition index</i>
<b>I014110</b>	0,986	<b>I014139</b>	1,086
<b>I014111</b>	1,069	I014140	0,964
<b>I014112</b>	1,161	<b>I014141</b>	1,066
<b>I014113</b>	0,968	I014142	0,939
<b>I014114</b>	1,126	I014143	0,790
<b>I014115</b>	0,887	I014144	1,046
<b>I014071</b>	1,110	I014145	1,041
<b>I014067</b>	0,949	I014146	1,075
I014116	1,136	I014147	0,895
<b>I014117</b>	1,033	I014148	1,059
<b>I014118</b>	0,928	I014149	1,008
<b>I014119</b>	0,944	I014150	0,989
I014121	1,102	I012801	1,035
I014122	1,089	I012802	1,126
I014123	1,059	I012803	1,023
<b>I014124</b>	0,892	I012804	0,909
I014125	0,957	I012805	0,768
I014126	1,106	I012806	1,151
I014127	0,998	I012807	1,127
<b>I014128</b>	0,860	I012808	0,833
<b>I014129</b>	0,848	I012809	0,963
<b>I014130</b>	0,941	<b>I012810</b>	1,028
I014131	1,118	I012811	1,036
I014132	1,088	<b>I012812</b>	0,987
I014133	1,129	I012813	1,023
I014134	0,908	<b>I012814</b>	0,947
I014135	1,062	<b>I012815</b>	0,859
		I012816	0,938
		I012817	1,111
		<b>I012818</b>	0,840
		<b>I012819</b>	0,883
<b>Average ± SD</b>	<b>1,017 ± 0,096</b>	<b>Average ± SD</b>	<b>0,985 ± 0,101</b>

Tab.6: body condition index (BCI) of the adults captured in Selvagem Grande (n=27) and Porto Santo (n=31). Monitored breeders are in bold.



Graph.1: graphics of the nestling growths in time (days) of 3 nestlings (in the legend there are the nests names of every 3 chicks monitored) according to weight (A), tarsus length (B) and wing length (C).

Characteristic	N	Minimum	Maximum	Average	Std. Deviation
EL	66	0,00 cm	123,00 cm	22,87 cm	19,36 cm
ES	54	-43,00 deg	44,00 deg	-0,44 deg	17,84 deg
EW	66	2,90 cm	25,00 cm	7,45 cm	3,49 cm
EA	54	10,200 cm <sup>2</sup>	218,80 cm <sup>2</sup>	72,10 cm <sup>2</sup>	48,01 cm <sup>2</sup>
CL	63	11,00 cm	54,00 cm	25,60 cm	8,38 cm
CW	63	7,00 cm	45,00 cm	21,32 cm	8,53 cm
CH	63	6,00 cm	42,00 cm	13,98 cm	6,84 cm
HEO	54	0,00 deg	180,00 deg	41,34 deg	36,33 deg
SEO	54	0,00 deg	105,00 deg	36,06 deg	28,87 deg
ET	66	0,00	2,00	0,17	0,41
Sub	62	0,00	5,00	2,63*	1,66
ENM	54	0,00	1,00	0,31	0,47
DLS	62	0,60 m	65,10 m	9,25 m	11,27 m
nLS	54	0,00	3,00	0,39	0,76
DCS	54	0,30 m	-	-	-
nCS	54	0,00	10,00	2,46	2,33
AvT	54	14,20 °C	28,80 °C	20,84 °C	2,65 °C
AvTd	54	15,10 °C	27,00 °C	21,66 °C	2,43 °C
AvTn	54	13,20 °C	28,20 °C	19,79 °C	2,54 °C
MaxTd	54	19,80 °C	41,90 °C	26,81 °C	4,42 °C
minTd	54	10,60 °C	22,60 °C	17,31 °C	2,85 °C
MaxTn	54	16,50 °C	35,90 °C	23,02 °C	2,92 °C
minTn	54	10,20 °C	22,90 °C	17,28 °C	2,83 °C
MaxT	54	19,80 °C	41,90 °C	26,84 °C	4,46 °C
minT	54	10,20 °C	22,60 °C	17,10 °C	2,87 °C
MaxT-minT	54	3,50 °C	26,10 °C	9,74 °C	4,28 °C
AvrH	54	58,10 %rH	88,40 %rH	70,31 %rH	6,82 %rH
AvrHd	54	56,70 %rH	88,90 %rH	68,82 %rH	7,70 %rH
AvrHn	54	58,80 %rH	87,80 %rH	71,93 %rH	6,53 %rH
MaxrHd	54	44,60 %rH	100,00 %rH	80,23 %rH	10,00 %rH
minrHd	54	25,70 %rH	82,60 %rH	55,21 %rH	10,73 %rH
MaxrHn	54	64,60 %rH	99,60 %rH	80,58 %rH	8,23 %rH
minrHn	54	46,80 %rH	80,10 %rH	60,74 %rH	6,97 %rH
MaxrH	54	64,90 %rH	100,00 %rH	81,39 %rH	8,39 %rH
minrH	54	25,70 %rH	80,10 %rH	54,33 %rH	10,27 %rH
MaxrH-minrH	54	8,90 %rH	58,60 %rH	27,06 %rH	10,32 %rH
Alt	54	18,00 m	103,00 m	62,89 m	24,08 m
VC	58	0,00	4,00	0,91	1,13
EggL	15	41,90 mm	49,70 mm	47,25 mm	2,23 mm
EggB	15	30,30 mm	35,70 mm	33,33 mm	1,32 mm

Tab.7: maximums, minimums, averages and standard deviations of the nest-site characteristics collected in Selvagem Grande and Porto Santo. \*A substrate with a value of 2,63 corresponds about to a mixed substrate of rock, gravel and sand.

### Univariate analysis

With the univariate analysis we can select independent variables candidated for the construction of the multivariate model based on the *P value* < 0.25 in the Wald test (tab.8).

A

Laying success Selvagem Grande				Hatching success Selvagem Grande			
	<i>B</i>	<i>Wald</i>	<i>P</i>		<i>B</i>	<i>Wald</i>	<i>P</i>
EL	+	1,935	0,164	EL	+	1,991	0,158
ES*	-	5,164	0,023	ES*	+	0,000	1,000
EW	-	3,146	0,076	EW	-	1,900	0,168
EA*	-	2,847	0,092	CL*	-	1,767	0,184
CL	+	1,387	0,239	CW*	+	1,843	0,175
CH*	+	1,870	0,171	SEO with sign*	-	4,108	0,043
HEO with sign	+	2,461	0,117	DLS*	+	4,084	0,043
ET*	+	1,359	0,244	DCS*	+	1,767	0,184
Sub*	-	1,565	0,211	nCS*	+	1,862	0,172
ENM*	+	9,253	0,002	AvT*	+	4,108	0,043
nLS*	-	1,864	0,172	AvTd*	+	3,644	0,056
DCS*	+	5,495	0,139	AvTn*	+	4,108	0,043
nCS*	+	1,687	0,194	MaxTd*	+	3,644	0,056
AvTd	-	2,552	0,110	minTd*	+	4,108	0,043
AvTn*	-	2,221	0,136	MaxTn*	+	4,084	0,043
MaxTd*	-	1,542	0,214	minTn*	+	3,743	0,053
minTd*	-	5,670	0,017	MaxT*	+	3,644	0,056
MaxTn*	-	2,145	0,143	minT*	+	4,108	0,043
minTn*	-	4,195	0,041	MaxrHd	+	2,007	0,157
minTn	-	2,084	0,149	MaxrHn	+	1,551	0,213
MaxT*	-	2,316	0,128	minrHn*	-	1,767	0,184
minT*	-	4,967	0,026	MaxrH*	+	1,998	0,158
AvHr*	+	8,493	0,004	EggL*	-	2,943	0,230
AvHrd	+	8,330	0,004	EggB*	+	2,798	0,094
AvHrn*	+	4,843	0,028	EA	+	0,011	0,918
MaxrHd	+	10,214	0,001	CH	-	0,119	0,730
minrHd*	+	2,221	0,136	HEO	-	0,039	0,843
MaxrHn	+	8,677	0,003	HEO with sign	-	0,995	0,318
minrHn*	+	3,518	0,061	SEO	+	0,596	0,440
MaxrH	+	9,310	0,002	ET	-	0,000	0,999
minrH	+	2,259	0,133	VC	-	0,000	1,000
MaxrH-minrH*	+	6,100	0,107	Sub*	+	0,362	0,547
Alt*	-	4,140	0,042	ENM*	+	0,049	0,825
VC*	-	5,565	0,018	nLS	-	0,000	1,000
CW*	-	0,369	0,544	MaxT-minT	-	0,003	0,958
HEO*	+	0,021	0,885	AvrH	-	0,001	0,969
SEO*	+	0,989	0,320	AvrHd	+	0,064	0,801
SEO with sign*	+	0,678	0,410	AvrHn	-	0,057	0,810
DLS*	+	0,362	0,548	minrHd	+	0,111	0,739
AvT*	-	1,306	0,253	minrH	+	0,014	0,905
MaxT-minT*	-	0,362	0,548	Alt	-	0,092	0,762
				BCI	-	0,138	0,710

B

Laying success Porto Santo				Hatching success Porto Santo			
	<i>B</i>	<i>Wald</i>	<i>P</i>		<i>B</i>	<i>Wald</i>	<i>P</i>
EW	-	2,215	0,137	EW	-	1,431	0,232
CH	-	1,394	0,238	VC	-	1,994	0,158
ET	+	0,010	0,921	Sub	0	0,000	1,000
EL	-	1,211	0,271	ET	+	0,000	0,999
CL	-	0,000	0,989	CL	-	0,000	0,998
CW	+	0,597	0,440	EL	+	0,231	0,630
Sub	+	0,362	0,547	CW	-	0,922	0,337
DLS	x	x	x	CH	-	0,000	0,998
VC	+	0,658	0,417	DLS	-	0,000	0,999
				BCI	x	x	x

Tab.8: univariate analysis for the laying and for the hatching success in relation to the nest-site characteristics of Selvagem Grande (A) and Porto Santo (B). *B* is the sign of the coefficient, *Wald* is the result of Wald test, *P* is the *P value* of the Wald test.

After the univariate analysis, we made a Spearman's correlation matrix between all the independent variables. From this analysis it was found that some variables were strongly correlated each other ( $r > 0.7$ ), so the correlated variables with the lowest *P value* were eliminated:

- Selvagem Grande laying success model: EA, NCS, AvTd, AvTn, MaxTd, minTn, minT, AvrH, AvrHd, AvrHn, minrHd, MaxrHn, and MaxrH minrH were eliminated
- Selvagem Grande hatching success model: DCS, AVT, AvTd, minTd, minTn, minT and MaxrHn were eliminated

Among the variables of Porto Santo was not found any strong correlation.

### Multivariate analysis

During the Stepwise Forward method we have gradually added the important variables to the Selvagem Grande laying success model: ENM, NLS, alt, SEO and VC. Therefore it seems that the extra-nest material, the number of neighbors, the altitude, the orientation of the nests towards the sea and the vegetation cover are important to explain why the birds choose to lay eggs in some nests instead of others. All the variables but the extra-nest material have a negative influence on the laying succes (tab.9).

We did two different tests to determine the good fit of the final model:

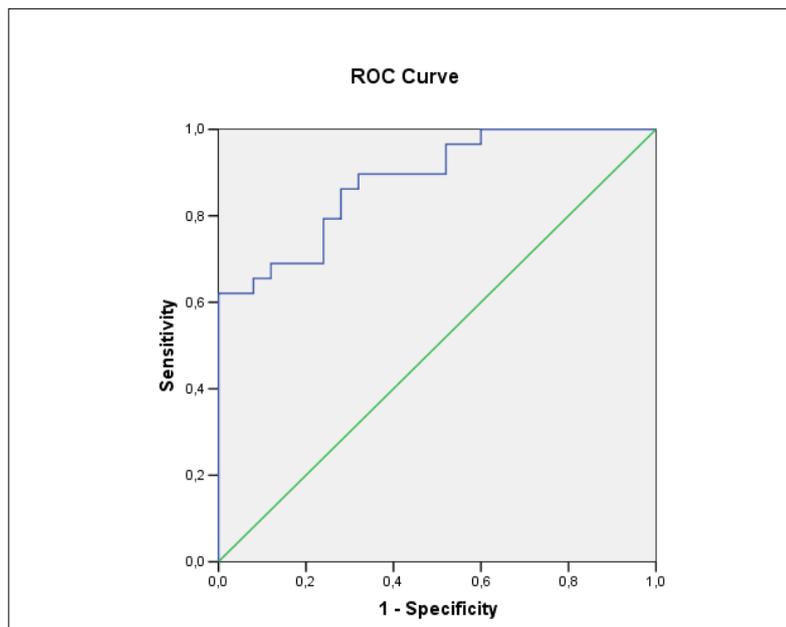
- 1) Hosmer & Lemeshow test:  $\chi^2 = 2,189$ ,  $df = 8$ ,  $P = 0,975$ . With these results we can say that the model has a very good fit.

- 2) Area Under the Receiver Operating Characteristic (or AUC Area Under the ROC): Area =  $0,881 \pm 0,044$ ;  $P < 0,001$  (graph.2). An area with this amplitude means a very good discrimination of the model (tab.4).

For the variables of Porto Santo and for the success of hatching on Selvagem Grande, it was not possible the construction of a model.

Characteristic	B ± S.E.	Wald	df	P
ENM	6,487 ± 2,394	7,343	1	0,007
nLS	-2,596 ± 0,919	7,979	1	0,005
Alt*		6,109	3	0,106
Alt(1)	-8,402 ± 3,489	5,797	1	0,016
Alt(2)	-2,714 ± 2,312	1,378	1	0,241
Alt(3)	-7,437 ± 3,210	5,366	1	0,021
SEO*		5,658	3	0,129
SEO(1)	-6,987 ± 3,020	5,353	1	0,021
SEO(2)	-4,055 ± 2,477	2,680	1	0,102
SEO(3)	-3,745 ± 2,668	1,970	1	0,160
VC*		6,746	2	0,034
VC(1)	-9,514 ± 4,049	5,522	1	0,019
VC(2)	-8,398 ± 3,247	6,689	1	0,010

Tab.9: multivariate model for the laying success in Selvagem Grande. This table shows the coefficient  $B$  and its standard error ( $SE$ ), the result of the Wald test ( $Wald$ ), degrees of freedom ( $df$ ) and the  $P$  value of the Wald test ( $P$ ). \*Categorical variables.



Graph.2: ROC curve of the multivariate model for the laying success in Selvagem Grande.

## DISCUSSION

### Comparison of the breeding biology between Selvagem Grande and Porto Santo colonies

From data collected in the field, we can observe some significant differences between Porto Santo and Selvagem Grande colonies.

First of all, and the most prominent, is the difference on the date of hatching. In Selvagem Grande colony, *P. assimilis* lays eggs one week earlier than in Porto Santo. This difference may be a consequence of various factors: 1) other Procellariiformes nesting in both colonies show this difference too, so the *P. assimilis* anticipated its breeding season to avoid the inter-specific nest-site competition; 2) the typical prey of the Little Shearwater could reach its maximum abundance during a slightly different period in the areas near the two colonies, so the times of hatching are different in the two islands to overlap the abundance of food and the nestlings food needs; 3) different climatic conditions in the colonies could allow the Little Shearwater to start its breeding season earlier, so it can give its offspring an earlier fledging or a longer period for development. However we must stress that our data is based on a small sample size and this could affect our results, even considering this species has a small population in the Atlantic and our data is the first to be collected on these islands.

Hatching success was higher in the Porto Santo colony, but the difference between the two colonies is not significant. An hatching success average near 50% ranks in the average of other long-life Procellariiformes (Monteiro et al, 1996).

Also hatching failure causes were different, but not significantly, between the two colonies: in Porto Santo the only cause of failure was nest desertion by both parents, instead in Selvagem Grande colony the break of the egg was another cause of failure. Desertion and egg breaking are two well known causes of breeding failure in other Procellariiformes too (Quillfeldt et al, 2003; Boersma & Wellwright, 1979). Some results showed by Booth et al. (2000) demonstrate that disturbance of researchers visiting the nest during parental incubation may be one of the causes of the desertion, but this is not significant for the breeding success of a colony. In our study we do not think this is an important factor because disturbance was kept to a minimum level. After a few days the nestling hatched, parents are less susceptible to this kind of disturb. This may be due to the fact that the time and energy investment in the egg care until the hatching motivate the parent to take risk of an exposure to danger, contrariwise the egg

not already hatched has still not enough worth to induce parent to take risks. Egg damage is another cause of hatching failure, caused by small stones in the nest floor puncturing the egg shell (Bolton et al, 2004). During the field work we tried to individuate the existence of nest predation by Madeiran lizard *Teira dugesii*. This reptile is already known as a nest predator for the Cory's Shearwater, another Procellariiformes nesting on Selvagem Grande (Matias et al, 2009). From this point of view we never observed a predatory act by lizards in nests of Little Shearwater, neither typical signs of predation (Matias et al, 2009) on broken eggs or on death nestlings, but we observed scavenging signs.

About parental body condition, we did not find any significant difference between the colonies. This suggests that the foraging grounds around both areas have similarities in terms of providing energy for maintenance of adult body condition.

#### **Offspring monitoring on Selvagem Grande colony**

Data shows that nestlings weight increases daily for the firsts days, than the weight fluctuates near the growth curve. Two explanation could be: 1) parents feed their offspring at least one time per day during the first days of life, than foraging journeys become longer, maybe because of the higher energetic request from their nestlings, until the feedings rise a frequency of one every two days, or 2) the amount of food and the feed frequency do not vary in time, but the storage food capacity of the nestling decreases while the energetic needs increase. In the graphics we can observe that the nestling PA20 (red) did not grow fast as the other two, so we can conclude that this individual did not reach the fledging or, at least, it fledged in poor conditions. A slow growth could be due to the loss of a parent or to the inexperience of the parents.

#### **Nest-site characteristics**

From the multivariate analysis, we obtained 5 nest-site variables which seem influence the laying success in Selvagem Grande colony.

The presence of extra-nest material is the only variable that shows a positive coefficient: this material makes it more probable the laying success. Another interpretation of these results could be that the presence of this material is not a cause, but an effect of the parental upkeep of the nest: after the borrow choice, the parents themselves furnish the incubation chamber with extra-nest material. Maybe this behavior is stimulated by the success of egg fertilization or it could depend from the parental experience. In the latter case, the presence of extra-nest material itself is not directly determinant for the laying success, but it would be a co-effect of the parental experience.

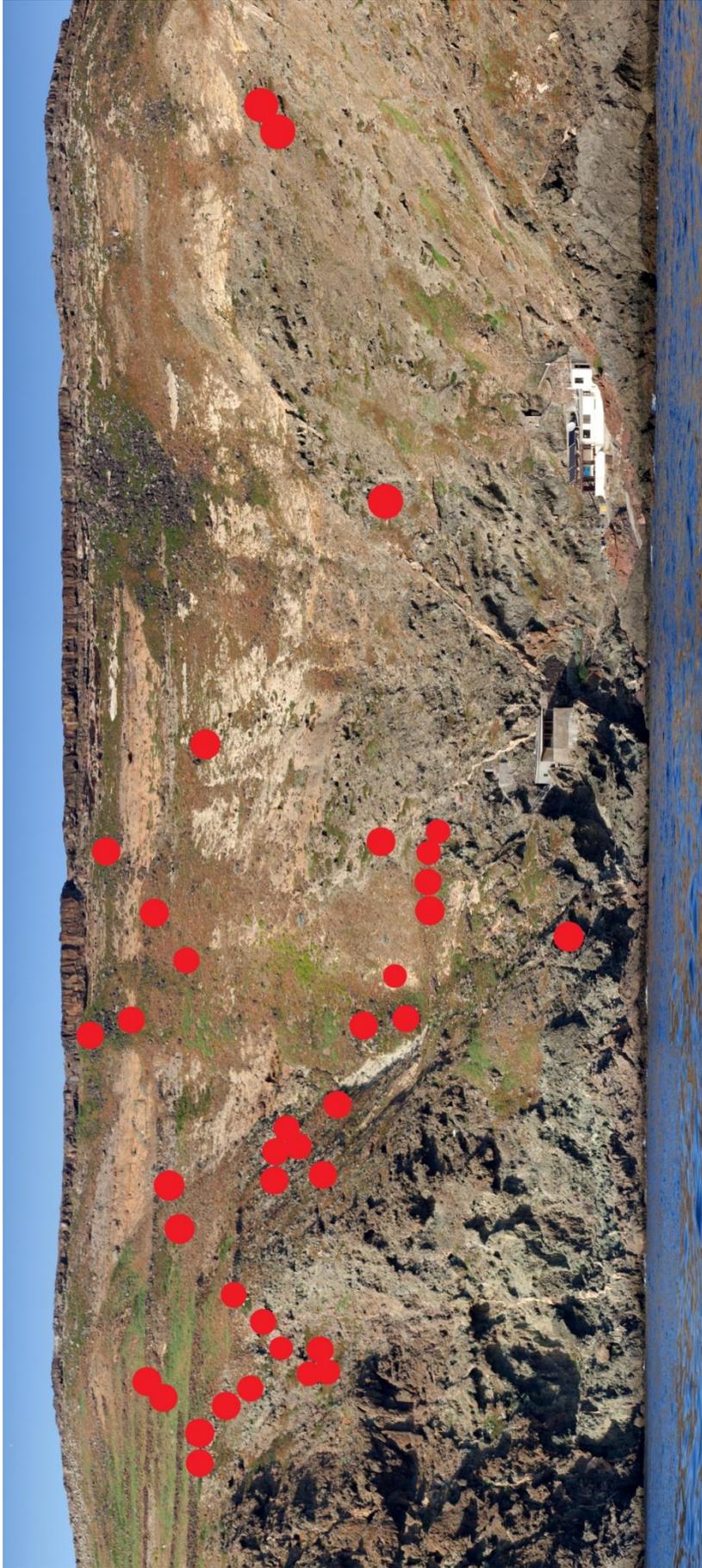


Fig.10: position of the Little Shearwater nests in Cagarra's Bay.

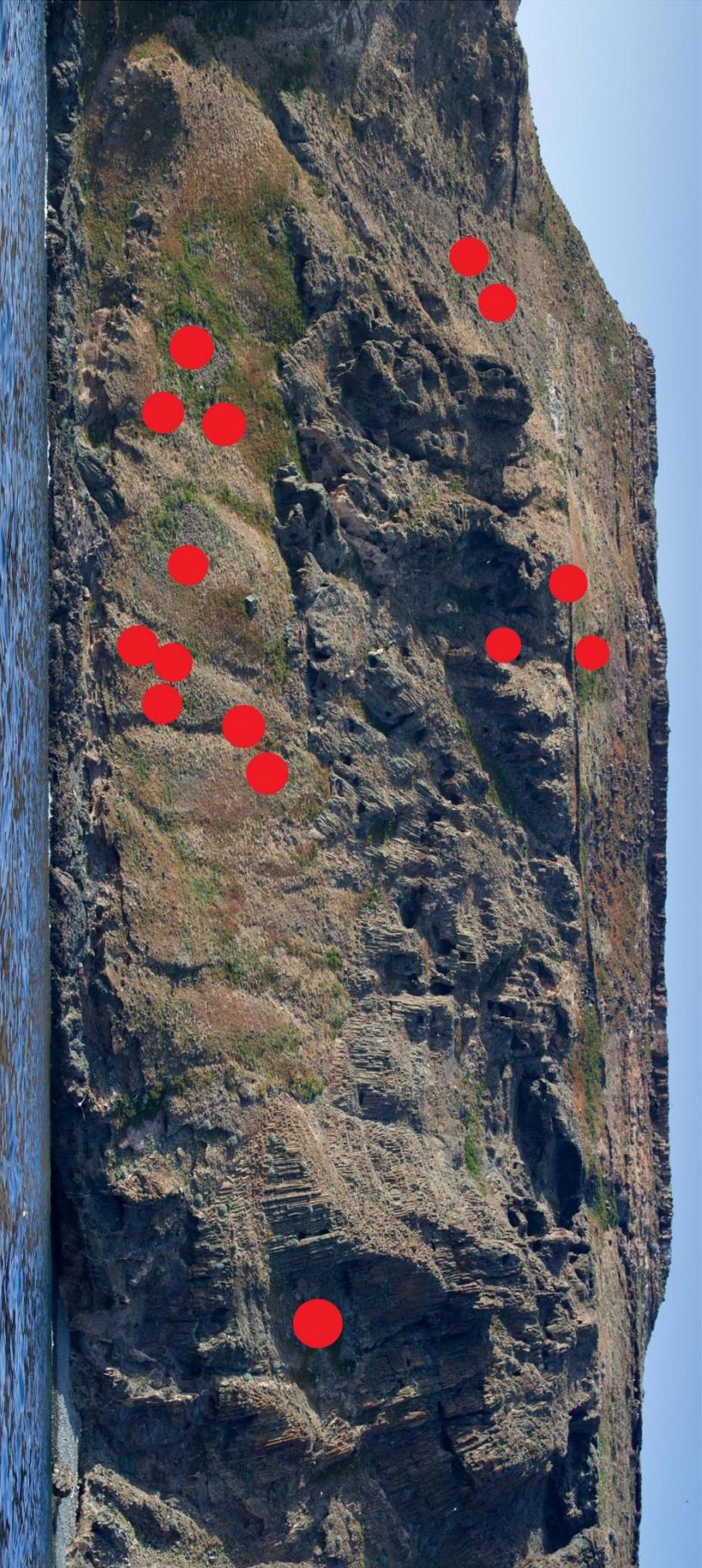


Fig. 11 : position of the Little Shearwater nests in Galinhas's Bay.

Number of neighbors within 3 meters is another significant variable. It has a negative coefficient, so it suggests that many neighbors may have a negative influence on the selection of a nest-site by this species. This could arise, for example, from the competition intra-specific for nest-site. We can find the same breeding colony structure for the Band-rumped Storm-petrel (*Oceanodroma castro*) nesting on Azores (Ramos et al, 1997). The colony dispersal structure could be, in this case, an adaptation to avoid intra-specific competition (Ramos et al, 1997) or to limit the predation risk (Picman, 1988).

Also the altitude seems to affect negatively the laying success. At an higher altitude corresponds a longer distance from the coastline and an higher intensity of the wind that could cause problems to inside-nest microclimate stability in borrows not very well protected. Furthermore, wind could be an obstacle for landing birds especially in dangerous rocky bumpy lands, like which are in Selvagem Grande.

The entry-sea orientation is another influent characteristic for the laying success: it seems that breeding pairs in a burrow with the entrance directly oriented towards the sea have an advantage in laying success. However we expected an opposite result: borrows with a more sheltered entry from the wind coming up from the sea should have a more stable in-chamber microclimate. Maybe the advantage is the more easier take-off for the fledging nestling or for the foraging parents.

Another result that disregards an our first argument concerns the entry vegetation cover. Initially we thought that a major cover provides a repair hiding the entry-nest to the predators because another paper (Zino, 1971) shows gull predation as an important factor for *C. diomedea*, another Procellariiformes nesting on Selvagem Grande. Perhaps predation pressure on Little Shearwater is very low in this colony (only one time we saw a gull during a predatory patrolling-like behavior in the Cagarras' Bay), so the presence of vegetation at the borrow entrance could be an obstacle for the parents passing in and out the nest.

Because the lack and maybe the variability of data collected, we were not able to do the same statistical analysis for the comparison of the nest-site characteristics and the hatching success in the Selvagem Grande colony. Also for Porto Santo colony we found the same problem.

Other characteristics which seem to be significant in the univariate analysis, both for laying and hatching success, deserve to be mentioned. Temperature and humidity data seem indicate a preference for a stable microclimate nest that could be favorable for embryonic develop, as for other species of birds (Booth,

1987). Analyzing the hatching success we found that also the distance from the nearest neighbor is important. This result reinforces the previous hypothesis that the Little Shearwater prefers to breed not close to many conspecifics.

Spatial measures results suggest that a nest with a long tight entry tunnel and a little incubation chamber are better for both laying and hatching successes: a long tight entrance can protect the core of the nest from predators and weathering, moreover a small chamber could be easier to warm with the body heat of the incubating parent.

Differently from what we expected, substrate do not seems to play a fundamental role in laying nor in hatching success. Contrarily in other burrow-nesting species it is an important factor (Stokes & Boersma, 1991), but perhaps our unexpected result could be due to a subjective and quite superficially categorization of the substrate.

The effect of the distance between the nest of a Little Shearwater and the closest nest of Cory's Shearwater on reproductive success is positive, although statistically not strongly correlated. The proximity to this species could be a factor of disturbance and a danger, not only about predation by the Cory's Shearwater (not observed in this study), but also for the aggressiveness of this species: frequently we observed furious fights (fig.12) for the nest-site between males of Cory's Shearwater, testified by the presence of many carrion scattered throughout the island after these combats. Disorder caused by the fights can damage the burrow of a near Little Shearwater and can induce the parent to escape, like it happens in case of disturbance by a researcher (Booth et al, 2000).



Fig.12: fighting males of Cory's Shearwater.

### **Inter-specific competition**

During the fieldwork we never observed a direct act of ousting in Little Shearwater nests by other Procellariiformes, but 11 old Little Shearwater nests, unoccupied by them in the breeding season 2011, were occupied by *Bulweria bulwerii* (n = 10) and by *C. diomedea* (n = 1). Apparently the occupation rate is low for the Little Shearwater (31% of the monitoring nests in Selvagem Grande), so other species, especially small petrels, can occupy these nests. For the bigger Procellariiformes, like Cory's Shearwater, is more difficult to occupies the small borrow of the Little Shearwater (Ramos et al, 1997) and for this reason the competition between these species is lower.

### **The problem of parental experience**

With this research we found some interesting details about the nest-site characteristic influencing parental choosing of the nest-site itself and the hatching success in these colonies of *P. assimilis*. We expected an higher signal of certain characteristics, like the type of substrate and the spatial measures of the entrance, but these did not emerge. Probably the scarcity of predators and a favorable climate (in two months it rained less than 10 cm) made lower the selection for these nest-site characteristics, so we have to search elsewhere for an higher selective pressure.

Breeding experience of the parents is one of the bigger influencing character on the breeding success in other Procellariiformes: Cory's Shearwaters change partners often, lose their egg, and forego reproduction for several years, but with experience, their performance improves (Mougin et al, 1990). Experience is not important just for the nest choice, but also in other aspects of breeding, like for example brooding and nestling feeding. Unfortunately, because the unknown age and the unknown past breeding stories of the pairs observed, we cannot insert these variables, probably very important, in the analysis.

### **The problem of stepwise analysis**

Some authors criticize the use of the stepwise logistic regression as an admission of ignorance about the phenomenon being studied (Studenmund & Cassidy, 1987). A computer-controlled stepwise procedure is inappropriate for theory testing because it capitalizes on random variation in the data, and produces results that tend to be difficult to replicate in any sample other than the sample in which they originally were obtained (Menard, 2001). However there are some authors that provide the use of this method in exploratory research (Wofford et al, 1994), as the case of the nest-site characteristics of *P. assimilis*.

## REFERENCES

- Amat JA, Visser GH, Pérez-Hurtado A, Arroyo GM (2000). Brood desertion by female shorebirds: a test of the differential parental capacity hypothesis on Kentish plovers. *Proceedings of the Royal Society B*, 267:2171-2176.
- Ashmole NP (1971). "Seabird Ecology and the Marine Environment" in *Avian Biology*, vol I (Farner DS & King JR. Eds.), pp 223-286. New York: Academic Press.
- Bannerman DA & Bannerman WM (1968). *History of the Birds of the Cape Verde Islands: Birds of the Atlantic Islands: Vol. IV*. Oliver & Boyd: Edinburgh.
- Bartholomew GA, White FN, Howell TR (1976). The thermal significance of the nest of the Sociable Weaver *Philetairus socius*: summer observations. *Ibis*, 118(3):402-411.
- Bendell RB & Afifi AA (1977). Comparison of stopping rules in forward regression. *Journal of the American Statistical Association*, 72(357):46-53.
- Birkhead TR, Greene E, Biggins JD, Nettleship DN (1985). Breeding site characteristics and breeding success in Thick-billed Murres. *Canadian Journal of Zoology*, 63(8):1880-1884.
- Blem CR & Blem RB (1990). Lipid Reserves of the Brown Water Snake *Nerodia taxispilota*. *Comparative Biochemistry and Physiology - A Physiology*, 97(3):367-372.
- Boersma PD (1986). Ingestion of Petroleum by Seabirds Can Serve as a Monitor of Water Quality. *Science, New Series*, 231(4736):373-376.
- Boersma PD & Wellwright NT (1979). Egg Neglect in the Procellariiformes: reproductive adaptations in the Fork-tailed Storm-petrel. *The Condor*, 81(2):157-165.
- Bolton M, Madeiros R, Hothersall B, Campos A (2004). The Use of Artificial Breeding Chambers as a Conservation Measure for Cavity-nesting Procellariiform Seabirds: a Case Study of the Madeiran Storm Petrel (*Oceanodroma castro*). *Biological Conservation*, 116(1):73-84.
- Booth AM, Minot EO, Imber MJ, Fordham RA (2000). Aspects of the breeding ecology of the North Island little shearwater *Puffinus assimilis haurakiensis*. *New Zealand Journal of Zoology*, 27:335-345.
- Booth DT (1987). Effect of Temperature on Development of Mallee Fowl *Leipoa ocellata* Eggs. *Physiological Zoology*, 60(4):437-445.
- Bourne WRP (1955). The birds of Cape Verde Islands. *Ibis*, 97(3):508-556.

- Bradley JS & Meathrel CE (2006). Prediction of individual reproductive success in Short-tailed Shearwaters, *Puffinus tenuirostris*. *Acta Zoologica Sinica*, 52(Supplement):91-95.
- Bried J, Pontier D, Jouventin P (2003). Mate fidelity in monogamous birds: a re-examination of the Procellariiformes. *Animal Behaviour*, 65(1):235-246.
- Brown ME (1996). Assessing body condition in birds. *Current Ornithology*, 13:67-135.
- Campos AR & Granadeiro JP (1999). Breeding Biology of the White-faced Storm-Petrel on Selvagem Grande Island, North-East Atlantic. *Waterbirds*, 22(2):199-206.
- Carvalho AMG & Brandão JM (1991). *Geologia do Arquipélago da Madeira*. Publicações do Museu Nacional de História Natural: Lisboa.
- Colabuono FI, Barquete V, Domingues BS, Montone RC (2009). Plastic ingestion by Procellariiformes in southern Brazil. *Marine Pollution Bulletin*, 58(1):93-6.
- Colabuono FI, Taniguchi S, Montone RC (2010). Polychlorinated Biphenyls and Organochlorine pesticides in plastics ingested by seabirds. *Marine Pollution Bulletin*, 60(4):630-634.
- Correia-Fagundes C, Romano H (2011). Macaronesian Shearwater *Puffinus baroli*. Available at [www.madeirabirds.com/macaronesian\\_shearwater\\_puffinus\\_baroli](http://www.madeirabirds.com/macaronesian_shearwater_puffinus_baroli).
- Cramp S, (1977). *Handbook of the Birds of Europe, the Middle-East and North Africa: The Birds of the Western Palearctic*. Oxford: Oxford University Press.
- Darwin C (1859). "Natural Selection" in *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. London: John Murray 1st edition.
- Dawkins R (1982). *The Extended Phenotype*. Oxford: Freeman.
- Dytham C (2003). *Choosing and Using Statistics: a Biologist's Guide*. Blackwell Publishing, Oxford.
- Foster KL, Wang SW, Mackay D, Mallory ML, Blais JM (2010). Preliminary Assessment of Avian Stomach Oils: A Vector of Contaminants to Chicks and Potential for Diet Analysis and Biomonitoring. *Environmental Science & Technology*, 44(17):6869–6874.
- Franco A & Southerland W (2004). Modelling the Foraging Habitat Selection of Lesser Kestrels: Conservation Implications of European Agricultural Policies. *Biological Conservation*, 120(1):63-74.

Franco A, Brito JC, J Almeida (2000). Modelling Habitat Selection of Common Cranes *Grus grus* Wintering in Portugal Using Multiple Logistic Regression. *Ibis*, 142(3):351-358.

Furness RW & Camphuysen CJ (1997). Seabirds as Monitors of the Marine Environment. *Journal of Marine Science*, 54(4):726-737.

Gosler AG, Greenwood JJD, Baker JK, Davidson NC (1998). The Field Determination of Body Size and Condition in Passerines: A Report to the British Ringing Committee. *Bird Study*, 45(1):92-103.

Granadeiro JP, Dias MP, Rebelo R, Santos CD, Catry P (2006). Numbers and population trends of Cory's Shearwater *Calonectris diomedea* at Selvagem Grande, northeast Atlantic. *Waterbirds*, 29(1):56-60.

Griggio M, Matessi G, Pilastro A (2003). Male Rock Sparrow (*Petronia petronia*) Nest Defence Correlates with Female Ornament Size. *Ethology*, 109(8):659-669.

Hansell M (2000). *Bird Nests and Construction Behaviour*. Cambridge: University Press.

Harris MP (1969). Breeding Season of Sea-birds in the Galapagos Islands. *Journal of Zoology*, 159(2):145-165.

Harrison CS, Hida TS, Seki MP (1983). Hawaiian Seabird Feeding Ecology. *Wildlife Monographs*, 85:1-71.

Hochachka W & Smith JNM (1991). Determinants and Consequences of Nestling Condition in Song Sparrows. *Journal of Animal Ecology*, 60(3):995-1008.

Hosmer D & Lemeshow S (2000). *Applied Logistic Regression*. 2nd edition, John Wiley & Sons Inc, New York.

Jääntti A, Hakkarainen H, Kuitunen M, Suhonen J (2007). The importance of landscape structure for nest defence in the Eurasian *Treecreeper Certhia familiaris*. *Ornis Fennica*, 84:145-154.

Mallory ML & Forbes MR (2010). Nest shelter predicts nesting success but not nesting phenology or parental behaviors in high arctic Northern Fulmars *Fulmarus glacialis*. *Journal of Ornithology*, 152(1):119-126.

Martin TE (1993). Nest predation among vegetation layers and habitat type: revising the dogmas. *American Naturalist*, 141(6):897-913.

Matessi G & Bogliani G (1994). Experiments on nest predation: effect of habitat fragmentation and landscape features. 21st International Ornithological Congress, Vienna, *Ornithological Notebook*, p 647.

Matias R, Rebelo R, Granadeiro JP, Catry P (2009). Predation by Madeiran Lizards *Teira dugesii* on Cory's Shearwater *Calonectris diomedea* Hatchlings at Selvagem Grande, North Atlantic. *Waterbirds*, 32(4):600-603.

Mayr E (2002). *What Evolution Is*. London: Weidenfeld & Nicolson.

Menard S (2001). *Applied Logistic Regression Analysis*. Sage University Paper series on Quantitative Applications in the Social Science, 07-106. Thousand Oaks, CA: Sage.

Menezes D, Gouveia L, Domingues M, Jardim N, Fontinha S (2004). *Selvagens Islands*. Parque Natural da Madeira. Funchal, Madeira, Portugal.

Monteiro LR, Ramos JA, Furness RW, del Nevo AJ (1996). Movements, Morphology, Breeding, Molt, Diet and Feeding of Seabirds in the Azores. *Colonial Waterbirds*, 19(1):82-97.

Mougin J-L, Jouanin C, Roux F (2000). Demography of the Cory's Shearwaters, *Calonectris diomedea* of Selvagem Grande (30°09'N, 15°52'W). *Revue d'Ecologie (La Terre et la Vie)*, 55(3):275-290.

Mougin J-L, Jouanin C, Roux F (1990). The influence of age and breeding experience on the evolution and success of breeding among the Cory's Shearwater *Calonectris diomedea borealis* of Selvagem Grande Island. *Oiseau et la Revue Francaise d'Ornithologie*, 60:39-49.

Newton I (1998). *Population Limitation in Birds*. Academic Press, London.

Oliveira PE, Mendez D, Trout R, Buckle A, Geraldés P, Jesus J (2010). Successful eradication of the European rabbit (*Oryctolagus cuniculus*) and house mouse (*Mus musculus*) from the island of Selvagem Grande (Macaronesian archipelago), in the Eastern Atlantic. *Integrative Zoology*, 5(1):70-83.

Oliveira PE & Moniz P (1995). Population size, breeding chronology, annual cycle and effects of interspecific competition on the reproductive success of the Little Shearwater *Puffinus assimilis baroli* on Selvagem Grande. Glasgow: Proceedings of the 5th international seabird group conference.

Osborne PE, Alonso JC, Bryant RG (2001). Modelling Landscape-scale Habitat Use Using GIS and Remote Sensing: a Case Study with Great Bustards. *Journal of Applied Ecology*, 38(2):458-471.

Paiva VH (2005). Contributo para o estudo da ecologia alimentar de andorinha-dormar anã *Sterna albifrons* em colónias reprodutivas na Ria Formosa. M.Sc. thesis, Universidade de Coimbra.

Palmer RS (1962). *Handbook of North American Birds I*. New Haven.

Paredes R & Zavalaga CB (2001). Nesting Sites and Nest Types as Important Factors for the Conservation of Humboldt Penguins (*Spheniscus humboldti*). *Biological Conservation*, 100(2):199-205.

Partridge L (1978). "Habitat Selection" in *Behavioural ecology: an evolutionary approach*. Edited by Krebs JR & Davies NB. Blackwell Scientific Publications Ltd, Oxford, pp 351-376.

Picman J (1988). Experimental study of predation on eggs of the ground nesting birds: effects on habitat and nesting distribution. *The Condor*, 90(1):124-131.

Pinilla JS (2002). Cartografía predictiva de la distribución de aves terrestres: un estudio piloto en Andalucía occidental. PhD thesis. Universidad Autónoma de Madrid.

Quillfeldt P, Masello JF, Strange IJ (2003). Breeding biology of the thin-billed prion *Pachyptila belcheri* at New Island, Falkland Islands: egg desertion, breeding success and chick provisioning in the poor season 2002/2003. *Polar Biology*, 26:746-752.

Press JR & Short MJ (1994). *Flora of Madeira*. Natural History Museum, Her Majesty's Stationery Office, London.

Ramos JA, Monteiro LR, Sola E, Moniz Z (1997). Characteristics and competition for nest cavities in borrowing Procellariiformes. *The Condor*, 99:634-641.

Ricklefs RE (1969). An analysis of nesting mortality in birds. *Smithsonian Contribution to Zoology* No. 9.

Robertson CJR, Hyvönen P, Fraser MJ, Pickard CR (2007). *Atlas of bird distribution in New Zealand 1999-2004*. Wellington, The Ornithological Society of New Zealand.

Sanz-Aguilar A, Tavecchia G, Pradel R, Mínguez E, Oro D (2008). The Cost of Reproduction and Experience-Dependent Vital Rates in a Small Petrel. *Ecology*, 89(11):3195-3203.

Stokes DL & Boersma PD (1991). Effects of Substrate on the Distribution of Magellanic Penguin (*Spheniscus magellanicus*) Burrows. *The Auk*, 108(4):923-933.

Studenmund AH & Cassidy HJ (1987). *Using Econometrics: A Practical Guide*. Boston: Little, Brown.

Tabachnick B & L Fidell (2007). *Using Multivariate Statistics*, 5<sup>o</sup> ed. HarperCollins Publishers Inc, New York.

Thompson KR (1987). *The Ecology of Manx Shearwater Puffinus puffinus on Rhum, West Scotland*. PhD Thesis to the Faculty of Science, University of Glasgow.

Tieleman BI, van Noordwijk HJ, Williams JB (2008). Nest Site Selection in a Hot Desert: Trade-off Between Microclimate and Predation Risk?. *The Condor*, 110(1):116-124.

Tryjanowski P & Goławski A (2004). Sex differences in nest defence by the red-backed shrike *Lanius collurio*: effects of offspring age, brood size, and stage of breeding season. *Journal of Ethology*, 22(1):13-16.

Walsberg GE & King JR (1978). The Heat Budget of Incubating mountain white-crowned sparrow (*Zonotrichia leucophrys oriantha*) in Oregon. *Physiological Zoology*, 51(1):92-103.

Werner AC (2010). Pre-breeding Period in Cory's Shearwater: Bird Quality and Foraging Behavior. Master Thesis in Ecology, Universidade de Coimbra.

Whittingham LA & Raleigh JR (1994). Food Availability, Parental Care and Male Mating Success in Red-Winged Blackbirds (*Agelaius phoeniceus*). *Journal of Animal Ecology*, 63(1):139-150.

Wofford S, Elliot DS, Menard S (1994). Continuities in material violence. *Journal of Family Violence*, 9(3):195-225.

Zar JH (1999). *Biostatistical Analysis*. Prentice Hall International Inc, New Jersey.

Zino PA (1971). The breeding of Cory's Shearwater *Calonectris diomedea* on the Salvage Islands. *Ibis*, 113:212-217.

Zweig MH & Campbell G (1993). Receiver-operating Characteristic (ROC) Plots: a Fundamental Evaluation Tool in Clinical Medicine. *Clinical Chemistry*, 39:561-577.