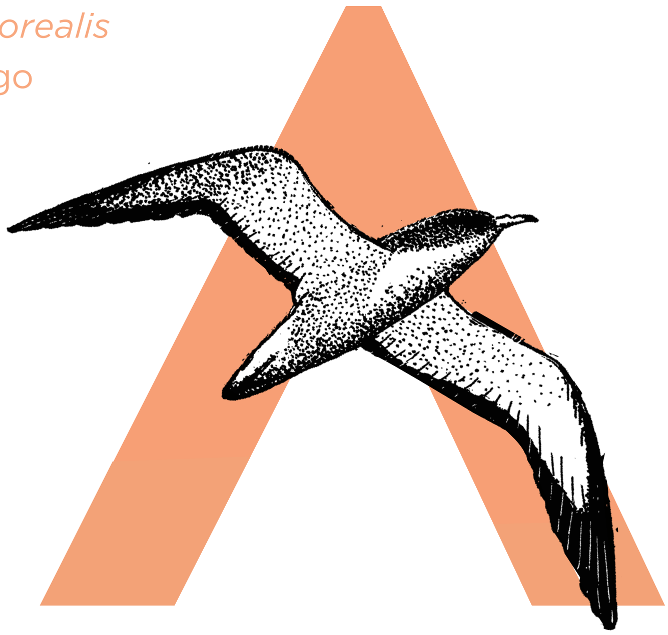
Evaluating the potential of artificial nests as a conservation measure for Cory's Shearwaters *Calonectris borealis* breeding in Berlengas Archipelago, Portugal

Avaliação da eficiência de ninhos artificiais como medida de conservação para as cagarras *Calonectris borealis* nidificantes no arquipélago das Berlengas, Portugal



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ABSTRACT

Seabirds are one of the avian groups facing the fastest and highest decline in population numbers around the world, suffering from many threats not only at sea but also on land. For burrow-nesting seabirds, the loss of adequate breeding habitat, human disturbance and competition with other species make the availability of adequate nesting burrows a limiting factor for the recovery of breeding numbers. Artificial nest provisioning has been broadly used as a measure to invert population declines, by increasing the availability of higher quality nests. Berlengas Archipelago holds an important breeding population of Cory's Shearwater *Calonectris borealis*, mainly concentrated in two different sites, Farilhão Grande Islet and Berlenga Island. On Berlenga Island, artificial nests have been provided since the late 1980's. In this study, we present the results of artificial nest provisioning as a conservation measure implemented over almost 30 years and its effectiveness in inverting a negative population trend found in Farilhão Grande Islet.

We also present up-to-date data on the population size and breeding parameters of Cory´s Shearwater nesting in Berlengas Archipelago. Breeding success was found to be higher in artificial nests (0.86 ± 0.05) than in natural nests (0.77 ± 0.12). Occupation rate for artificial nests built after 2015 increased along the first 4 years after installation, resulting in an annual growth rate of 9%. In 2015, 32-34% of the Cory's Shearwater population was breeding in artificial nests. A total of 681 active nests were counted along the entire archipelago in 2015, with an estimate of 800 – 975 breeding pairs. In Farilhão Grande, breeding success was particularly low and the breeding population showed a significant negative trend (annual growth rate of -2% since 2005). However, demographic modelling indicates that a decrease on productivity by itself may not explain the observed negative population growth, and that other factors (e.g., adult survival) may be driving the negative trend. The identification of demographic parameters responsible for such changes will provide relevant information for conservation managers and authorities on the proper solutions to put in place. Artificial nests were shown to be an effective conservation measure for Cory's Shearwater on Berlenga Island, and may thus contribute to the increase of breeding success and of the breeding population size at Farilhão Grande islet.

Keywords: Adult survival, Breeding success, Demography, Farilhão Grande, Seabirds.

RESUMO

As aves marinhas representam um dos grupos de aves com o maior e mais rápido decréscimo populacional a nível global. Este grupo enfrenta um grande número de ameaças, quer no mar como em terra. No caso das aves que se reproduzem em cavidades, a perda de habitat adequado para a sua reprodução, a perturbação humana e a competição com outras espécies leva a que a disponibilidade de cavidades adequadas para a sua nidificação represente um fator limitante para a estabilidade das populações reprodutoras. A construção de ninhos artificiais tem sido amplamente usada como medida para inverter os declínios destas populações, proporcionando o aumento da disponibilidade de ninhos de maior qualidade. O arquipélago das Berlengas alberga uma população reprodutora importante de cagarra *Calonectris borealis*, concentrando-se em dois locais, o ilhéu Farilhão Grande e a ilha da Berlenga. Na ilha da Berlenga têm sido construídos ninhos artificiais desde o final dos anos 1980 para favorecer a reprodução da cagarra. Neste estudo apresentamos os resultados de cerca de 30 anos a usar as cavidades artificiais como medida de conservação e o seu potencial para inverter a tendência populacional negativa observada no Farilhão Grande. Também apresentamos dados atuais do tamanho da população reprodutora de cagarra nidificante no arquipélago da Berlenga, bem como os seus parâmetros reprodutores. O sucesso reprodutor foi maior nas cavidades artificiais (0.86 ± 0.05) que nos ninhos naturais (0.77 ± 0.12). A probabilidade de ocupação dos ninhos artificiais construídos após 2015 aumentou ao longo dos primeiros 4 anos após a instalação dos mesmos, representando uma taxa de crescimento anual de 9%. Em 2015, 32-34% da população de cagarra da ilha da Berlenga encontrava-se a nidificar em cavidades artificiais. Um total de 681 ninhos ativos de cagarra foi contado em todo o arquipélago das Berlengas em 2015, com uma estimativa total de 800 – 975 casais reprodutores. No Farilhão Grande, o sucesso reprodutor foi particularmente baixo e o tamanho da população reprodutora mostrou uma tendência negativa (taxa de crescimento anual de -2% desde 2005). Contudo, os modelos demográficos gerados indicam que uma redução na produtividade por si só, não explica o crescimento negativo observado. Outros fatores (ex.: a sobrevivência dos adultos) poderão estar a influenciar esta tendência negativa. A identificação dos parâmetros demográficos, responsáveis por tais alterações, poderão ser usados para informar as entidades com competências na gestão e na conservação acerca das melhores soluções a implementar. Os ninhos artificiais mostraram ser uma medida efetiva para a conservação da população de cagarra na ilha da Berlenga que poderá ser utlizada no Farilhão Grande, assim espera-se que estas estruturas tenham uma contribuição relevante para aumentar o sucesso reprodutor e também o tamanho da população reprodutora do Farilhão Grande, possibilitando um crescimento da população ao nível de todo o arquipélago.

Palavras-chave: Sobrevivência dos adultos, Sucesso reprodutor, Demografia, Farilhão Grande, Aves marinhas.

Introduction

Seabirds are one of the groups facing the highest and fastest declines in terms of population numbers around the world (Butchart et al. 2004). Several reasons are pointed out to explain this phenomenon. While at sea, seabirds are mainly threatened by fisheries bycatch, prey reduction, windmills and marine pollution (Dias et al. 2019). On the other hand, at the breeding grounds seabird populations face predation by alien species, loss of habitat, light pollution and predation by avian sympatric species (Croxall et al. 2012). Artificial nests have been broadly used as a conservation measure to recover threatened seabird populations (Jones & Kress 2012, Sutherland et al. 2015). These artificial structures may offer better conditions for nesting than natural nests in terms of thermal and humidity insulation, and providing protection against heavy rains and predators. The provision of artificial nests has previously shown a positive effect on survival rates, breeding success and population density (Priddel & Carlile 1995, Libois et al. 2012). Depending on the species, artificial nests provide more stable and persistent breeding habitat allowing the recruitment of new breeders (Bourgeois et al. 2015). Furthermore, easy access to the nest chamber in artificial nests is an advantage for long-term monitoring, facilitating inspection of its content and handling of adults, eggs and chicks (Priddel & Carlile 1995, Gummer et al. 2015). The potential of artificial nest provisioning as a conservation measure remains unclear in some cases, since only a few studies explored population-level effects and if the use of artificial nests may actually represent an increase in numbers but instead a redistribution of the same number of birds (Williams et al. 2012).

Berlengas Archipelago is located off the western coast of mainland Portugal. The archipelago is composed by Berlenga Island and surrounding small islets, including Farilhão Grande. Berlengas was designated as Natural Reserve in 1981, and as Biosphere Reserve by UNESCO later in 2011. It represents the main breeding site for Cory's Shearwater *Calonectris borealis* in the Iberian Peninsula coast. Despite the positive trend observed in the population size of Cory's Shearwater nesting on Berlenga Island, a census done in 2011 pointed to a decrease in the number of breeding pairs counted in the largest colony, located in Farilhão Grande (Lecoq et al. 2011). On Berlenga Island, artificial nests have long been used to increase the availability of secure nesting sites for the Cory's Shearwater (Lecoq et al. 2010). The first artificial nests were placed in 1989 and since then, 227 new nests have been built and installed at five different subcolonies of Berlenga Island. Three different types of artificial nests were placed depending on available materials and funding. Here, we present the results obtained over 30 years of artificial nests used as a conservation measure at the Berlenga Island. The main factors affecting nest occupancy were explored in order to define the most suitable artificial nests for this seabird species. A demographic analysis of the breeding population from Farilhão Grande was made using a simple model in order to identify which parameters may be affecting this population and which conservation measures may contribute to invert its decrease.

Methods

Study area

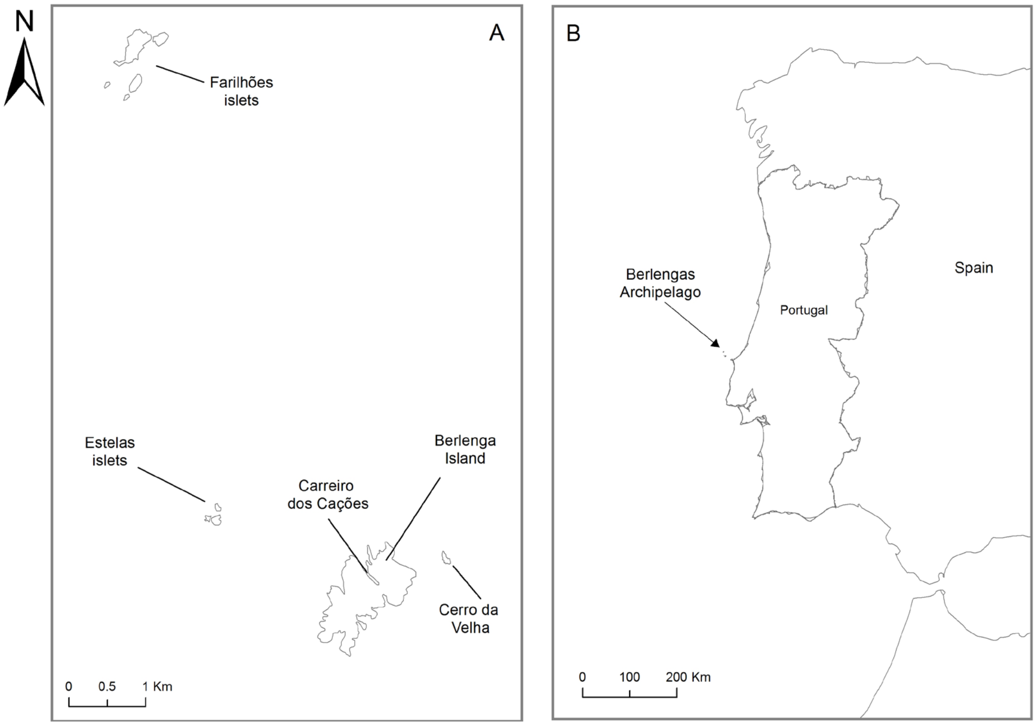
Berlengas Archipelago (39.42°N, 9.51°W) is located ~7km off Peniche, the centre of mainland Portugal, and covers nearly 104 ha. The archipelago includes Berlenga Island and the surrounding small islets, plus Farilhões (Farilhão Grande, Farilhão do Nordeste, Farilhão da Cova, Farilhão dos Olhos and Rabo d'Asno), Estelas (Estela Grande, Estelão and Manuel Jorge) and Cerro da Velha islets (Fig. 1). The field work covered the entire archipelago. All islets lack flat ground and are mostly surrounded by steep cliffs, with maximum altitude near 98 m above sea level. The small islets are characterized by bare rock faces and the presence of little or no vegetation cover. The predominant vegetation is composed by herbaceous annual plants with some perennial shrubs, mainly *Sueda* sp., on Berlenga island and larger islets (Lecoq et al. 2011, Nascimento et al. 2019.

Breeding population size of Cory's Shearwater

Direct nest counts of Cory's Shearwater took place over the entire archipelago from

Figure 1- Geographic location of (B) Berlengas Archipelago and (A) main island and groups of islets, Portugal.

Figura 1 - Localização geográfica do (B) arquipélago das Berlengas e da (A) ilha principal e grupos de ilhéus, Portugal.



the 5th to the 10th of June 2015, following the method proposed by Lecoq et al. (2010). A nest was considered active when an incubating adult was present or when strong breeding evidence (namely a broken and/or deserted egg) was found. The number of breeding pairs using inaccessible areas was estimated (and presented separately) by assessing the proportion of available breeding habitat in those areas and assuming similar nest densities across the nearest and most similar counted area. On Berlenga Island, the density observed in the accessible counted caves was used to estimate the number of nests present on the non-prospected five small caves. On Farilhão Grande, approximately 90% of the islet was prospected. Only a small rocky beach located on the northeast side and a small area of a wall located on the east cliff were not visited. However, we used the nest density observed on a similar rocky beach and on the walls located nearby the non-prospected area, respectively, to estimate the number of nests present in each area. Although Estela Grande, Farilhão do Nordeste and Farilhão da Cova islets had a good survey effort, some nests potentially located in inaccessible vertical cliffs might have been missed. Estelão, Manuel Jorge and Farilhão dos Olhos were not prospected and numbers were estimated based on data from the closest islet with most similar habitat, Estela Grande and Rabo d'Asno.

Artificial nest provisioning and nest characteristics

Three different types of artificial nests were placed on Berlenga Island between 1989 and 2018. For the first type, we took advantage of natural small crevices, and fitted local rocks together to close the chamber (hereafter referred as semi-artificial). A small burrow was left clear to allow the entrance of birds. The second type was built using only local rocks, but some required small portions of concrete to fix the main rocks together. The third type was made using a wooden box (height * width * length: 0.20 * 0.30 * 0.50 m) covered by local rocks. A total of 224 artificial nests over 5 different subcolonies were made available on Berlenga Island (Melreu, Furado, Capitão, Flandres and Quebradas; Table 1). In 2018, 90 artificial and 23 natural nests from the Melreu subcolony (the larger subcolony of Berlenga Island and where the

Table 1- Number of artificial nests installed for Cory's Shearwaters in five sub colonies on Berlenga Island, between 1989 and 2018.

Tabela 1 - Número de ninhos artificiais disponibilizados em cinco sub colónias da ilha da Berlenga, no período entre 1989 e 2018.

SITE	1989-2014	2015	2016	2017	2018
Melreu	94	94	94	94	98
Furado	15	42	42	42	42
Capitão	15	15	20	45	45
Flandres	0	12	12	12	23
Quebradas	0	0	0	16	16
Total	**124**	**163**	**168**	**209**	**224**

first artificial nests were placed) were compared in terms of type of nest (semi-artificial – S, only rocks – R, wooden box – W, natural – N) and also in terms of the maximum length of the chamber (from the entrance to the back), the entrance height and width and the type of substrate (soil, rock, gravel). This comparison was then used to understand the influence of such features on nest occupancy and on breeding success. The number of occupied nests located within a circle of 3 m radius from each nest was also recorded as a proxy for nest density.

Artificial nest occupancy and breeding success

From 2015 to 2018, occupancy of nests and breeding success data were collected for all artificial nests on Berlenga Island. Almost all natural nests in Melreu (n = 38) and Furado (n = 6) subcolonies, plus a subsample of natural nests in Capitão (n = 9) and Flandres (n = 1) subcolonies were also monitored on this island. All monitored natural nests were located in the vicinity of the monitored artificial nests. Additionally, 35 and 36 natural nests were monitored on Farilhão Grande in 2017 and 2018, respectively. From those, 20 were located in covered cavities, while the remaining were only covered by native vegetation or not covered at all. All nests were visited three times a year, shortly after egg laying, during the first days after egg hatching and just before fledging. A nest was considered to be truly occupied when the occupation was recorded in more than one year. Nests occupied only once were pulled together with unoccupied nests. Breeding success was estimated as the ratio between the number of nests with a fledgling present in the third visit and the number of active nests. The occupancy rate was estimated as the ratio between the number of occupied artificial nests and the number of available artificial nests. The occupation for the first time rate was estimated as the ratio between the number of occupied artificial nests for the first time (non-occupied in previous years) and the number of available artificial nests. Both rates were estimated for each year between 2015 and 2018. Also, the instantaneous growth rate, the annual multiplication rate and the annual growth rate were estimated. The instantaneous growth rate (r) was calculated as a function of the number of occupied nests at outset (N0) and the number of occupied nests after the period t in years (Nt)($r = [\ln Nt - \ln N0] * t^{-1}$). The annual multiplication rate (γ) was estimated as an exponential function of r ($\gamma = e^r$) and the annual growth rate (%) was expressed as (γ-1) * 100.

Farilhão Grande population modelling

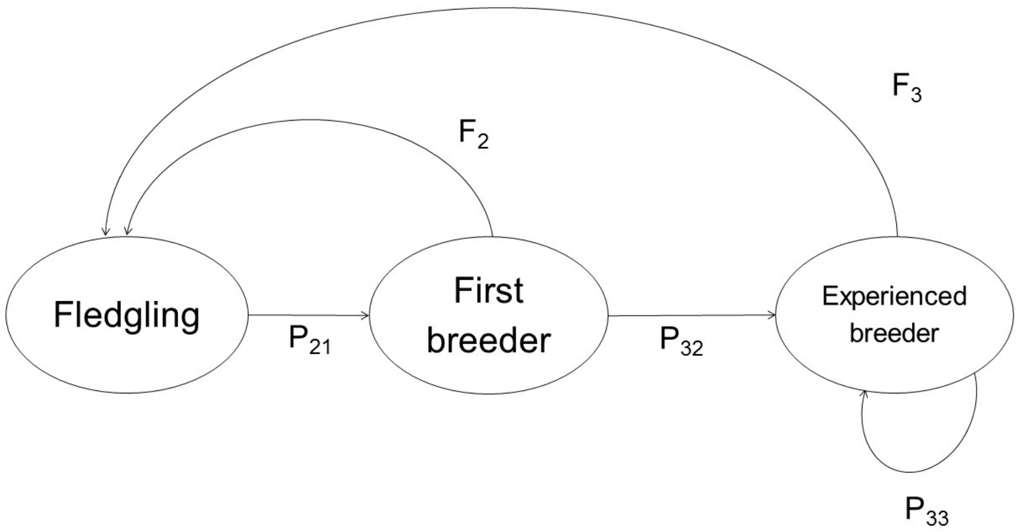
Leslie Matrix analysis was used to model Cory's Shearwater demographic parameters of the breeding population from Farilhão Grande Islet. A simple demographic model was used (Fig. 2) and the following Leslie matrix was built:

$$A = \begin{pmatrix} 0 & F_2 & F_3 \\ P_{21} & 0 & 0 \\ 0 & P_{32} & P_{33} \end{pmatrix}$$

where F_2 is the breeding success of first breeders, F_3 is the breeding success of experienced breeders and assumed to be equal to F_2, P_{21} is the survival rate of immatures between fledgling and first breeding, P_{32} is the annual survival of first breeders and P_{33} is the annual survival of experienced breeders. All birds after their first breeding season were considered experienced breeders. In the absence of information for the Farilhão Grande population, demographic parameters from the population breeding on Selvagem Grande Island were used (Mougin et al. 2000). Thus, the values for the mean annual survival of the experienced breeders, for the annual survival of first breeders (both = 0.927) and for the survival rate of the immatures between fledging and first breeding (0.328) were assumed as similar to those obtained for the Selvagem

Figure 2- Model explaining the population structure, life cycle and demographic parameters of Cory's Shearwater *Calonectris borealis* population in Farilhão Grande. F_2 is the breeding success of first breeders, F_3 is the breeding success of experienced breeders, P_{21} is the survival rate of immatures between fledgling and first breeding, P_{32} is the annual survival of first breeders and P_{33} is the annual survival of experienced breeders. All birds after their first breeding season were considered experienced breeders.

Figura 2 - Modelo usado para explicar a estrutura populacional, o ciclo de vida e os parâmetros demográficos da população de cagarra *Calonectris borealis* do Farilhão Grande. F_2 representa o sucesso reprodutor dos reprodutores pela primeira vez, F_3 é o sucesso reprodutor dos reprodutores experientes, P_{21} é a taxa de sobrevivência dos imaturos até à idade da primeira reprodução, P_{32} é a taxa de sobrevivência anual dos reprodutores de primeiro ano e P_{33} é a taxa de sobrevivência anual dos adultos reprodutores experientes. Todas as aves foram consideradas reprodutoras experientes após a sua primeira época reprodutora.



Grande breeding population (Mougin et al. 2000). Several models were then run using different breeding success rates. Therefore, we inferred the contribution of each matrix element to the total population growth rate through a perturbation analyses on the matrix. By changing one of the demographic parameters, keeping all other parameters constant, the change in the growth rate will mirror the change in that parameter. Between 1999 and 2004 the Cory's Shearwater censuses made at Farilhão Grande and Berlenga Island were only partial, but in 2005 an exhaustive census was carried out over the entire archipelago (Lecoq et al. 2010). Therefore, in the present study we used the number of 401 breeding pairs (Lecoq et al. 2010), a breeding success rate of 0.39 (estimated in 2018 for Farilhão Grande) and a survival rate of the immatures between fledging and first breeding of 0.328 to calculate our initial condition vector (N (t)), which included 3 age classes. This resulted in 51 first breeders (calculated as the number of nestlings that survived until first breeding = 156*0.328), 350 experienced breeders (after removing first breeders from the counted number of breeding pairs = 401-51) and a production of 156 nestlings in 2005. Base on these figures, we projected the breeding population size for the next year (N (*t*+1) under six different scenarios (N *(t*+1) = A*N (t)): A) the observed breeding success plus a high experienced breeder survival and high first breeder survival (P_{32} = P_{33} = 0.927), (B) a low annual experienced breeder survival (P_{33} = 0.82), (C) a low first breeder survival (P_{32} = 0.82), (D) a higher breeding success (F_2= F_3 = 0.5), (E) a low annual experienced breeder and first breeder survival rates (P_{32} = P_{33} = 0.82) plus higher breeding success, and (F) a low annual experienced breeder and first breeder survival rates (F_2= F_3 = 0.8) plus the breeding success found on Berlenga Island colonies (see results; hereafter referred as natural breeding success). Then, we compared those projections with data collected in 2015. The annual growth rate was estimated for each scenario using the formula described in the previous section and compared with the annual growth rate obtained from the counts carried out during 2005 (Lecoq et al. 2010) and 2015 (this study). Population modeling and annual growth rate estimates were developed with RStudio software (RStudio Team 2019) under R environment (R Core Team 2019).

Statistical analysis

The anomaly of each artificial nest physical parameter (maximum length of the chamber, entrance height, entrance width and the number of occupied nests in a 3m radius) was calculated. A logistic regression was used to evaluate the effect of artificial nest physical parameters (calculated as anomalies) on occupancy by birds. Type of nest (semi-artificial – S, only rocks – R and wooden box – W) and type of substrate (soil, rock, gravel) were also included in the analysis. Only nests monitored every year between 2015 and 2018 were considered in this analysis (n = 101). Due to the small sample size, a model including all explanatory variables was trained using the entire dataset. The fitting of the model and the contribution of each variable for the model were evaluated by analyzing a deviance table using Chi-square test. Statistical significance was assigned to $p < 0.05$. The performance of the trained model was assessed by plotting the Receiver Operating Characteristic Curve (ROC) and the Area Under Curve (AUC) using predicted occupancy against observed occupancy. AUC may range from 0.5 to 1, where a value of 0.5 is no better than random, and a value of 1 would be a perfect model (Fielding & Bell 1997). Accepted thresholds for model performance are: low accuracy (0.5 – 0.7), useful applications (0.7 – 0.9) and high accuracy > 0.9 (Manel et al. 2001). Confusion metrics were used to measure accuracy and precision of the trained model. Accuracy was given as the ratio between the sum of true positive (TP) with true negative (TN) and the total number of classified items (TP, TN, false positives (FP) and false negatives (FN)) as (TP + TN) * (TP + TN + FP + FN)-1. Precision was given as the ratio between the number of true positives (TP) and the sum of TP with false positives (FP), as $TP*(TP+FP)^{-1}$.

The effect of nest protection (covered vs uncovered) on breeding success of the Farilhão Grande colony was tested using a Chi-square test for each year (2017 and 2018). All values are presented as mean ± standard deviation. Analysis were developed with RStudio software (RStudio Team 2019) under R environment (R Core Team 2019).

Results

Breeding population size of Cory's Shearwater

In 2015, 681 active nests of Cory's Shearwater were counted in the entire archipelago. More than 90% of the suitable habitat was prospected. The species was found breeding in all islets and all over Berlenga Island (Table 2). In the latter, 32-34% of the population occupied artificial nests (n = 95). Farilhão Grande islet holds the largest breeding colony of Cory's Shearwater within the Berlengas Archipelago (320-425 pairs; Table 2).

Artificial nest occupancy and breeding success on Berlenga Island

The average breeding success estimated for the Berlenga Island between 2015 and 2018 was 0.83 ± 0.07 (mean ± SD; n = 157). No differences were found between breeding success in artificial nests (0.86 ± 0.05, n =123) and natural nests (0.77 ± 0.12, n = 34, Wilcoxon test W = 0, p = 0.10). Taking into account only nests from Melreu, Capitão and Furado subcolonies (the largest subcolonies of Berlenga Island and the ones under longer monitoring effort), 101 of a total of 130 breeding pairs (78%) and 121 out of 148 (82%) used artificial nests in 2015 and 2018, respectively (Table 3). However, for the artificial nests built before 2014, the occupancy rate was stable (0% of increment) along the 2015-2018 period, resulting in 88 occupied nests. Only six of those artificial nests (8%) were occupied during a single breeding season during this period. Regarding occupancy rate for the 102 artificial nests built between 2015 and 2018 (including two rebuilds), 37 (36%) were occupied in 2018. The occupation rate increased as the years went by (Fig.3), representing an annual growth rate of 9.1%, although the occupation for first time rate decreased considerably (Fig. 3).

Table 2- Number of breeding pairs of Cory's Shearwater *Calonectris borealis* counted and estimated in Berlengas Archipelago in four previous studies and during the current study in 2015. Estimates are given in brackets.

Tabela 2 - Número de casais reprodutores de cagarra *Calonectris borealis* contados e estimados no arquipélago das Berlengas em quatro estudos prévios e durante o presente estudo em 2015. As estimativas são apresentadas entre parêntesis.

ISLAND / ISLET	AREA (ha)	1987 (GRANADEIRO 1991)	2005 (LECOQ et al. 2010)	2010/2011 (LECOQ. et al. 2011)	2015 (THIS STUDY)
Berlenga	79	100	219 (300)	237 (310)	245 (280 - 300)
Inês Islet	>1	-	-	-	3 (3 - 6)
Cerro da Velha	1.4	-	-	19 (25)	15 (15 - 20)
Estela Grande	1.2	-	-	3 (10 – 15)	16 (16 - 20)
Estelão	0.6	-	-	(5)	* (5 - 10)
Manuel Jorge	0.4	-	-	(5)	* (5 - 10)
Farilhão Grande	8.2	-	401 (500 -550)	261 (500 – 550)	325 (350 - 425)
Farilhão da Cova	2.3	-	-	58 (100 – 120)	56 (100 - 150)
Farilhão do Nordeste	2.4	-	-	9 (15 – 20)	15 (15 - 18)
Farilhão dos Olhos	0.5	-	-	(5 – 10)	* (5 - 10)
Rabo d'Asno	0.5	-	-		6
TOTAL	-	-	-	590 (980 – 1070)	681 (800 - 975)

* Not visited, estimated from available breeding habitat

Table 3- Number of breeding pairs, percentage of pairs using artificial nests and breeding success recorded over the last 16 years, in the three main subcolonies (Melreu, Furado and Capitão) of Cory's Shearwater *Calonectris borealis* from Berlenga Island. The number of available artificial nests in each year at the three colonies is also presented.

Tabela 3 - Número de casais reprodutores, percentagem de casais a ocupar ninhos artificiais e sucesso reprodutor registados ao longo dos últimos 16 anos nas três principais subcolónias (Melreu, Furado e Capitão) de cagarra *Calonectris borealis*, da ilha da Berlenga. É também apresentado o número de ninhos artificiais disponíveis em cada ano.

	2002	2010	2015	2018
Number of breeding pairs	93	137	130	148
Number of available artificial nests	45	45	151	185
Percentage of pairs using artificial nests	19%	33%	78%	82%
Breeding success	0.22	0.60	0.75	0.80
Source	(Lecoq 2003)	(Lecoq 2010)	This study	This study

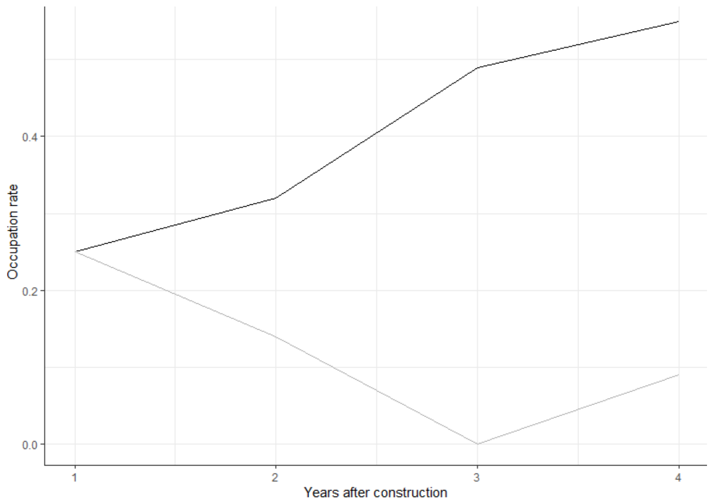


Figure 3 - Occupation (black line) and occupation for the first time (grey line) rates estimated for artificial nests installed on Berlenga Island for Cory's Shearwater *Calonectris borealis* during the period 2015-2018.

Figura 3 - Probabilidade de ocupação (linha a preto) e probabilidade de ocupação pela primeira vez (linha a cinzento) estimadas para os ninhos artificiais de cagarra *Calonectris borealis*, instalados na ilha da Berlenga durante o período 2015-2018.

Artificial nest characteristics

The discriminant ability of our trained model was acceptable (AUC = 0.75), with an estimate accuracy around 0.97. Occupied artificial nests showed significant ($p < 0.05$) higher entrances (mean entrance height (cm) ± SD: 18.92 ± 8.10, n=86) than unoccupied ones (mean distance (cm) ± SD: 14.47 ± 5.00, n=27). All the other measured nest parameters did not have a significant effect on occupancy rate (all $p > 0.05$). Moreover, breeding success was not significantly affected by any of the artificial nests parameters (all $p > 0.05$).

Breeding success in Farilhão Grande

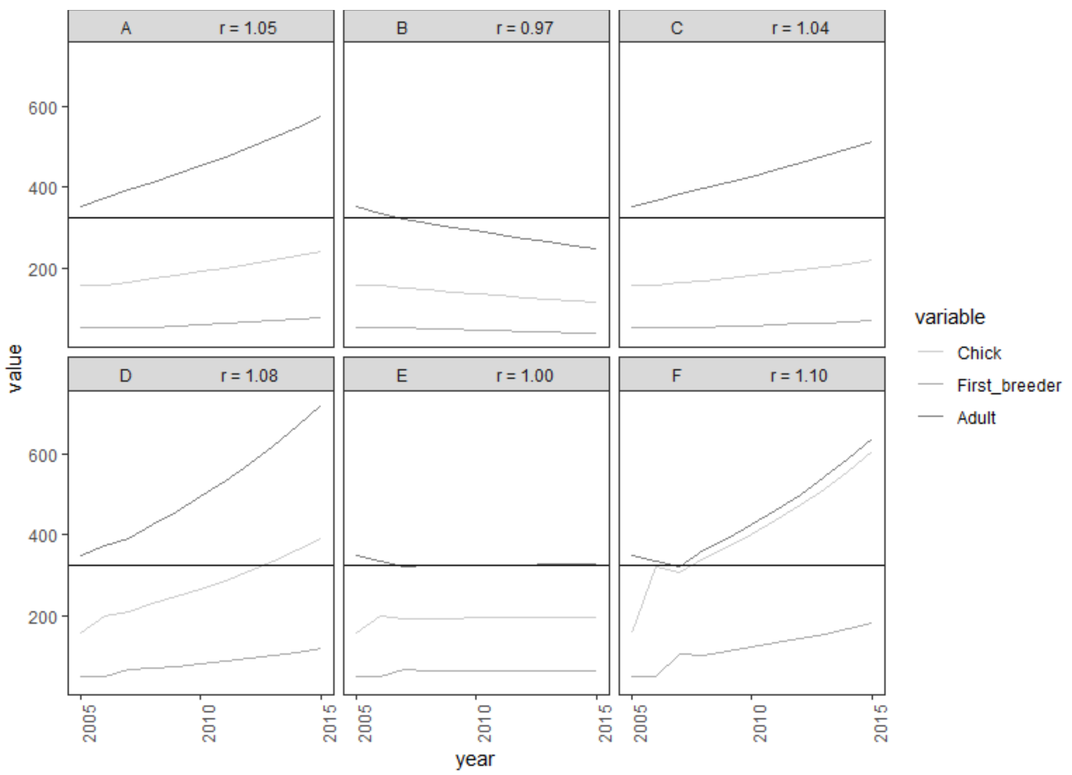
In Farilhão Grande, the breeding success of Cory's Shearwaters was 0.43 (n = 35) in 2017 and 0.39 (n = 36) in 2018. Furthermore, in both years, breeding success was higher in covered (2017: 0.60, n = 20; 2018: 0.65, n = 20) compared to uncovered nests (2017: 0.20, n = 15; 2018: 0.06, n = 16; 2017: X_1^2 = 4.09, $p < 0.05$, n = 35; 2018: X_1^2 = 10.56, $p < 0.01$, n = 36).

Farilhão Grande population modelling

Among the six modeled scenarios (Fig.4), scenario B (low annual experienced breeder survival) presented the most similar 10-year projection (r = 0.97) to the one obtained using only the census data from 2005 and 2015 (r = 0.97).

Figure 4 - Leslie Matrix analysis to model different scenarios of Cory's Shearwater *Calonectris borealis* population trends in Farilhão Grande. Our scenarios included A) the breeding success estimated for Farilhão Grande colony in 2018 (F_2= F_3 = 0.39) plus a high breeder survival (P_{32} = P_{33} = 0,927), B) a low annual experienced breeder survival (P_{33} = 0.82), C) a low first breeder survival (P_{32} = 0.82), D) a higher breeding success (F_2= F_3 = 0.5), E) a low annual experienced breeder and first breeder survival rates (P_{32} = P_{33} = 0.82) plus high breeding success, and F) a low annual experienced breeder and first breeder survival rates plus the breeding success found on Berlenga Island colonies (F_2= F_3 = 0.8; referred in the text as natural breeding success). The horizontal black line represents the 2015 breeding population size (325 pairs) counted in Farilhão Grande.

Figura 4 - Análise com base na Matriz de Leslie usada para criar vários cenários para a tendência da população de cagarra *Calonectris borealis* do Farilhão Grande. Os cenários apresentados incluíram A) o sucesso reprodutor estimado para a colónia do Farilhão Grande em 2018 (F_2= F_3 = 0,39) juntamente com uma elevada taxa anual de sobrevivência dos adultos (P_{32} = P_{33} = 0,927), B) uma taxa de sobrevivência anual dos adultos experientes baixa (P_{33} = 0,82), C) uma taxa de sobrevivência baixa dos reprodutores pela primeira vez (P_{32} = 0,82), D) um elevado sucesso reprodutor (F_2= F_3 = 0,5), E) uma reduzida taxa anual de sobrevivência dos adultos (P_{32} = P_{33} = 0,82) com um elevado sucesso reprodutor, e F) uma reduzida taxa anual de sobrevivência dos adultos com um sucesso reprodutor observado nas colónias da ilha da Berlenga (F_2= F_3 = 0,8; referido no texto como sucesso reprodutor natural). A linha preta horizontal indica o tamanho da população observado no Farilhão Grande em 2015 (325 casais).



Discussion

Considering our estimate of ca. 280-300 breeding pairs in 2015 at the Berlenga Island, 32-34% of Cory's Shearwaters nesting in artificial nests represented a considerable part of their total colony. Furthermore, our data showed a notable acceptance by the birds of new nest sites made available. Birds occupied the new artificial nests very rapidly, particularly in the first few years after being built. Few old artificial nests were never occupied by breeding birds, representing less than 12%. Taking into account that the majority of those nests were always kept in good conditions in order to be occupied (only 2 nests required major intervention), bird preferences may be related with other aspects, namely biological (Libois et al. 2012) or habitat aspects (León & Mínguez 2003, Bolton et al. 2004). In our study, the breeding birds seemed to prefer artificial nests with larger entrances (18 cm width) but none of the other evaluated variables showed a significant effect on occupancy or breeding success. In fact, seabirds are likely to occupy an artificial nest regardless of the materials it was built with, the substrate or any small differences in main nest measures (León & Mínguez 2003, Bourgeois et al. 2015) since insulating features are sufficient to retain the buffering capacities expected in natural nests (Fischer et al. 2018). Regarding the biological related aspects, many seabirds are known to be colonial and to nest in quite populated areas (Rolland et al. 1998). However, sometimes the density may act as a limitation, preventing birds to virtually occupy the entire available habitat for nesting (Crespin et al. 2006). On Berlenga Island, the density of breeding pairs by itself did not act as a limiting factor for the Cory's Shearwater population, despite the notable increment in terms of numbers along the last few decades (Lecoq et al. 2010). The Berlengas archipelago is located in a high productive oceanic area and thus, Cory's Shearwaters find little competition for food resources with other seabird species during the breeding season (Meirinho et al. 2014). Furthermore, the fast response in terms of the increase in the number of nesting birds after the implementation of the first artificial nests should not only be attributed to the supply of nest sites. A natural recovery of the population after intensive historical persecutions (Lockley 1952, Araújo & Luís 1982, Teixeira 1983) may have also contributed to such increase. Notable growth was noted between 1981 and 2010, resulting in an average growth rate of 10.1% per year (Lecoq et al. 2010). However, the same trend was not evident during the 2010 - 2015 period. Such slow down on population increase may indicate that suitable nest availability is now acting as a limiting factor for this population, and its growth is directly dependent on the availability of new artificial nests. In fact, occupancy rate in artificial nests was found to be higher on Berlenga Island than in other studies either during the first few years (Priddel & Carlile 1995, Bolton et al. 2004, Libois et al. 2012) or later after settlement (León & Mínguez 2003, Bourgeois et al. 2015, Bried & Neves 2015).

The census of Cory's Shearwater carried out in 2015, covered nearly 90% of the Berlengas archipelago, resulting in a global estimate of 800 - 975 breeding pairs. Our estimate was slightly lower than the 980 - 1070 breeding pairs estimated for 2010 by Lecoq et al. (2011). Nevertheless, using only raw counting data, the breeding numbers on Berlenga Island and on most of the islets obtained during the 2005 census were similar to those obtained in the 2015 census. However, there was a notable decrease from 401 to 325 breeding pairs during the same period on Farilhão Grande. This corresponds to a negative annual growth rate of ca. 2% per year since 2005. Identifying the demographic parameters driving such changes may inform conservation authorities about the proper solutions to put in place (Dillingham & Fletcher 2011). Similarly to what happens with other seabird species, Cory's Shearwaters are affected by several threats at sea (e.g. bycatch, reduction on food availability, competition with fisheries, windmills, marine pollution and contamination) and in land (e.g. introduction of alien predators, loss of habitat and predation by native species). In the case of Farilhão Grande population, breeding success was found to be very low, mainly due to predation upon eggs and chicks by Yellow-legged Gulls *Larus michahellis* (unpubl. data, Lecoq et al. 2010). Although no historical data is available for this population, breeding success was found to be similar (0.39 – 0.43) to the one recorded before the building of artificial nests on Berlenga Island, at 0.53 in 1987 (Granadeiro 1991) and at 0.24 in 2002 (Lecoq 2003). However, such low productivity by itself does not explain the negative population trend found in Farilhão Grande. One possible explanation, supported by our models, is that the current breeding success plus a reduction on adult survival would lead to the current situation, as observed for other seabird species in Iberian Peninsula (Munilla et al. 2007). Cory's Shearwaters are particularly susceptible to bycatch in fishing gears (Bugoni et al. 2008, Báez et al. 2014, Oliveira et al. 2015) and such events have been recently recorded in Berlengas Archipelago waters (Oliveira et al. 2018). Bycatch was mainly observed in small-scale demersal longliners but also reported by fishermen operating gillnets and trammel nets. Although the direct effect of bycatch mortality in demographic parameters is hard to measure, a direct link is known to occur (Tuck et al. 2001, Lewison et al. 2004). The effect is more evident in small populations (Baker & Wise 2005), especially for those with little genetic flux and/or under several threats. In fact, the high breeding success from the Berlenga Island population may be the reason why the annual growth rate was still positive. No data on spatial distribution at sea or feeding behaviour is available for Farilhão Grande population, but the proximity to Berlenga Island points out to very similar behaviour. Cory's Shearwaters are known to intensively use the waters around the breeding colonies to feed and rest just before entering the nesting area (Paiva et al. 2010). During this time, birds may be more susceptible to fisheries bycatch (Cortés et al. 2017).

Low breeding success together with an apparently reduced adult survival seems to be driving the Farilhão Grande colony to a seriously negative trend. However, the results from our population modelling suggest that an increase in breeding success may compensate the reduced adult survival. In accordance with our results, birds breeding in artificial nests had higher breeding success than birds in natural nests (Byrd et al. 1983, Bolton et al. 2004, Bried et al. 2009, Libois et al. 2012). Since the number of protected natural nests in Farilhão Grande is very limited, the building of ca. 100 artificial nests might increase in 10% the breeding success of this colony during a period of ten years (10% corresponds to the minimum expected value needed to invert the effect of low adult survival). With an annual occupation rate (9.1%) similar to the observed on the Berlenga Island and a constant breeding success on natural nests of 0.42, the breeding success on Farilhão Grande may reach 0.54. A positive effect of artificial nests on population growth was also recorded for other seabird populations (e.g. Bried et al. 2009, Libois et al. 2012, Bourgeois et al. 2015), whilst some studies found no effect at all (Podolsky & Kress 1989, Cruz & Cruz 1996). The benefits of artificial nests may be enhanced when put together with other conservation measures, namely the removal of invasive species (Bried et al. 2009, Kappes & Jones 2014), placing attraction devices to speed up occupation (Bolton et al. 2004) and/or chick translocation (Priddel et al. 2006). Although, increasing the number of available artificial nests may not have a significant impact on other demographic parameters, namely adult survival, like in other small seabird populations that are susceptible to adult predation by native or exotic species (Libois et al. 2012). In the case of Cory's Shearwater breeding in Berlengas Archipelago, adult survival is more likely to be affected by threats at sea.

Our data suggests that artificial nests are an effective conservation measure in areas with limited availability of nest cavities. Furthermore, birds using artificial nests are easier to detect and handle, allowing the development of long-term studies (e.g. Bried & Neves 2015). Nevertheless, more efforts should be taken to accurately measure the impact of bycatch in adult Cory's Shearwaters survival and consequently in the demography of Berlengas Archipelago breeding population.

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