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New estimates at sea suggest a larger global population of the Balearic Shearwater *Puffinus mauretanicus*

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Summary: The Balearic Shearwater *Puffinus mauretanicus* is considered the most threatened seabird in Europe, based on a prediction of extinction within 3 generations. Such prediction was computed in 2004, based on a population estimate of 2,000 breeding pairs at that time. However, the breeding population has been recently updated to 3,193 pairs. Furthermore, figures for the global population, merely inferred from the breeding population, were thought to be within the range of 8,000-15,000 individuals at most. New estimates of the global population are presented here, from two different approaches: boat-based surveys at sea and coastal counts of migrating birds. Boat-based surveys consisted in transect counts that covered systematically the Iberian Mediterranean shelf in November-December 2003-2005, i.e. during the pre-breeding period, when the bulk of the global population is present there. Bootstrap procedures were used to infer a global estimate of Balearic Shearwaters from the observed densities at sea. Coastal counts were performed from Tarifa (Strait of Gibraltar) from mid-May to mid-July 2007-2010, covering the peak of the post-breeding outflow to the Atlantic. Coverage varied among years from 37% to 67% of the daylight time and estimates for the whole period were inferred using GAM models. Both methodological approaches provided similar figures, which were also consistent between years, with conservative estimates of about 25,000 birds. These figures could not be easily explained with the currently estimated breeding population, according to a basic model that incorporated conceivable demographic parameters to link breeding and total populations. It is crucial to clarify the species’ population size and its demographic structure by reinforcing census and monitoring effort in the breeding grounds, as well as keeping the census efforts at sea, since they provide key information to assess the extinction time of a species while misestimating could result in ineffective conservation strategies.

Key Words: census, conservation, demography, Mediterranean, migration, seabird

Introduction

The Balearic Shearwater *Puffinus mauretanicus* is considered the most threatened seabird at European level, following its listing as Critically Endangered in 2004 according to the IUCN criteria (BirdLife International 2004). This categorization was based on the prediction that the species could become extinct in an average 40 years (less than 3 generations) according to the combination
of an extremely rapid population decline (-7.4% per year) and a small population size (estimated then in ca. 2,000 breeding pairs), which is restricted to the Baleairc Islands (Oro et al. 2004). However, information of both population trends and figures is subject to considerable uncertainty. It is therefore crucial to improve these estimates and properly assess the status of the species. Here we focus on the issue of population estimates.

Estimates for the breeding population of the Balearic Shearwater have ranged between ca. 1,750 and 4,500 breeding pairs during the last 20 years (Aguilar 1991, Ruiz & Martí 2004), with the last update being 3,193 pairs, although differences between those figures appear to be primarily related to different methodological approaches rather than to actual changes in numbers (Arcos 2011). Indeed it is extremely difficult to properly assess the numbers of a seabird breeding in caves, burrows and crevices of sea cliffs and islets, and any population estimate needs to rely on indirect methods at least for the most inaccessible colonies, thus being subject to biases (Gregory et al. 2004, Mitchell et al. 2004). As for the global population, no systematic counts are available, but different sources have considered it to range between 8,000 and 15,000 birds at most, mainly based on inferences from the breeding population estimates and partial information from counts at sea (Gutiérrez & Figuerola 1995, Mayol et al. 2000, Arcos & Oro 2002, Ruiz & Martí 2004, BirdLife International 2004). Here we consider two alternative approaches to assess the population of the Balearic Shearwater, both based on counts at sea of the global population outside the breeding grounds: (1) boat-based transect counts at sea; and (2) coastal counts from a strategic migratory point, the Strait of Gibraltar. We also elaborate a simple model to infer which would be the global population departing from different breeding figures, compare these results with those estimated from the counts at sea, and discuss the discrepancies.

Methods

Boat-based transect counts. Systematic seabird counts were conducted by SEO-BirdLife over the Mediterranean Iberian shelf (Figure 1) in November-December 2003, 2004 and 2005, taking advantage of the annual ECOMED cruise onboard R/V Comide de Saavedra (Spanish Institute of Oceanography, IEO). This cruise was designed to assess the abundance of small pelagic fish by acoustical means in the study area, providing ideal conditions for the census of seabirds. Indeed, the vessel conducted systematic transects over the continental shelf (as delimited by the 200 m isobath) and uppermost shelf slope, perpendicular to the coastline and spaced either 4 or 8 nautical miles apart, depending on the width of the shelf, from NE to SW. The bulk of the Balearic Shearwater global population is expected to be within the study area at this time of year, prior to the breeding season, after their return from the post-breeding outflow to the Atlantic (Gutiérrez & Figuerola 1995, Ruiz & Martí 2004, Arcos et al. 2012, Guilford et al. 2012).

Seabirds were counted within a 300 m strip transect band, at one or two sides ahead of the vessel depending on census conditions, and snap-shot counts were used to count flying birds (Tasker et al. 1984). Seabird observations were summed up into 10 minute survey units, for which species density values were estimated (birds/km²). On each cruise between 1,300 and 1,900 km of line transects were surveyed, totaling ca. 500 count bins per year (see details in Arcos et al. 2009).
Figure 1. Study areas for the land based coastal counts (a) and the boat-based transect counts (b). Figure 1a shows the Strait of Gibraltar with details of the African and Spanish coastline and Tarifa Island, the coastal survey point. Figure 1b shows the Mediterranean Iberian shelf, with the five geographical sectors (I-V) and the bathymetric categories considered (0-100, 100-200 and 201-1000 m). For each year of survey, the transect locations and the shearwater densities are also shown (each 10 min transect bin is represented by a small dot if shearwaters were not observed, and by a circle proportional to the density if shearwaters were observed).
The study area was divided in three bathymetric categories (0-100, 100-200 and 200-1000 m) and then in five geographical regions according to their topographic and hydrographic features (Salat 1996, Millot & Taupier-Letage 2005) (Figure 1). For each region and bathymetric category the number of shearwaters was inferred by extrapolating density values to its total surface. Since density data were highly variable between transect bins and did not fit a normal distribution, 95% confidence intervals were estimated using bootstrapping (Efron & Tibshirani 1991).

Coastal counts. Systematic counts of Balearic Shearwaters were carried out from Tarifa Island, the southernmost point of the north coast of the Strait of Gibraltar (Figure 1), in the context of the Migres programme. The Strait of Gibraltar, with only 14.4 Km at the nearest point between European and African coasts, represents a migratory bottleneck for pelagic seabirds and it concentrates the totality of the Balearic Shearwaters post-breeding migration moving out the Mediterranean in late spring and early summer (Programa Migres 2009, Arcos et al. 2009, de la Cruz et al. 2011). Moreover, previous studies have demonstrated that Balearic Shearwaters passing across the northern sector of the Strait (where the post-breeding migration of the species is most notorious) tend to concentrate closer to the coast than randomly expected (Mateos-Rodríguez et al. 2010, Mateos-Rodríguez & Arroyo 2011), making them particularly detectable from particular vantage points such as Tarifa Island.

Daily censuses were conducted from mid-May to mid-July in 2007-2010. Counts were carried out by two experienced seabird ornithologists, occasionally assisted by trained volunteers, during daylight hours (details in Programa Migres 2009, de la Cruz et al. 2011). Despite a high census effort (see below), gaps in counts occurred due to resting breaks or missed days. To estimate the numbers of birds passing during those gaps, we modelled the counts using Generalized Additive Models (GAM), following the method described by Mateos-Rodriguez et al. (2012).

Relationship between breeding population and global population. To understand the relationship between breeding birds and global population, we inferred an estimate for the global population based on available breeding figures and considering the following demographic parameters: breeding success (BS), survival (S; age-dependent), recruitment (R; age-dependent), and rate of sabbaticals (Sb) (Figure 2). We defined 3 scenarios encompassing the conceivable variability of values in demographic parameters (Oro et al. 2004, Louzao et al. 2006), to get a reasonable range of values for the total population (Table 1). On one hand, scenario A considered low breeding success and low survival rates, high recruitment and high rate of sabbaticals, thus resulting in a small total vs. breeding population ratio; on the other hand, scenario C considered relatively high breeding success and survival rates, low recruitment and high rate of sabbaticals, thus making highest the ratio of total vs. breeding populations; scenario B used intermediate values for these parameters. We also considered three different values of breeding population size as departing point, considering the range of published estimates: 2,000 (figure used to assess the population viability analysis, Oro et al. 2004), 3,200 (current estimate), and 4,400 pairs (maximum estimate in the last 20 years, see Ruiz & Martí 2004, Arcos 2011).

Results

Boat-based transect counts. Balearic Shearwaters were common throughout the Iberian Mediterranean shelf during the pre-breeding period, mostly in shallow waters (0-100 m) (Figure 1).
Figure 2. Outline of the model used to relate the breeding and the total populations of Balearic Shearwater. The model builds up on the number of breeding adults, and from this figure it estimates the number of non-breeding mature adults (birds on sabbatical), juveniles and sub-adults of different age classes (here a bird is considered as sub-adult if it has not bred yet, irrespective of its age). Demographic parameters used to link these figures are breeding success (BS), survival (S; age-dependent), recruitment (R; age-dependent); and rate of sabbaticals (Sb). The model is “static”, as it does not contemplate changes in the population of breeding adults, and should be taken as a mere approximation.

The bulk of the population concentrated in the eastern coast between S Catalonia and N Murcia, although there were slight differences in the distribution patterns between years. In any case, total estimates were quite consistent, although confidence intervals based on bootstrapping were wide (Table 2). Average estimates ranged from 23,148 birds in 2005 to 36,108 in 2004 (Table 2).

Coastal counts. Raw counts of Balearic Shearwaters flying westwards ranged from 12,835 in 324 hours in 2010 to 17,874 in 477 hours in 2009 (Table 3). A markedly lower number of Balearic Shearwaters were registered flying east, from 585 in 2007 to 267 in 2008. Annual variations were principally due to the different coverage in observation time, from 37.5% of the daylight time in 2007 to 67.3% in 2008. Once the gaps were filled using GAM, we inferred a net westwards passage across the Strait ranging from 23,780 birds in 2008 to 26,535 in 2009. These estimates
Table 1. Demographic parameters used to infer the global population of Balearic Shearwater from the breeding figures. Three scenarios were considered, allowing using a conceivable range of demographic values. Scenario A would provide the most conservative ratio of total to breeding populations, whereas scenario C would result in the largest ratio. Scenario B would be in between, and would be the most realistic according to currently published information.

were robust (with standard deviations lower than 7% in all the cases) and consistent throughout the years (Table 3).

Relationship between breeding population and global population. Departing from the most recent estimate of almost 3,200 breeding pairs, the expected global population would range between ca. 10,800 and 17,500 individuals according to our modeled scenarios (Table 4). Only when considering a figure of 4,400 breeding pairs the inferred estimates for the global population (range ca. 14,800-24,000) approached the figures obtained from the two survey methods described in this paper, though only marginally.

Table 2. Balearic Shearwater estimated numbers (average ± 95% confidence intervals, CI) inferred from the boat-based transect counts at sea, in the three years of study. Results are presented separately for each bathymetric stratum, and for the whole study area.
<table>
<thead>
<tr>
<th>Year</th>
<th>Period</th>
<th>Effort (days)</th>
<th>Shearwaters counted</th>
<th>Shearwaters estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>W</td>
<td>E</td>
</tr>
<tr>
<td>2007</td>
<td>23 May-9 July</td>
<td>42</td>
<td>12,858</td>
<td>585</td>
</tr>
<tr>
<td>2008</td>
<td>15 May-9 July</td>
<td>56</td>
<td>17,805</td>
<td>267</td>
</tr>
<tr>
<td>2009</td>
<td>15 May-14 July</td>
<td>61</td>
<td>17,874</td>
<td>271</td>
</tr>
<tr>
<td>2010</td>
<td>17 May-4 July</td>
<td>49</td>
<td>12,835</td>
<td>376</td>
</tr>
</tbody>
</table>

Table 3. Extreme dates of census (period), observation effort (number of days; also actual and inferred number of hours: Time) and total numbers of Balearic Shearwater (separated according to flight direction) per year off Tarifa, 2007-2010. The table also shows the inferred estimates of total westwards flow of shearwaters (Net flux, average ± standard deviation, SD) after the census gaps were filled using GAM calculation.

<table>
<thead>
<tr>
<th>Breeding population</th>
<th>2,000 bp</th>
<th>3,200 bp</th>
<th>4,400 bp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td>6,748</td>
<td>10,797</td>
<td>14,845</td>
</tr>
<tr>
<td>Scenario B</td>
<td>8,232</td>
<td>13,172</td>
<td>18,111</td>
</tr>
<tr>
<td>Scenario C</td>
<td>10,919</td>
<td>17,470</td>
<td>24,021</td>
</tr>
</tbody>
</table>

Table 4. Inferred global population of Balearic Shearwater according to the three demographic scenarios described in Table 1 (A, B & C) and three potential figures for the breeding population (number of breeding pairs, bp).

Discussion

Results presented here show that the global population of the Balearic Shearwater is considerably larger than the 8,000-15,000 birds previously thought. This is so even when only the raw data from Gibraltar are considered (up to 17,397 birds in net flow in 2009), but the difference is more obvious once inferred data are calculated to represent either the whole study period (post-breeding migration at Gibraltar) or study area (counts at sea). According to these approaches, we propose a conservative estimate of ca. 25,000 birds for this species. The fact that two complementary at sea methodological approaches provided similar figures, which were also consistent between years, reinforces our statement. A further reinforcement came recently from the observation of 16,421 birds in only 2 hours off Cullera (Valencia, NE Spain) during a coastal census in December 2009 (Aleixos-Alapont, in press).

Reliability of the new estimates. Seabird estimates at sea are subject to various potential biases,
which deserve consideration here. The consistency of our complementary approaches suggests that such biases were minimized; nevertheless they cannot be excluded. For transect counts at sea, density values should only be considered as indicative (Haney 1985) and therefore the derived estimates could be biased, but Tasker et al. (1984) methodology was developed to minimize such biases. The main potential bias for these counts would be related to the lack of detection of some birds, as no related corrections have been applied (Distance Sampling, Buckland et al. 2001). Such corrections, if relevant, would however give an even larger estimate than the one presented here. Another point is that due to the species’ gregariousness, the estimates could be inflated by the inclusion of large rafts of shearwaters in transects. However the observed distribution is considerably scattered, with only a few large rafts observed in very coastal waters, which were predominantly outside the census band and therefore did not contribute significantly to the density estimates. It might also be thought that the bird flow between different areas would have entailed repeating individuals between counts. However, the counts were conducted during the return passage of the shearwaters into the Mediterranean (main flow from SW to NE) and the cruise took the opposite direction, thus reducing the possibility of repeating individuals. Finally, the possible effect of the boat as attractor, inflating the estimates, is reduced as fishing operations were only performed at night during the cruise.

Concerning coastal counts at Gibraltar, the reliability of land-based counts for quantifying seabirds at sea is constrained by the distance at which birds can be detected, being unrealistic to assume coverage of the whole Strait of Gibraltar width. However, Balearic Shearwaters passing along the north part of the Strait tend to concentrate near the coast, with the great majority of birds flying closer than 3 km according to radar studies (Mateos-Rodríguez et al. 2010 and Mateos-Rodríguez & Arroyo 2011). Moreover, ship-transects across the Strait of Gibraltar have confirmed that movements of Balearic Shearwaters are very rare across both the central and the southern part of the Strait (see appendix in Mateos-Rodríguez & Arroyo 2011). Thus, the number of Balearic Shearwaters undetected by observers should be negligible, and in such case this bias would indicate a slight underestimation. There are not evidences of the occurrence of neither reverse migration or nocturnal migratory movements of the species based on the above sources of information (see also Guilford et al. 2012).

A final point to consider is that both approaches presented here conservatively assumed that the whole population of Balearic Shearwaters is constrained to the corresponding study area and period. For the boat-based counts, the bulk of the Balearic Shearwater population seems indeed concentrated in Mediterranean Iberia during the sampling period (Ruiz & Martí 2004, Guilford et al. 2012), but there is increasing evidence that some birds remain in European Atlantic waters during the autumn-winter (Mouriño et al. 2003, Poot 2005, Wynn & Yé sou 2007), and birds also visit other areas within the Mediterranean (Rebassa et al. 1988, Guilford et al. 2012), suggesting that the global population could be even greater than proposed here. The same occurs for the Strait of Gibraltar counts, as the bulk of the migration takes place between mid May and mid July, but some birds pass through the area either earlier or later (Programa Migres 2009), or just remain in the Mediterranean or the Atlantic the whole period.

How to explain the discrepancies? Assuming that the figures provided in this paper for the total
population of Balearic Shearwater are correct, it seems unlikely to explain them with the currently estimated figure of 3,200 breeding pairs, according to the simple modeling approach developed here. Indeed, taking into account a wide range of conceivable values, the estimates of the global population inferred from those of the breeding population were always below the figures obtained from counts at sea, even when considering the most optimistic estimates for the breeding population (i.e. 4,400 breeding pairs). The modeling approach was however simplistic, assuming a “static” population, and was used as a tentative guess. There are still many gaps regarding the population structure of the species, and therefore this inference should be taken with care.

Tentatively, the alternative must be considered that the breeding population is really underestimated and might be closer to 5,000 breeding pairs or even more. Whatever unlikely this might seem at first glance, it is important to bear in mind that the Balearic Shearwater often breeds in inaccessible and discrete sites, which require indirect census methods potentially subject to strong biases (e.g. Gregory et al. 2004, Mitchell et al. 2004). Thus, the number of breeding pairs could be underestimated in known colonies, and/or new colonies might still to be discovered, especially in the rugged NW coast of Mallorca. It could also be proposed that colonies are to be found outside the Balearic archipelago, for example on the Algerian coast, but there is no firm evidence, or even suggestion, to that.

Implications for conservation. The estimates reported in this study could be good news for the Balearic Shearwater, although they should be taken with extreme caution. First of all, it is necessary to clarify the actual breeding and total population size. Second, it is necessary to update the data on demographic parameters and properly assess the current population trend, taking into account data from a representative selection of colonies. Although the population figures now appear to be larger than previously expected, it is also likely that the alarming decline described by Oro et al. (2004) actually is even sharper, as it was based on data from colonies free of introduced predators. This threat is particularly serious in the case of carnivores, which prey on adults and thus influence negatively on survival rates, with about one third of the known breeding population exposed to them (Arcos 2011). Ultimately, the species faces serious threats both on land (predation, disturbance) and at sea (fishing bycatch, pollution, fish prey overexploitation and others; see review in Arcos 2011), and its declining trend seems beyond any doubt. A larger population than previously assumed, if confirmed, might “buy years to extinction”, but the declining trend deserves urgent conservation action to allow the safeguarding of the species in the long term (Louzao et al. 2006).

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