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Consistent foraging areas and commuting corridors of the critically endangered Balearic shearwater *Puffinus mauretanicus* in the northwestern Mediterranean

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ABSTRACT

Unprecedented changes to the marine environment and growth of bio-logging science make detailed study of the movement ecology of threatened marine species timely. Here, we study spatial and temporal patterns of marine space use by a critically endangered seabird: the Balearic shearwater *Puffinus mauretanicus*. Using a suite of bio-logging systems, 67 foraging trips were recorded during incubation periods between 2011 and 2014 from one of the species' largest colonies (Sa Cella, Mallorca). Most birds followed narrow flight corridors to restricted neritic foraging grounds on the Iberian continental shelf. Productive foraging areas along the Catalan coast (NE Spain) were consistent across multiple years and between sexes, indicating extensive use of predictable resources. While our study emphasises the vulnerability of this species to anthropogenic activity in nearshore waters, consistent commuting corridors and foraging grounds represent tractable habitat for protection and offer hope for developing area-based management approaches. Preferred foraging areas showed strong overlap with recently declared Special Protection Areas, strengthening the evidence base for targeted management at these sites.

1. Introduction

Seabirds are one of the most threatened groups of marine vertebrates (Croxall et al., 2012; Spatz et al., 2014), and while there have been some successes in protecting terrestrial breeding sites, this group spend the majority of their lives at sea where the level of protection afforded is poor (Grémillet and Boulinier, 2009; Lewison et al., 2012). Recent marine conservation measures have largely focused on establishing networks of marine protected areas (MPAs) (Abdulla et al., 2009). While these tools show promise for some taxa (Halpern, 2003; Selig and Bruno, 2010), protection of seabirds and other highly mobile top predators is challenging (Game et al., 2009; Hooker et al., 2011; Ronconi et al., 2012). For example, predictable oceanographic features are potential priority areas for conservation (e.g. Hazen et al., 2013; Scales et al., 2014b), yet few pelagic environments and associated species have been incorporated into existing management frameworks (Game et al., 2009). Furthermore, movement corridors (e.g. migration or commuting) between key marine habitats are ecologically important, but often overlooked, areas in need of protection (Hooker et al., 2011). Initiatives to identify marine Important Bird Areas (IBAs),

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such as the recent inventories of Spain and Portugal (Arcos et al., 2009; Ramírez et al., 2008), and ongoing work in other regions (Lascelles et al., 2012), represent an important step towards improving levels of protection for seabirds. However, comprehensive knowledge of at-sea movements and their spatio-temporal variability is often lacking.

The Mediterranean Sea is under particular pressure from increasing human activity (Bianchi, 2007; Coll et al., 2012; Lewison et al., 2014). This semi-enclosed basin contains high biodiversity, high levels of endemism, and significant extinction threats (Coll et al., 2010). Seabirds are no exception, with several endemic taxa of immediate conservation concern due to their small and declining populations (Zotier et al., 1999). One such species is the Balearic shearwater, Europe's only critically endangered seabird (Arcos, 2011; IUCN, 2014). Breeding is restricted to the Balearic Islands (Ruiz and Martí, 2004), with an estimated breeding population of ~3200 pairs (although this figure contains considerable uncertainty: Arcos et al., 2012a). This species is experiencing severe decline driven by low rates of adult survival (Oro et al., 2004), likely because of direct and indirect effects of human activity. Although small pelagic fish represent the main prey of Balearic shearwaters (Gutiérrez and Figuerola, 1995), they also feed on fisheries discards, leading to severe risk of bycatch (Arcos and Oro, 2002a; Le Mao and Yésou, 1993; Navarro et al., 2009; Oliveira et al., 2015). Other factors, including unregulated levels of predation by introduced mammals at colonies (Arcos, 2011), climate change (Luczak et al., 2011; Wynn et al., 2007), changes in discard availability (Bicknell et al., 2013), fisheries overexploitation (Arcos et al., 2008) and coastal development (Arcos, 2011) place the long-term survival of this seabird in jeopardy.

Intensive research in the western Mediterranean has provided important insights into the distribution and ecology of the Balearic shearwater in recent years. Vessel-based observations and tracking data have revealed that the species preferentially forages in highly productive, but heavily fished, waters along the Iberian continental shelf and Balearic archipelago (Abelló et al., 2003; Ruiz and Martí, 2004). Additional information on the species' variable foraging habits and oceanographic characteristics of high-density areas has aided interpretation of marine habitat use (i.e. Arcos et al., 2000; Arcos and Oro, 2002a; Louzao et al., 2006, 2012). Despite such attention, this species has been the focus of relatively few tracking studies. Satellite tracking on Mallorca and Menorca (Bartumeus et al., 2010; Ruiz and Martí, 2004), and more recently on Eivissa (Louzao et al., 2012) has provided insights into at-sea movements of birds from known colonies. Nevertheless, detailed multi-year information on foraging movements of confirmed breeders is lacking, and little is known about at-sea behaviours outside of the chick-rearing period.

Following identification of marine IBAs in Spanish waters (Arcos et al., 2009), the Spanish Government is engaged in affording protection to these sites under the European Union Birds Directive (2009/147/EC). A network of Special Protection Areas (SPAs) covering nearly 50,000 km^2 was designated in July 2014 as part of the Natura 2000 network, and efforts to establish management plans are now underway (Boletín Oficial del Estado, 2014). Of 39 new SPAs, 20 sites were considered relevant for conservation of Balearic shearwaters, including 14 sites used during the breeding period. There is now a need to validate the importance of these conservation areas for breeding birds of known origin, and to assess their stability of use over time.

We undertook the first multi-year tracking study of incubating Balearic shearwaters from one of the largest known colonies on Mallorca, with the aim of generating detailed information on the movement ecology of this species of relevance to conservation management. We aimed to: (i) identify the main commuting and foraging areas of breeding birds, (ii) determine levels of inter-annual variability in foraging distributions, (iii) determine the extent to which current Special Protection Areas (SPAs) overlap with at-sea distribution and behaviour and (iv) test previously unexplored environmental controls of observed commuting and foraging strategies.

2. Materials and methods

2.1. Study site and field methods

The study was conducted at one of the largest Balearic shearwater breeding colonies (Sa Cella cave; ~6.3% of the global population), situated on the western tip of Mallorca, Spain, during March–April 2011–2014 (Fig. 1; 39°36′N, 02°21′E). To investigate at-sea movements and activity patterns, 61 incubating birds were fitted with both i-gotU GPS loggers (modified GT-120: 11.2–15.4 g) and British Antarctic Survey geolocators (MK18 or MK14: 1.4–1.9 g) during 82 deployments over 4 years. To validate behavioural information collected with GPS and geolocators, a subset of 22 individuals were also fitted with 2.7 g time–depth recorders (TDRs: Cefas Technology Ltd, Lowestoft, UK) in 2013 and 2014.

Targeted birds were temporarily removed from the nest and GPS loggers were attached to contour feathers on the back using Tesa tape (details in Guilford et al., 2008), while geolocators and TDRs were mounted on plastic leg rings attached to the tarsus (details in Guilford et al., 2012). GPS devices were configured to obtain hourly positions, while TDRs collected pressure readings at 1-s intervals. Geolocators provided a measure of time spent on or in the water, by recording the number of 3-s blocks in a 10-min period that the device was immersed. The total weight of combined bio-loggers and attachments was $\leqslant$4.7% of the body mass of birds (mean: 4.2 ± SD 0.3%; body mass: 508 ± 33 g), and was thus within the 3–5% limit recommended by most authors (Phillips et al., 2003; Wilson et al., 2002).

To reduce potential detrimental effects to the birds, bio-loggers were deployed for the duration of one foraging trip and, upon return to the cave, birds were caught and devices removed. On three occasions birds evaded recapture after a single trip and two or more trips were recorded. Feather loss was low-to-negligible in all cases, and birds were handled on average for 19 (±SD 6) minutes during device deployment and 23 (±SD 6) minutes during recovery. Birds were sexed from DNA extracted from blood (Vetgenomics, Spain) or feathers (Avian Biotech, UK) collected during device recovery.

2.2. Ethics statement

All research work was performed under relevant permits issued by the Government of the Balearic Islands (Permit numbers: CAP04/2010, CAP31/2011, CEP04/2012, CEP03/2013, CEP15/2014), in accordance with regional legislation (BOIB 97 Decret 65/2004) and following established field procedures that minimise colony disturbance (see Guilford et al., 2012).

To assess potential impact of tag attachment, breeding success (measured by egg hatching and chick fledging success of a pair) was recorded for both experimental birds and a set of unhandled closely matched control nests within the colony (see Section 3.1). To minimise disturbance, individuals were only tagged once during a season.

2.3. Data analysis

2.3.1. Data processing

Geolocator activity data were processed using BAStrak software (British Antarctic Survey, Cambridge, UK). To account for the