



## Breeding biology of a winter-breeding procellariiform in the North Atlantic, the Macaronesian shearwater *Puffinus lherminieri baroli*



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### ABSTRACT

The breeding success of burrow-nesting seabirds may be influenced by both nest site characteristics and oceanographic conditions influencing food availability at sea. In this study we describe the breeding biology of the winter-breeding Macaronesian shearwater (*Puffinus lherminieri baroli*), including nest site characteristics and interspecific competition. We also evaluate the possible effects of changing oceanographic conditions on breeding phenology and breeding success. The study was carried out over two breeding seasons on two islands in the North Atlantic Ocean, Cima Islet and Selvagem Grande. Oceanographic characteristics differed between years. On a regional scale, the North Atlantic Oscillation (NAO) index was low and negative in 2011, and on a local scale, birds used areas with significantly lower values of chlorophyll a concentration and significantly higher values of sea surface temperature anomalies. Hatching success was higher in 2012 than in 2011. At both colonies, egg cracking was the main cause of hatching failure, but in 2011 several eggs on Selvagem Grande were deserted. In 2012 birds laid earlier and chicks had longer wings and were heavier. At both colonies, nests that were deeper, were sheltered from prevailing winds and had small chambers and a soil substrate had a higher probability of being used successfully by the birds. Nests occupied solely by Macaronesian shearwaters were much deeper and had less volume than nests shared with other species. Our study suggests that the breeding success of Macaronesian shearwaters is strongly related to nest site characteristics and that at-sea environmental conditions exert a strong influence on reproductive parameters, with birds breeding in a poor year (evaluated in terms of lower marine productivity) laying much later and their chicks growing at a slower rate than in a good year. The influence of nest site characteristics and environmental conditions may be very important for understanding the breeding ecology of Procellariiformes and may help explain the negative population trend of Macaronesian shearwaters.

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### 1. Introduction

In central-place foraging species that exhibit a protracted breeding season such as seabirds (Orlans and Pearson, 1979), parents need to select and defend suitable nest sites to protect their eggs and chicks and must optimise prey delivery to chicks in order to breed successfully (Drummond and Leonard, 2010). Breeding success of burrow-nesting Procellariiformes (e.g., albatrosses, petrels and shearwaters) may be influenced by both nest site

characteristics and oceanographic conditions that influence food availability at sea.

Annual or medium-term variations in sea surface temperature (SST) and chlorophyll a (Chl a) concentration have been linked to fluctuations in the distribution and reproductive success of seabirds (e.g., Durant et al., 2003; Quillfeldt et al., 2007; Paiva et al., 2013a; Berlincourt and Arnould, 2015) and have generally been analysed in the context of large-scale (spatial and temporal) atmospheric processes such as the El Niño Southern Oscillation (ENSO) in the Pacific Ocean, or the North Atlantic Oscillation (NAO) in the North Atlantic Ocean (e.g., Ramos et al., 2002; Durant et al., 2003; Sandvik et al., 2005). Increasing SST and subsequent higher SST anomalies (SSTa) may block nutrient-rich up-welling zones that can influence primary productivity and impact seabird breeding success through

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changes in prey availability (Ramos et al., 2002; Peck et al., 2004; Quillfeldt et al., 2007).

Nest site selection can be driven by a combination of physical and social features, including nest microclimate, level of disturbance from conspecifics, distance and density of individuals from different species and predation risk (Ramos et al., 1997; Mallory and Forbes, 2011). The characteristics of the nest sites of burrow-nesting Procellariiformes may also influence their reproductive success (Ramos et al., 1997), particularly for winter-breeding species, when adverse meteorological conditions, such as strong rainfall, could increase the importance of burrow characteristics for breeding success (Thompson and Furness, 1991). In fact, Ramos et al. (1997) showed that nest cavities of winter-breeding Procellariiformes appear to be more concealed than nest cavities of summer-breeding species, but this aspect has received very little attention. In the Pacific Ocean, Bester et al. (2007) observed that egg and chick mortality of the providence petrel (*Pterodroma solandri*), a tropical burrow-nesting procellariiform breeding during the winter on Lord Howe Island, Australia, were strongly correlated with the distance between the nest chamber and the burrow entrance, with more losses occurring in nests whose chamber was closer to the nest entrance. McClelland et al. (2008) observed that egg abandonment and breeding success of Tristram's storm petrel (*Oceanodroma tristrami*) on Laysan Island and French Frigate Shoals, Northwest Hawaiian Islands, were affected by rainfall and competition with larger burrowing seabirds for nest sites.

In the North Atlantic, global positioning system (GPS) and global location sensing (GLS) tracking devices have been widely used to describe the foraging distribution of summer-breeding seabirds such as Cory's shearwater (*Calonectris borealis*; Haug et al., 2015; Missagia et al., 2015) or Desertas petrel (*Pterodroma deserta*; Ramírez et al., 2016). Recently, GLS devices were also used to evaluate the at-sea distribution of the winter-breeding Macaronesian shearwater *Puffinus lherminieri baroli* (Neves et al., 2012; Ramos et al., 2015; Paiva et al., 2016). In the North Atlantic, the breeding biology of summer-breeding species such as Cory's shearwater (Ramos et al., 2003 and references therein) has also been well studied, yet there is little information regarding the breeding biology of winter-breeding species such as the Macaronesian shearwater. Monteiro et al. (1996a) provided information about breeding phenology and egg dimensions, and Ramos et al. (1997) described the nest site characteristics of several procellariiform species breeding in the Azores archipelago, including the Macaronesian shearwater. An important finding of these previous studies is the existence of interspecific competition for nesting burrows, with excavation and occupation of nests of smaller species, including the Macaronesian shearwater, by the much larger Cory's shearwater. However, the possible effect of nest site characteristics on the breeding success of winter-breeding Procellariiformes has not been examined.

The Macaronesian shearwater is endemic to the Macaronesian Islands, North Atlantic Ocean. Recent revision of the taxonomy of the *Puffinus assimilis*/*P. lherminieri* complex led BirdLife International (2014) to suggest that *P. baroli* breeding on the Azores, Madeira, Selvagens and Canaries and *P. boydi* on the Cape Verde islands should be regarded as subspecies of *P. lherminieri*. Macaronesian shearwater is considered rare by BirdLife International and is a species of conservation concern in Europe (BirdLife International, 2004). According to the European Red List of Birds (BirdLife International, 2015) the population size is estimated to be decreasing at a rate approaching 10% in 67 years. As this species has a small, apparently decreasing population, it is presently classified as near threatened (BirdLife International, 2015). Selvagem Grande holds the largest population of the species, with 2050 to 4900 breeding pairs (Oliveira and Moniz, 1995), but recent trends are unknown. Considering the recent population decline on Tenerife, Canary Islands (Rodríguez et al., 2012), information on the

breeding biology of Macaronesian shearwater at other important localities in the North Atlantic is crucial to identify conservation issues at breeding colonies, as the factors influencing breeding success are often site-specific (Warham, 1990; Ramos and del Nevo, 1995). A burrow-nesting procellariiform, the Macaronesian shearwater is expected to show strong nest site fidelity (Warham, 1990; Bried et al., 2003), but data are needed to evaluate this assumption. This species may also be affected by annual changes in oceanographic conditions (e.g., SST and Chl a), leading to strong variations in diet and feeding ecology (Ramos et al., 2015), but no information is available concerning how such annual changes might affect the breeding success of Macaronesian shearwaters.

Food availability (determined by oceanographic and climatic features; Ramos et al., 2015) and nest site characteristics (Ramos et al., 1997) are likely to be the two most significant determinants of reproductive performance in burrow-nesting Procellariiformes, but most studies have not examined these two aspects in conjunction. Nest site characteristics are of great importance in terms of conservation because providing appropriate artificial nest sites can improve the breeding success and consequently the conservation status of threatened seabird species (Bolton et al., 2004; Bourgeois et al., 2015), whereas other threats such as climatic variations impacting food availability are often much more difficult to target. In the present study we describe the breeding biology, including a detailed examination of nest site characteristics, of the winter-breeding Macaronesian shearwater on two islands, Cima Islet and Selvagem Grande, in the Madeira and Selvagens archipelagos, respectively, for two consecutive breeding seasons (2010–2011 and 2011–2012). Our specific objectives were to determine: (i) annual and inter-island variation in reproductive success, (ii) the influence of interspecific competition for nest sites and of environmental factors on hatching success for each population, and (iii) the possible effects of changing oceanographic conditions on the breeding phenology and breeding success of each population.

## 2. Materials and methods

### 2.1. Study sites

Field work concerning breeding phenology, breeding success and nest characteristics on Cima Islet (CI) and Selvagem Grande (SG) (Fig. 1) was carried out during the breeding seasons of 2010–2011 and 2011–2012 (2011 and 2012 hereafter). Nest site fidelity was studied between 2010 and 2013.

Cima Islet (33°01'N 16°22'W) is a 32-ha rocky islet located south-east of Porto Santo Island, 50 km north-east of Madeira Island. It holds small populations of Macaronesian shearwaters, Cory's shearwaters, Bulwer's petrels (*Bulweria bulwerii*), and band-rumped storm petrels (*Hydrobates castro*). Selvagem Grande (30°09'N, 15°52'W; 245 ha) is located ~296 km south of Madeira Island. Besides Macaronesian shearwaters, the island has the world's largest colony of Cory's shearwaters (~30,000 breeding pairs; Granadeiro et al., 2006) and large populations of Bulwer's petrels, white-faced storm petrels (*Pelagodroma marina*) and band-rumped storm petrels.

### 2.2. At-sea distribution and environmental variability

In 2010 and 2011, 10 GLS devices (MK18L; British Antarctic Survey, Cambridge, UK) were deployed each year on incubating Macaronesian shearwaters, and 13 were recovered between February and April of the following years (2011: 3 on CI and 4 on SG; 2012: 4 on CI and 2 on SG). Tracking devices were attached with a cable tie to numeric metal rings and represented ~1% of bird body mass.

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