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SHORT REPORT

A geolocator-tagged fledgling provides first evidence on juvenile movements of Cory’s Shearwater Calonectris borealis

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ABSTRACT

Using geolocator-immersion loggers, we tracked for the first time the migration of one Cory’s Shearwater Calonectris borealis fledgling, from its breeding colony in the Canary Islands, and along its first year of life. The juvenile bird initially followed the same migratory path as the adults but visited different areas of the Central and the South Atlantic Ocean.

Since the nineties, the number of tracking studies has increased exponentially, and those directly connected to conservation have also increased steadily (Fraser et al. 2018). However, most studies focused on adult ecology and behaviour, whereas juvenile and immature individuals have been relatively neglected, mainly due to the difficulty in studying them before their first breeding attempt (Hazen et al. 2012).

In the marine environment, the distribution and abundance of seabirds, during the breeding or non-breeding seasons, are increasingly used to identify and manage relevant areas for the conservation of marine ecosystems (Lascelles et al. 2012). However, this process is mainly based on the movements of adults, because the spatial distribution of juvenile seabirds is often difficult to obtain due to an extended multi-year at-sea period following fledging (Phillips et al. 2017), which complicates the recapture of tagged birds. Nevertheless, seabirds in earlier life stages can differ significantly from adults in the spatial distribution at sea (Phillips et al. 2017) and may be more exposed to threats and experience higher mortality than adults in fisheries because of their naïve behaviour (Riotte-Lambert & Weimerskirch 2013, Fay et al. 2015).

Among pelagic seabirds, Calonectris shearwaters are relatively well-studied regarding the spatial ecology of their adult populations (details of the species are provided in online Appendix S1). In the Atlantic and the Mediterranean, they undertake long and rapid transoceanic migrations from their breeding grounds to their numerous wintering areas spread along the North, Central and South Atlantic (Reyes-González et al. 2017). Fledglings usually leave the colony from the middle to the end of October and do not return to the natal colony for breeding until they reach about nine years of age (Mougin et al. 2000). However, our current understanding of postnatal dispersion of these birds and their at-sea behaviour is rather limited to fledglings tracked for short periods of time (Raine et al. 2011, Péron & Grémillet 2013, Afán et al. 2019) and a single track of a 4 year old immature bird (Dias et al. 2011). Here, using miniaturized light-level geolocators, we report the first-year migration of one Cory’s Shearwater Calonectris borealis that fledged from its natal breeding population in the Canary Islands (Spain) in 2017. Our main aim is to understand whether the annual movements, the schedule and the at-sea activity patterns of this unique 10-month track of the juvenile differ from those of adults tracked in the same colony and year, thus providing the first evidence of individual exploratory behaviour in juvenile shearwaters.

The study was conducted in Gran Canaria, Canary Islands, Spain (15°47′18″ N 27°50′41″ W). In early October 2017, geolocaTION-immersion loggers (Intigeo-C330 from Migrate Technology Ltd, Cambridge, UK) were leg-mounted on 43 fledgling birds (online Figure S1). The weight of these geolocators (2.6 g) corresponded to 0.3–0.4% of bird body mass, thus well below the threshold of 3.0% above which detrimental effects are more likely to occur (Phillips et al. 2003). Despite their relative lack
of accuracy (Phillips et al. 2004), geolocators are useful for identifying broad foraging areas throughout the annual cycle. Previously, and for comparative purposes, geolocator deployment on breeding adults was carried out during the incubation period (June–July). On 5 July 2018, one tagged juvenile Cory’s Shearwater was unexpectedly recovered dead on a beach in Florida, USA (29°12’ N 80°59’42” W). Throughout the breeding season of 2018, we also recovered geolocators from 33 breeding adults at the colony.

The geolocators measured light intensity every minute, recording the maximum at 5-minute intervals. Twilight events from raw light intensities were visually supervised and computed with Intiproc software from Migrate Technology Ltd (Coton, Cambridge, UK; Fox 2015). To compute and model realistic positions for birds, we applied a probabilistic algorithm designed in R (probGLS package; Merkel et al. 2016), which used a four-step filter (including a land mask, travel speed [max 80 m s⁻¹]), behaviour [inferred from saltwater immersion data], and environmental [Sea Surface Temperature; SST] data. The algorithm computed stable results with uncertainty estimates, including around the equinoxes, and did not require calibration of solar angles. From migratory birds (i.e. we excluded resident birds), we estimated: (1) departure date from breeding area (i.e. the Canary Current), (2) date of crossing the Equator on their outward migrations and (3) date of crossing the Equator on their return migrations (Table 1). All dates were estimated using routines written in R, and then confirmed by visual inspection on the reconstructed tracks. Additionally, geolocators had saltwater immersion sensors recording contact with saltwater every 3 s. From these immersion values, we derived the activity patterns and matched them with the light data to calculate the proportion of daily time spent on the water and in flight during darkness and daylight throughout the tracking period (Dias et al. 2012, Ramos et al. 2016). For plotting purposes, activity budgets were modelled using generalized additive mixed models (GAMMs) through the library mgcv in R (Wood 2017). While modelling daily resting time year-round for adults, we included migratory strategy (migratory or resident) as a fixed term, timing throughout the annual cycle as a smooth term, and bird identity as a random term. Similarly, for modelling circadian activity, we included timing throughout the day as a smooth term, and bird identity as a random term. This allowed us to determine for the juvenile and adult birds the general behavioural patterns throughout the annual cycle, as well as circadian behavioural patterns in specific areas of the Atlantic Ocean.

The tagged juvenile Cory’s Shearwater left its natal colony on 30 October 2017 and moved southward, spending a few days in the Canary Current and around Cape Verdean waters (Figure 1(a)). This juvenile bird shared habitat in space and time with adult birds in the Canary Current, but only for a short period of time (for details see Appendix S1). Adult shearwaters use this productive upwelling area for moultng a number of wing feathers at the end of the breeding season (around 1 October; Ramos et al. 2009). This moult affects the flying capacity of birds during September and October (Alonso et al. 2009) as also revealed by the daily time spent on the water for adults (Figure 2). On the contrary, fledgling birds, with fresh plumage, do not have such flight impairment, and can, therefore, afford to spend more time flying (Figure 2). These differences become more obvious during daylight, when inexperienced birds should benefit from daylight for foraging and finding prey in a novel environment. Similar differences between the juvenile and adults can be seen in the other shared area, the Brazil Current. Thus, the higher flight activity of the tagged juvenile, compared with that of the adults in the two common foraging areas, suggests that the absence of wing moult reported on juveniles of most Procellariform species during the first year of life (Huettmann & Diamond 2000, Bugoni & Furness 2009) may enable juveniles to invest more hours foraging to compensate for their low foraging efficiency.

Our results indicate that juvenile and adult Cory’s Shearwaters could leave the breeding grounds

Table 1. Comparison of migratory parameters between one juvenile and 26 adults of Cory’s Shearwaters from Gran Canaria, Canary Islands, Spain. Departure from the colony is only estimated for the juvenile as it relies on light data, which was not available for adults because, excluding incubation, they only attend burrows during night-time.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Juvenile bird</th>
<th>Adult birds</th>
</tr>
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<tbody>
<tr>
<td>Departure from the colony</td>
<td>30 Oct 2017</td>
<td>–</td>
</tr>
<tr>
<td>Departure from the breeding area</td>
<td>24 Nov 2017</td>
<td>14 Nov ± 11.3 (26) (31 Oct 20 Dec)</td>
</tr>
<tr>
<td>Crossing the Equator (Outward)</td>
<td>24 Jan 2018</td>
<td>20 Nov ± 12.0 (26) (05 Nov 29 Dec)</td>
</tr>
<tr>
<td>Crossing the Equator (Return)</td>
<td>08 Jun 2018</td>
<td>22 Feb ± 19.1 (26) (23 Jan 20 Mar)</td>
</tr>
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</table>
simultaneously (Table 1), although previous reports on Scopoli’s Shearwaters *Calonectris diomedea* suggested differently (Péron & Grémillet 2013). Previous studies already pointed out that Cory’s Shearwaters cross the Equator in their outward migrations through a narrow corridor centred at 20° W that, in terms of energetic costs due to wind intensity, represents the lowest cost pathway (Felicísimo et al. 2008). In our case, both the juvenile and adult outward trajectories closely resembled that minimum wind cost trajectory moving southwest (Figure 1). Therefore, our results suggest that although juveniles have limited initial orientational abilities, they might compensate for this by either following the adults during the first days post-fledging, or at least following the same general cues than adults do while migrating.

After its first long-distance movement, the juvenile bird stayed, between November and January, in a vast area of the Central Atlantic Ocean, clearly influenced by the Equatorial Counter-current and limited by Atlantic North and South Equatorial Currents. These tropical oceanic waters, only inhabited by smaller shearwater and petrel species, such as *Pterodroma* petrels (Ramos et al. 2017), Bulwer’s Petrel *Bulweria bulwerii* (Ramos et al. 2015), and Boyd’s Shearwater *Puffinus boydi* (Zajková et al. 2017), show typically low productivity and resource predictability. In addition, this area represents a narrow belt of calm winds around the Equator (Felicísimo et al. 2008), something that could act as an environmental trap for inexperienced seabirds. Indeed, no adult *Calonectris* shearwater uses this area throughout their annual cycles. Thus, according to the ‘exploration-refinement’ hypothesis ( Guilford et al. 2011), we believe this might be the first challenge this young bird faced, and the first evidence that naïve young shearwaters could learn progressively the optimal migration routes towards more profitable wintering areas.

After crossing the Equator months later than the adults did, the juvenile bird kept moving southwards, following the edge of the South American continental shelf. From February to May, long after the breeding adults had returned to the Northern Hemisphere, the bird stayed in the Brazil Current area (including part of the South Atlantic Current). This warm water current was also exploited by the adult population (four tracked birds spent different periods of time in the area), although none of the adults temporally overlapped with the long stay of the juvenile

Figure 1. Spatial distribution of one juvenile (a) and adult bird (b) of Cory’s Shearwaters from Gran Canaria, Canary Islands, Spain, tracked with geolocators throughout the annual cycle. (a) Track of the juvenile from its natal colony to the beach where it was found dead (Florida, USA: 29°12′11″N 80°59′42″W). The bird fledged on 30 October 2017, and beached on 06 July 2018. (b) Schematic annual phenology and distribution of 33 adult Cory’s Shearwaters. Main phenological events are plotted clockwise in the upper circle: breeding period in dark red, outward migration in light green, wintering period in dark green, and return migration in pink. Coloured areas are minimum convex polygons of bird positions during the breeding and wintering periods (in dark red and dark green, respectively). The main wintering areas were associated with Benguela and Agulhas Currents (*n* = 22 individuals), Brazil-Malvinas confluence region (*n* = 2), and Canary Current (*n* = 7). Additionally, outward individual trajectories of the migratory adult birds (modelled using positions 6 days after leaving the breeding area) are plotted as green lines. Exclusive Economic Zones (EEZs) are also shown in white dashed lines and sampled colony is depicted with a yellow star on both figures.
shearwater. This area is also exploited by Scopoli’s Shearwaters (González-Solís et al. 2007), and by the entire population of Cape Verde Shearwater Calonectris edwardsii (González-Solís et al. 2009), highlighting the habitat suitability for the juvenile. However, adult populations of such closely-related species did not temporally overlap with this juvenile shearwater. This temporal mismatch might represent further evidence of the occurrence of an early learning process of juvenile birds to understand the best wintering spots through an individual exploratory behaviour of the Atlantic (Guilford et al. 2011).

In late May, when breeders start laying their egg at the colony, the juvenile bird returned to the Northern Hemisphere along the coast of Brazil (Figure 1(a)). Contrary to what happened on its way south, the juvenile moved north against the prevailing winds, thus travelling rather inefficiently in terms of the energetic costs (Felicísimo et al. 2008, González-Solís et al. 2009). The decision to return to the Northern Hemisphere, albeit long after all adults had left the area, could be attributed to the annual migratory instinct of the species.

Once in the Northern Hemisphere, the bird spent June moving west towards the Lesser and Greater Antilles, where, apparently, no adult bird occurs throughout the year (Figure 1). Typically, adults returning from their wintering grounds and moving towards their breeding grounds close a figure-of-eight migratory pattern, performing the clockwise loop in the Northern Hemisphere, sometimes spending a few days in the North Atlantic Ocean, but earlier in the year and far from the area the juvenile was apparently moving towards (González-Solís et al. 2007). Significant numbers of non-breeding birds can be seen regularly along North American waters from June to August, and most of them are assumed to be immature birds (Haney & McGillivary 1985, Gjerdrum et al. 2018). However, because the juvenile appeared dead a few weeks later on the Florida Peninsula, this last movement should be interpreted with
caution, as its poor body condition (Appendix S1) could have influenced its last movements. The low level of activity during this last period further supports the hypothesis of a bird in a deteriorating body condition (Figure 2). In addition, the tropical storm affecting the western Atlantic at that time (Hurricane Chris, in early July 2018) could have also played a definitive role in the death of such an inexperienced bird. This casualty and its associated uncertainty highlight the need for a much better understanding of the distribution and abundance of juvenile seabirds at sea, and especially the factors influencing their early mortality (Daunt et al. 2007, Fay et al. 2015).

Here, we report, for the first time, the trans-equatorial movements of a juvenile Cory’s Shearwater during its first year of life. This represents the first evidence of potential segregation between juvenile and adult populations of the species, something that has tremendous relevance for marine conservation. Finally, the dissimilarities found between the spatial ecology of this inexperienced juvenile bird with that of the adult population provide the first evidence of the early learning process of individual exploratory behaviour in juvenile shearwaters during their first years of life, supporting the exploration-refinement hypothesis.

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