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Article

Wettability of juvenile plumage as a major cause of mortality threatens endangered Barau's petrel

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Seabirds spend most of their life at sea and have to possess a waterproof plumage to be able to sit on water for extended periods. We tracked juvenile Barau's petrels for the first time, when they leave their birth colony and found that half of the transmitters stopped soon after they first landed on the water off Réunion Island. We suspected from observation at sea that birds may have problems with the waterproofness of their plumage. Therefore during the next season we set up a simple protocol to assess waterproofness of the plumage of the birds just before they fledge. This protocol is based on the calculation of a wettability index expressed as the mass of water logged in the plumage after simulating the bird sitting on the sea surface. We found that at least one third of chicks ready to fledge gained more than 4 g of water in 20 s, indicating that plumage was not waterproof. Within a sample of birds having fledged and before reaching the sea surface, a similar proportion of birds had their plumage not waterproof. For the birds tracked, only those with an index indicating a waterproof plumage successfully dispersed after their first touch on the sea surface. We provide evidence of a possible major cause of mortality of juvenile seabirds that has not been described previously in wild seabirds, but could exist in other species. This issue may be a major cause of threat to the endangered Barau's petrel.

Keywords: seabird, plumage structure, tracking

Introduction

Very few birds allow water to penetrate to the skin and all feathers invariably exhibit structural and functional adaptations allowing a lasting water repellence (Rijke 1987). Seabirds spend most of their life at sea, and especially on the sea surface on which they float to rest, sleep, feed, moult. Therefore, in most species, especially oceanic species, their plumage is waterproofed so that they are isolated from surface water (Mahoney 1984). This characteristic is probably vital for the thermoregulation of

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these species since it isolates the animal from temperatures that are much lower than that of the bird, but also avoid plumage soaking that would reduce manoeuvrability, take off capabilities and foraging performance (Ortega-Jiménez et al. 2010). Exceptions exist in cormorants that have not completely waterproofed plumage and return on land to dry it (Grémillet et al. 1998) or in the extreme case of darters that have a wettable plumage (Ryan 2007).

Waterproofness is obtained by a combination of specific microstructure of feathers and hydrophobic coating, produced by the uropygial gland, spread on the plumage by the birds (Rijke 1987, Srinivasan et al. 2014). For animals spending their life at sea, the quality of the water repellency of the plumage has probably been under strong selection over evolution of life at sea of these animals (Rijke 1970).

Barau's petrel *Pterodroma baraui* is an endangered species endemic to Réunion Island, south-western Indian Ocean (Pinet et al. 2009). Recent anecdotal observations by local fishermen have suggested that many newly fledged individuals observed off Réunion Island were unable to take-off from the sea surface, because of apparent plumage soaking. In the course of a study on the juvenile phase of seabirds, we tracked juvenile Barau's petrels and investigated the waterproofness of the plumage of juveniles just before and when they fledge from the colony to go at sea for the first time. We found that at least one third of juveniles lack proper waterproofness of their plumage at fledging, and that this inability constitutes a major cause of mortality that may have been overlooked in other species because the juvenile stage is a poorly studied stage of life in animals.

Material and methods

The study was carried out on Réunion Island (21.1°S, 54.4°E). In March–April 2017 and 2018 we captured juvenile Barau's petrels in their burrow in a long-term monitoring colony at Grand Benare, at 2600 m of altitude (Pinet et al. 2009). In 2017 we fitted miniaturised 5 g solar-panelled Argos PTTs (Microwave Telemetry) on 10 juveniles ready to leave their burrow, with complete fresh plumage. Tags were fitted on 6–7 April on the back feathers with ©Tesa tape and ©Loctite glue on 8 individuals, and 2 birds were equipped with Teflon harnesses. Birds fledged after 2–13 d (mean 7 d). In 2018, 9 individuals were fitted with the same tags with Teflon harnesses on 4–5 April and fledged after 2–8 d (mean 5.5 d).

In 2018, following observation of 2017, we estimated the wettability of plumage of 13 fledglings ready to leave in the study colony, including those fitted with transmitters. To do so we devised a specific protocol. We defined a plumage wettability index as the gain in body mass incurred by a dry bird put in contact with water (Mahoney 1984). However, differently from (Mahoney 1984) who submerged the birds tested entirely, we put the petrels in a situation as if it was naturally sitting on the water surface, since Barau's petrels do not dive. To do so, we first took individuals taken from their burrow, put them in a PVC tube that restrained the bird from any movement, and weighed them using an electronic balance (precision 0.1 g). We then took the bird from the tube, gently put the individual held in one hand in a bucket containing water, so that only the underparts of the body and the breast was submerged. This position simulated a petrel naturally sitting on the sea surface. The bird was held for 20 s. The bird was then held vertically for 5 s for water to drop, and weighed again in the PVC tube. The difference in mass indicated the quantity of water trapped in the plumage or left at the plumage surface. On Réunion Island, large numbers of juvenile Barau's petrel (and other petrel and shearwater species) are attracted by artificial light when they fledge from their high altitude colonies before they reach the open ocean (Le Corre et al. 2002). Since 1996, birds that have been attracted by lights are rescued by a network of volunteers from a local NGO (SEOR) and released at the coast. We applied the same protocol to measure plumage wettability on a sample of 31 juveniles rescued during the 2018 rescue campaign.

Data deposition

Data available from the Dryad Digital Repository: <https://doi.org/10.5061/dryad.r15h104> (Weimerskirch et al. 2018).

Results

The mass of fledglings taken from their burrow in the colony on 4–6 April was similar in 2017 and 2018 (average 435 ± 113 g, $F_{1,19} = 1.7$, $p = 0.20$) (see Supplementary material Appendix 1 Table A1 for details). In 2017, 8 juveniles equipped with PTTs left the colony and landed on the sea surface 34–117 km off the coasts of Réunion Island (Fig. 1A). The two other birds did not provide signals from the sea, suggesting that they died in the colony from predation, during the transit to the sea, or just after landing on the sea-surface before the transmitter start emitting. Four individuals (one with harness, 3 with taped logger) started dispersal to the north after a few hours (range 0–8 h) (Fig. 1B). Four (with taped loggers) remained in the vicinity of the island and their transmitters stopped 2–36 h (mean 18.2 h) after the first landing (Fig. 1A).

In 2018, before equipping the juveniles in the colony we estimated the wettability of the plumage of 13 individuals ready to fledge from their burrows. Mass gained ranged from 0.2 to 22 g (Fig. 2A). We equipped 9 individuals with PTTs with harnesses having wettability indexes ranging between 0.2 and 6 g (Fig. 2A). These birds left the colony a few days later, landed on the water off Réunion (Fig. 1C), and started their dispersive movements after a few hours (mean 1.8, range 0–4.5) (Fig. 1D), except 2 birds that stayed off Réunion and stopped transmitting immediately or after 63 h

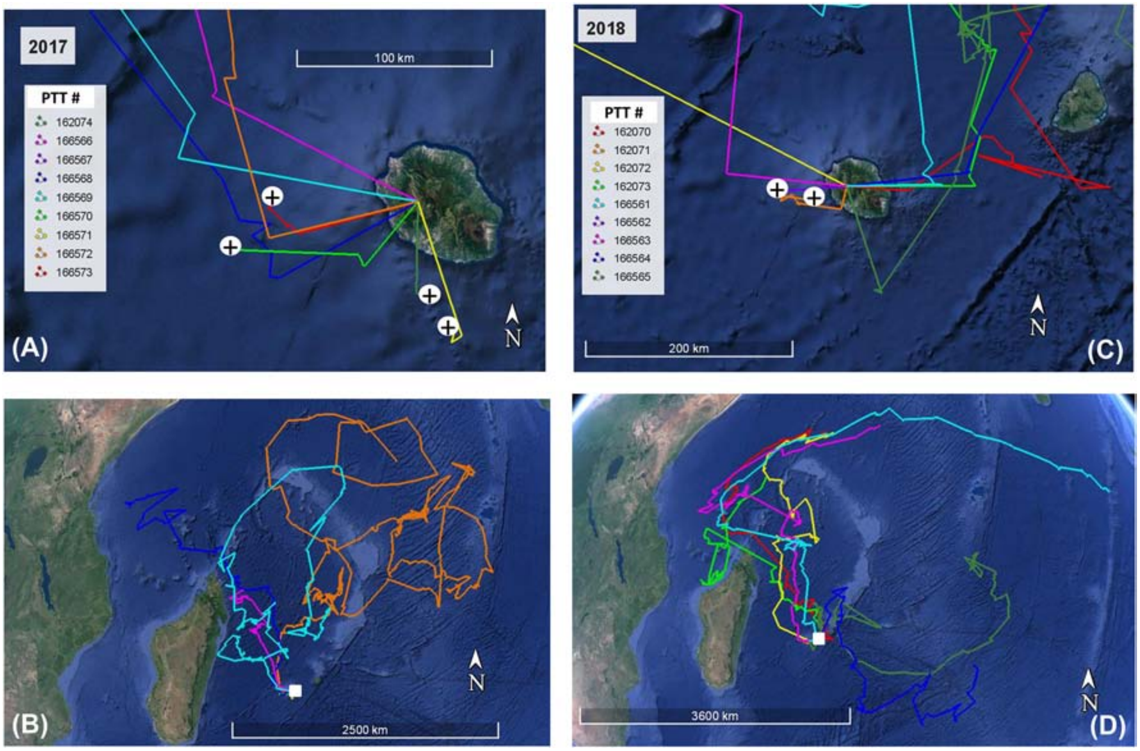

Figure 1. Tracks of juvenile Barau's petrels fledged from Réunion Island in 2017 and 2018 over the south-western Indian Ocean; (A) and (C) zones of the first landing close to Réunion Island with the location where mortality occurred (indicated by a white dot with a black cross). Movements of the surviving juveniles from Réunion Island (white square) in (B) 2017 (8 April–15 September 2017) and in (D) 2018 (8 April–30 May 2018).

(Fig. 1C). These 2 birds that stopped transmitting were the two with the highest wettability index, higher than 4 g in 20 s (Fig. 2A).

Birds found grounded after fledging before reaching the sea were lighter than those captured at the colony (435 ± 113 g and 368 ± 32 g respectively, $F_{1,41} = 42.9$, $p < 0.001$). The wettability index of birds fledged had a similar range to that of the birds equipped on the colony (Fig. 2B) and wettability index was not significantly different between the two groups ($Z = 1.6$, $p = 0.105$). There was no relationship between wettability and mass (Spearman rank test $r_s = 0.21$, $p > 0.05$).

Discussion

This study provides the first evidence that an important proportion of the juveniles of a seabird species have a wettable plumage at fledging and that reduced waterproofness may be a major cause of mortality in these birds. This is the first time that such problem is reported for a seabird in natural conditions, but since wettability of plumage in juvenile seabirds is not measured in colonies, but only in rehabilitation centres, it may be a problem for other species, and future investigations are required. In rehabilitation centres, rescued fledglings are tested for wettability by examining the presence of water trapped in the plumage, or on the skin (e.g. <www.hawaiiwildlifecenter.org/the-waterproofing-process.html> or <www.vetmed.ucdavis.edu/owcn/oiled_wildlife/rescue_and_treatment.cfm>), but we have not found any precise protocols in the literature. We propose here a simple test protocol that can be applied easily on many seabird species for detection of plumage wettability, and can be applied in colonies, i.e. also in remote places, and that is quick and with reduced stress for birds. This test provides an index of plumage wettability.

The quantities of water trapped in the plumage during our tests may appear low, especially when compared to other tests of plumage wettability (Mahoney 1984, Ortega-Jiménez et al. 2010). However in the two studies cited here, birds were entirely submerged in the water, i.e. the test does not mimic the situation encountered by a non-diving petrel sitting at the sea-surface. The structure of the plumage on the belly, that is naturally the part in contact with seawater, is different from the back feathers, that are never in contact with seawater apart from seawater sprays. The back is thus not as waterproof as the belly has to be. It is thus not surprising that the birds entirely submerged quickly absorbed much more water than a bird in more natural conditions. A gain of 4–20 g of water in 20 s is probably significant, especially because young petrels stay on the sea-surface for hours before starting their dispersive movements. The reasons for wettability of juvenile plumage have to be investigated. Resistance to water penetration into the plumage is based first

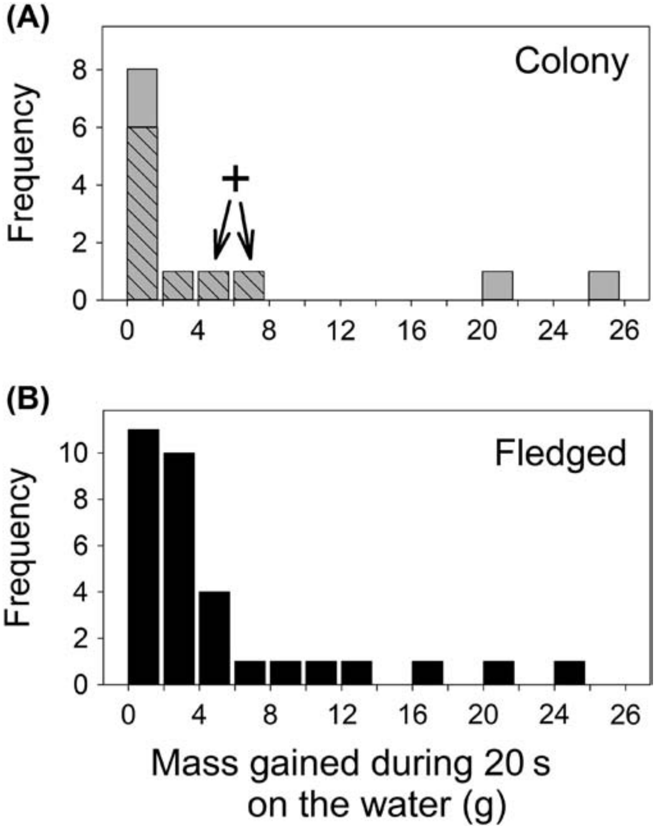

Figure 2. Wettability index as mass of water kept in plumage after 20 s sitting on water of (A) birds ready to fledge caught in their burrow on Grand Benare colony (hatched parts correspond to birds equipped with PTTs, arrows and + indicate the 2 birds whose transmitters stopped after 1–2 d spent on the sea surface), (B) birds rescued on land attracted by light after they fledged.

on the feather structure and second on the use of preening oil that serves as a hydrophobic coating. The water repellency of feathers is determined mainly by the structure of feathers in terms of diameter and spacing of the barbs and barbules (Rijke 1970). Waterbirds have specific feather structure allowing limited quantities of air being trapped in the plumage to adjust buoyancy and water resistance of the plumage in contact with water (Pap et al. 2017). Thus it would be important to compare the feather structure of wettable and waterproof plumages. The amount and quality of preening oil and the size of the uropygial gland should also be investigated to complement studies on plumage structure. The role of the uropygial gland is increasingly recognised as an important component of the life history of birds (Moreno-Rueda 2017). Further studies should also consider the size and functionality of the uropygial gland that can be affected by many factors such as food, stress or contaminant (Vincze et al. 2013).

When they fledge from their birth place, juvenile flying seabirds rapidly land on the sea-surface and make a series of short take-offs and landings, remaining close to the colony for a few hours, before starting their dispersive or migratory movements (Weimerskirch et al. 2006, de Grissac et al. 2016). There are several potential reasons for a transmitter to stop emitting, such as battery failure, feathers covering the solar panel, early detachment, and death. For the few species in which juveniles have been tracked, mortality – inferred from the stop of emission from the transmitter – does not occur during this early phase of dispersal, but mortality occurs later during the first two months after fledging (Péron and Grémillet 2013, Riotte-Lambert and Weimerskirch 2013, de Grissac et al. 2016). It seems unlikely that half of the loggers stopped transmitting immediately after landing on the waters because of early detachment or battery failure, and that the other loggers lasted for months as it occurred in our study. In a previous study we tracked 10 adult Barau's petrels with Argos transmitters; the transmitters were attached with tape similarly to the tape attachment used in the present study, none of the PTT's stopped just after the birds returned at sea and the loggers transmitted for 16 to 65 d (Pinet et al. 2012). Therefore mortality seems the most likely cause of the stop of emissions, especially because independently dying juvenile Barau's petrels are observed off Réunion Island with plumage soaked since several years. High mortality off the birth colony of petrels has not so far been reported, but we cannot exclude the possibility that it occurs in other species.

During their life as adults, Barau's petrels spend more than 50% of their time sitting on the sea-surface (Pinet et al. 2011), for sleeping, resting, feeding and moulting. The activity of juvenile is not known but it is likely that young individuals also spend long periods sitting on the water, and possibly more time especially during the first months at sea as found in other oceanic seabirds (Riotte-Lambert and Weimerskirch 2013). Therefore having a waterproof plumage is vital for juvenile survival. Even a small amount of water diffusing slowly into the plumage may pose a thermoregulatory problem on the longer term. In 2010, 5 juvenile Barau's petrels rescued were equipped with PTTs and 4 stopped transmitting after a few days off Réunion Island (Pinet et al. unpubl.). In 2017, half of the fledging's stopped transmitting rapidly after their first landing on the sea-surface, suggesting rapid death. In 2018 for the birds whose wettability was tested in the colony, the two with wettability of 5 and 6 g 20 s^{-1} stopped transmitting immediately after landing on water and after 63 h, suggesting death. The others dispersed and transmitted for at least one month and had wettabily indexes < 2 g. If we consider that 4 g in 20 s is the maximum wettability that juvenile can have without dying rapidly, then 34% of juveniles may die a few days after fledging. These preliminary results have to be considered with caution in view of the small sample size. Yet the observation of juvenile petrels with soaked plumage at sea combined to our results suggest that the problem may be serious. Even though the growth rate of long-lived species such as Barau's petrels is especially susceptible to variation in adult survival (Saether et al. 2005), a mortality rate of > 30% during the first days after fledging due to wettability of the plumage should have a very strong impact for the long term maintenance of this endangered species (Fay et al. 2015). Our study suggests that the problem of wettability not only concerns our study colony at Grand Benare, but all the colonies since a similar proportion of birds are wettable in the individuals attracted by light after fledging. This problem of wettability is a major concern for the sustainability of the species on the long term, and future research should examine the reasons for the wettability of juvenile plumage in Barau's petrels. However wettability should also be investigated in other species to examine whether this problem occurs in other seabird species.

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Conflicts of interest – None.

Permits – This study was carried out within the framework of the project LIFE + Pétrels (Grant Agreement: LIFE13 BIO/FR/000075), authorising to work on the colony and approving the field procedures for the study. The tracking and banding of Barau's petrels was done under the Research Program PP609 leaded by MLC and agreed by the Centre de Recherche sur la Biologie des Populations d'Oiseaux (CRBPO) and with the agreement ENVT-DE-126-2017 for animal experimention.

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Supplementary material (Appendix JAV-02016 at <www.avianbiology.org/appendix/jav-02016>). Appendix 1.