

TAXONOMIC AFFINITIES OF AUDUBON'S SHEARWATER FROM EUROPA ISLAND¹MATTHIEU LE CORRE²

CEBC-CNRS Villiers en Bois, 79360 Beauvoir/Niort, France

Abstract. The western Indian Ocean holds five subspecies of the pantropical Audubon's Shearwater (*Puffinus lherminieri*), but none was known to breed in the Mozambique Channel. Here, I describe a newly discovered population of Audubon's Shearwaters on Europa Island, southern Mozambique Channel. Comparison of geographic variation of morphometric characters showed that the birds of this population belong to the *P. l. bailloni* subspecies, previously thought to be endemic to the Mascarenes Islands. They were distinct from the three subspecies of the Comoro, Aldabra, and Seychelles group, suggesting that few successful exchanges of individuals occur between north of the Mozambique Channel and Europa Island. This biogeographic pattern is similar to that of two phylogenetically independent pelagic species from Europa Island. This suggests that a common cause related to geographic isolation and oceanic conditions in the Mozambique Channel may explain the apparent isolation of these three seabird populations from Europa Island.

Key words: Audubon's Shearwater, endemism, Europa Island, geographic variation, Indian Ocean, *Puffinus lherminieri*.

Although pelagic seabirds forage over large oceanic surfaces, many species show high natal philopatry and breeding-site fidelity (Weimerskirch et al. 1985), which may lead to geographic isolation between colonies. The oceanic environment also influences movements of pelagic seabirds at sea (Ashmole 1971), which may have important consequences on exchanges between colonies.

Petrels and shearwaters have evolved numerous endemic forms, particularly in tropical waters (Warham 1990, 1996). In the tropical Indian Ocean, six species of petrels and shearwaters are known to breed; two are endemic species from Réunion Island (Barau's Petrel *Pterodroma barau* and Mascarene Black Petrel *Pseudobulweria aterrima*). A third species, the Audubon's Shearwater (*Puffinus lherminieri*), is pantropical but has evolved five distinct subspecies in the area (Jouanin and Mougin 1979, Louette and Herremans 1985, Shirihai and Christie 1996). In 1994, a small population of Audubon's Shearwaters was found at Europa

Island, a remote islet of the southern Mozambique Channel (Le Corre and Jouventin 1997), although no breeding colonies were known in the Mozambique Channel, Madagascar or along the eastern coasts of Africa (Feare 1984, Langrand 1995).

Recent studies on geographic variation of seabirds of the western Indian Ocean showed that two pelagic species from Europa Island were distinct from all other populations of the Indian Ocean (Le Corre and Jouventin 1999, Le Corre, in press). The oceanic environment of the Mozambique Channel, particularly the high sea-surface temperature (Piton 1989) may constitute an ecological barrier for pelagic seabirds. If such an ecological barrier exists in the Mozambique Channel, it should have strong effects on highly sedentary species like Audubon's Shearwater.

The aim of my study was to determine the taxonomic affinities and biogeographic relationships of this newly discovered population of Audubon's Shearwaters. Biometrics and color patterns of the birds from Europa Island are described and compared with those of the other subspecies of the Indian Ocean. Based on these comparisons, I discuss the hypothesis of biogeographic isolation of seabirds of the southern Mozambique Channel. I also describe the breeding habitat and breeding season, estimate population size, and identify possible threats induced by human-related factors to this population.

METHODS

Europa (22°20'S, 40°21'E) is a 28 km² coralline island of the southern Mozambique Channel. Its remoteness and absence of fresh water preserved it from extensive human exploitation, and the island still holds large seabird breeding colonies (Le Corre and Jouventin 1997). During my field work, observations and censuses of shearwaters were made at dusk from vantage points on the coastline, when the birds were returning to the island. The colonies were located by crepuscular and nocturnal observations and listening for displaying adults, together with diurnal searching for burrows.

The birds examined were caught by hand at the entrance of their burrows or mist-netted when flying above their colonies. Some of them (4 out of 23) were lured with playback vocalizations of *P. l. bailloni*. All captured birds were measured, photographed, ringed, and released. Their coloration pattern was recorded (plumage and bare parts). Measurements taken (in mm) were flattened wing length, tarsus length, culmen length, bill depth at gonys, maximal unguis, and weight (g). I also checked for incubation patch. I was not able to sex the birds in the field. Bretagnolle and Attié (1996) found no sex differences in biometrics of

¹ Received 22 September 1998. Accepted 12 July 1999.

² Current address: SEOR, Muséum d'Histoire Naturelle, Rue Poivre 97400 Saint Denis, Réunion Island, e-mail: lecorre@univ-reunion.fr

TABLE 1. Variation of plumage pattern and coloration of bare parts of *Puffinus lherminieri* subspecies of the western Indian Ocean and of *P. atrodorsalis*.

Locality (Taxa)	Upper parts	Under tail coverts	Under wing coverts	Tarsus
Europa Island (<i>bailloni</i> ?)	brownish black	mostly white	mostly white	black and blue
Réunion Island (<i>bailloni</i>)	brownish black	mostly white	mostly white	black and blue
? (<i>P. atrodorsalis</i>)	black	mostly white	mostly white	black and blue
Aldabra Island (<i>colstoni</i>)	brownish black	brown	mostly white	pink
Seychelles (<i>nicolae</i>)	brownish black	brown	mostly white	pink
Comoro (<i>temptator</i>)	brownish black	brown	brown	black and blue
Arabian Sea (<i>persicus</i>)	brownish black	brown	brown	?

adult *P. l. bailloni* at Reunion Island. The birds from Europa were compared to birds from the other subspecies of the Indian Ocean: *P. l. bailloni* from Réunion Island (unpubl. data), *P. l. nicolae* from the Seychelles (Jouanin 1970), *P. l. colstoni* from Aldabra (Shirihai and Christie 1996), *P. l. persicus* from the Arabian Sea, and *P. l. temptator* from the Comoro Islands (Louette and Herremans 1985), and the newly described *P. atrodorsalis* (Shirihai et al. 1995). Measurements of adult *P. l. bailloni* from Réunion Island were made on skins and live specimens, but there were no significant differences in measurements between the two groups, therefore these data were pooled. Statistics were computed with LOGITHEQ and STAT-ITCF. Biometrics are expressed as mean \pm SD.

RESULTS

COLORATION PATTERN AND BIOMETRICS

Twenty-three birds from Europa Island were caught from April 1995 to May 1997. All birds had similar plumage pattern and bare part coloration (Table 1). Out of 19 birds for which the incubation patch was examined, 7 had partially (5) or completely (2) bare incubation patch, suggesting that they were adults, breeding or about to breed. Measurements did not differ according to whether birds had an incubation patch or not but the birds which had an incubation patch were heavier (272 ± 12 g and 234 ± 11 g, respectively, Mann-Whitney *U*-test, $U = 0$, $P < 0.001$). As there was no difference in biometrics between birds with and without an incubation patch, I considered that the birds captured at Europa were all adults or subadults, some of them were probably breeding or about to breed (heaviest birds with bare incubation patch), and others were merely prospecting for a nesting site (lightest birds with no incubation patch).

Birds from Europa had a different plumage pattern than those from Aldabra, the Seychelles, the Comoros, or the Persian Gulf (Table 1). They were similar to adults from Réunion Island in plumage pattern (Table 1), but tended to have a larger bill depth and a longer wing length (Table 2). They also had a longer wing, larger bill depth, and larger unguis than juveniles from Réunion Island (Table 2).

BREEDING SEASON, HABITAT, AND POPULATION SIZE

The birds were observed displaying above the breeding places from March to June 1995, 1996, and 1997,

and in September and October 1995 (I did not visit the island in July and August). I did not observe them in December and January despite intensive field work in the appropriate places. Therefore, this species probably breeds during the winter at Europa Island, like two other pelagic species from this island (Sooty Terns *Sterna fuscata*, and Red-footed Boobies *Sula sula*) associated with surface-feeding tunas (unpubl. data). The places where all displaying birds were observed and heard were in an area of about 1 km², covered with shrubs (*Pemphis acidula* and *Psiadia altissima*). The ground was composed of coralline limestone rocks, regularly interrupted with sandy holes. Several burrows were discovered in some of these holes with birds entering just after landing, but I was able to check the content of only one of these burrows, in September 1995. Although I did not find any egg or chick, the presence of feces, down, feathers, and typical odor of shearwater strongly suggested that the birds had attempted to breed.

I never observed more than 25 birds per evening and per breeding place (maximum 23 different birds counted on 20 April 1995). As there are only 2 or 3 breeding places on the island, population size must be very small, probably less than 100 individuals.

DISCUSSION

TAXONOMIC AFFINITIES

The systematics of the "little shearwater" group, including *P. assimilis*, *P. lherminieri* and *P. atrodorsalis* are very complex and not fully agreed upon (Jouanin and Mougin 1979, Shirihai et al. 1995, Bretagnolle and Attié 1996). However, most subspecies of the two generally accepted species (*P. assimilis* and *P. lherminieri*) can be separated both by size and plumage pattern (Jouanin and Mougin 1979). The birds from Europa do not belong to any subspecies of *P. assimilis* because of their larger size (all the *P. assimilis* subspecies are smaller, see data in appendix in Shirihai et al. 1995), plumage pattern, and ecology (*P. assimilis* breeds in subtropical or temperate rather than in tropical waters). They also differ from all the Atlantic and Pacific subspecies of *P. lherminieri* by their white undertail coverts (brown in the other subspecies) and black and blue legs (pink in the other subspecies). In the western Indian Ocean, comparisons of measurements and plumage pattern show that they are distinct from all known subspecies except *P. l. bailloni* from which

TABLE 2. Measurements (mean \pm SD, in mm)^a of *P. lherminieri* of the western Indian Ocean and of *P. atrodorsalis*.

Locality (Taxa, sample size)	CL	BD	MU	WL	TL	Data from
Europa, adults (<i>bailloni</i> ?, 23)	28.6 \pm 1.0	8.0 \pm 0.5	13.9 \pm 0.7	208.0 \pm 5.0	41.6 \pm 1.1	This study
Réunion, adults (<i>bailloni</i> , 13)	28.7 \pm 1.1	7.1 \pm 0.5	13.9 \pm 0.7	206.0 \pm 3.0	41.1 \pm 0.7	unpubl. data
Réunion, fledglings (<i>bailloni</i> , 53)	28.6 \pm 1.2	6.7 \pm 0.6	12.7 \pm 0.8	199.0 \pm 8.0	40.4 \pm 1.3	unpubl. data
? (<i>P. atrodorsalis</i> , 1)	28			204.0	40	Shirihai et al. 1995
Aldabra Island (<i>colstoni</i> , 3)	27.8 \pm 1.6			197.0 \pm 3.0	40.0 \pm 2.2	Shirihai and Christie 1996
Seychelles Group (<i>nicolae</i> , 13)	26.1 \pm 1.2			193.0 \pm 5.0	36.9 \pm 1.3	Shirihai and Christie 1996
Comoro (<i>temptator</i> , 1)	31			>203	40.5	Louette and Herremans 1985
Arabian Sea (<i>persicus</i> , 5)	32.8 \pm 0.8			200.0 \pm 10.0	39.2 \pm 0.8	Shirihai and Christie 1996

^a CL = culmen length, BD = bill depth, MU = maximum unguit, WL = wing length, TL = tarsus length. Comparisons (one-way ANOVA) between adults from Europa and Réunion Islands: WL: $F_{1,34} = 3.72$, $P < 0.05$; BD: $F_{1,34} = 25.38$, $P < 0.001$; between adults and fledglings from Réunion Island: WL: $F_{1,64} = 4.48$, $P < 0.05$; MU: $F_{1,64} = 26.66$, $P < 0.001$; between adults from Europa and fledglings from Réunion Island: WL: $F_{1,74} = 53.74$, $P < 0.001$; BD: $F_{1,74} = 33.52$, $P < 0.001$; TL: $F_{1,74} = 13.51$, $P < 0.01$; the other parameters did not differ significantly.

they differ only by slight differences in bill depth and wing length (Tables 1 and 2).

I will not discuss the affinities between the birds of Europa with *P. atrodorsalis* because the validity of this species is not fully agreed upon (Bretagnolle and Attié 1996, Shirihai et al., unpubl. data). I suggest that the birds from Europa constitute an isolated population of *P. l. bailloni*, which was previously thought to be endemic to the Mascarene Islands (Jouanin 1987, Barré et al. 1996). The slight differences in measurements may indicate that there is little successful exchange between the two populations but that this apparent isolation is recent. No study attempted to identify the dispersal of fledglings and nonbreeding adults in this species, so that we have no data of the level of isolation between adjacent colonies. However, the present number of known subspecies worldwide (13) and especially in the western Indian Ocean (5) suggests that the different populations are highly isolated from each other. Further studies using both molecular techniques and ringing data are necessary to address this question.

BIOGEOGRAPHIC IMPLICATIONS

It has been argued elsewhere that the geographic isolation of Europa Island and high sea-surface temperatures in the center of the Mozambique Channel may have contributed to the isolation of two seabird species, the White-tailed Tropicbird *Phaethon lepturus* and the Red-footed Booby *Sula sula* (Le Corre and Jouventin 1999, Le Corre, in press).

Warm waters are known to be poor feeding areas for pelagic seabirds (Ashmole 1971). Thus, the central Mozambique Channel waters, which are on average 1°C warmer than those of the Indian Ocean at same latitudes (Piton 1989), may constitute an ecological barrier for seabirds. The data on Audubon's Shearwater suggest that they are different from those breeding to the north of Madagascar (*P. l. temptator*, *P. l. nicolae*, *P. l. persicus*, and *P. l. colstoni*). This is consistent with the hypothesis that there are few successful exchanges between seabird colonies north of the Mozambique Channel and those in the south (Europa Island). Interestingly, White-tailed Tropicbirds, Red-footed Boobies, and Audubon's Shearwaters have the same pattern of geographic variation in the western Indian Ocean, although they are phylogenetically independent, suggesting a common response to environmental constraints.

POPULATION SIZE AND THREATS

The number of birds observed every night when returning to the island suggests that the population size may be less than 100 birds. Such a small population is very vulnerable and at risk of local extinction. Black rats (*Rattus rattus*) were introduced to Europa at least 100 years ago (Le Corre and Jouventin 1997), and they are now widespread all over the island, where they prey upon all ground nesting seabird species (pers. observ.) and may be responsible for the small population size of Audubon's Shearwaters at Europa Island. Barn Owls (*Tyto alba*) are also abundant at Europa Island (Le Corre and Jouventin 1997). I have no evidence of predation of Audubon's Shearwater by Barn Owls at Europa, but, in the Seychelles, they prey upon this species (Diamond and Feare, in Lever 1987).

The existence of this small population of *P. l. bailloni*, suggest that this taxon has a larger range than previously thought. Knowing the size of the breeding population of Audubon's Shearwater at Europa and the potential threats, a conservation program should be undertaken to preserve this small and isolated population.

This work was supported by the Direction Régionale de l'Environnement (DIREN—Ministère de l'Environnement) of Réunion Island and by the Office National de la Chasse (ONC), to whom I am particularly grateful. The stays on the island were authorized by the Prefect of Reunion Island, and organized with the help of the Direction Régionale de Météo France. Transports to Europa were allowed with the collaboration of the Force Armée de la Zone Sud de l'Océan Indien (FAZSOI). I am indebted to Sonia Ribes, curator of the Natural History Museum of Reunion Island, and Pierre Jouventin, director of the Centre d'Etudes Biologiques de Chizé (CNRS), who gave me the opportunity to conduct research on Europa. I also thank J. Bried, F. Lagarde, H. Lormée, and J. M. Probst for field assistance, C. Jouanin, J. Bried, W. D. Koenig, and two anonymous reviewers for their useful comments on an early draft, and V. Bretagnolle for providing recorded vocalizations of *P. l. bailloni* from Reunion Island.

LITERATURE CITED

- ASHMOLE, N. P. 1971. Sea bird ecology and the marine environment, p. 223–286. *In* D. S. Farner, J. R. King, and K. C. Parkes [EDS.], Avian biology. Academic Press, New York.
- ATKINSON, I. A. E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifauna. *Int. Council Bird Preserv., Tech. Publ.* 3:35–81.
- BARRÉ, N., A. Barau, and C. Jouanin. 1996. Les oiseaux de La Réunion. Edition du Pacifique, Paris.
- BRETAGNOLLE, V., AND C. ATTIE. 1996. Coloration and biometrics of fledgling Audubon's Shearwater *Puffinus lherminieri* from Réunion Island, Indian Ocean. *Bull. Brit. Ornithol. Club* 116:194–197.
- FEARE, C. J. 1984. Seabirds status and conservation in the tropical Indian Ocean. *Int. Council Bird Preserv. Tech. Publ.* 2:457–471.
- IMBER, M. J. 1978. The effects of rats on breeding success of petrels, p. 67–72. *In* P. R. Dingwall, I. A. E. Atkinson, and C. Hay [EDS.], The ecology and control of rodents in New Zealand nature reserves. Dept. Land and Survey Information Series, Auckland, New Zealand.
- JOUANIN, C. 1970. Note taxonomique sur les Petits Puffins *Puffinus lherminieri* de l'Océan Indien occidental. *Oiseau et RFO* 40:303–306.
- JOUANIN, C. 1987. Notes on the nesting of Procellariiformes in Réunion, p. 359–363. *In* A. W. Diamond [ED.], Studies of Mascarene Island birds. Cambridge Univ. Press, Cambridge.
- JOUANIN, C., AND MOUGIN, J. L. 1979. Order Procellariiformes, p. 48–121. *In* E. Mayr and G. W. Cottrell [EDS.], Check-list of birds of the world. Vol. 1. Mus. Comp. Zool., Cambridge.
- LANGRAND, O. 1995. Guide des Oiseaux de Madagascar. Delachaux et Niestlé, Lausanne.
- LE CORRE, M. (In press). Plumage polymorphism of Red-footed Boobies (*Sula sula*) in the western Indian Ocean: an indicator of biogeographic isolation. *J. Zool.* 249.
- LE CORRE, M., AND P. JOUVENTIN. 1997. Ecological significance and conservation priorities on Europa Island (western Indian Ocean), with special reference to seabirds. *Terre et Vie* 52:205–220.
- LE CORRE, M., AND P. JOUVENTIN. 1999. Geographic variation in the White-tailed Tropicbird (*Phaethon lepturus*) with the description of a new subspecies endemic to Europa Island (western Indian Ocean). *Ibis* 141:233–239.
- LEVER, C. 1987. Naturalized birds of the world. Longmann Scientific and Technical, Harlow, England.
- LOUETTE, M., AND M. HERREMANS. 1985. A new race of Audubon's Shearwater *Puffinus lherminieri* at Moheli, Comoro Islands. *Bull. Brit. Ornithol. Club* 105:42–49.
- MOORS, P. J., AND I. A. E. ATKINSON. 1984. Predation on seabirds by introduced animals and factors affecting its severity, p. 667–690. *In* P. J. Moors [ED.], Status and conservation of the world's seabirds. *Int. Council Bird Preserv. Tech. Publ.* 2.
- PITON, J. 1989. Quelques aspects nouveaux sur la circulation superficielle dans le Canal du Mozambique (océan Indien). *Documentation Scientifique Orstom* 14:289–299.
- SHIRIHAI, H., AND D. A. CHRISTIE. 1996. A new taxon of small shearwater from the Indian Ocean. *Bull. Brit. Ornithol. Club* 116:180–186.
- SHIRIHAI, H., I. SINCLAIR, AND P. R. COLSTON. 1995. A new species of *Puffinus* shearwater from the western Indian Ocean. *Bull. Brit. Ornithol. Club* 115:75–87.
- WARHAM, J. 1990. The petrels: their ecology and breeding systems. Academic Press, New York.
- WARHAM, J. 1996. The behavior, population biology and physiology of the petrels. Academic Press, New York.
- WEIMERSKIRCH, H., J. L. MOUGIN, J. C. STAHL, AND J. C. VAN BEVEREN. 1985. Banding recovery and dispersion of seabirds breeding in the French Austral and Antarctic territories. *Emu* 85:22–23.