

## Monteiro's Storm-petrel *Oceanodroma monteiroi*: a new species from the Azores

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The existence of two seasonally distinct breeding populations of *Oceanodroma* storm-petrels in the Azores islands was first documented in 1996. The discovery of morphological differences between the populations led to the suggestion that they may represent cryptic sibling species. Recent mtDNA and microsatellite analysis from storm-petrel populations has considerably advanced our understanding of their taxonomic relationships. Here we present new information on the timing of breeding and moult of the two Azores populations, the extent of exchange of individuals between seasons, and diet from feather isotopes. We conclude that the hot-season Azores population should be considered a new species for which we propose the name *Oceanodroma monteiroi*, Monteiro's Storm-petrel. The species is both genetically distinct and genetically isolated from the sympatric cool-season population of Madeiran Storm-petrel *Oceanodroma castro*, and from all other populations of *Oceanodroma castro* in the Atlantic and Pacific Oceans examined to date. Differences in the vocalizations permit species recognition, and the extent of primary feather wear and stage of moult aids separation of the two species in the Azores, which is especially valuable during August when both attend the breeding colonies in large numbers. Feather carbon and nitrogen isotopes reveal that the diet of Monteiro's Storm-petrel differs from that of the sympatric Madeiran Storm-petrel during both breeding and non-breeding seasons, and unlike the Madeiran Storm-petrel, Monteiro's Storm-petrel appears to maintain the same foraging environment during the summer and winter months, though it shows a dietary shift to higher trophic levels during the non-breeding season. Monteiro's Storm-petrel is thought to be confined to the Azores archipelago, where it is currently known to nest on just two small neighbouring islets. The total population size was estimated at 250–300 pairs in 1999.

**Keywords:** genetics, isotopes, moult, taxonomy, vocalizations.

Records from the Azores of a small, white-rumped nocturnal burrowing seabird date back to the 16th century (Fructuoso 1561), when thousands were attracted nightly to fires and killed for food and oil. The description of the species closely matches the Madeiran Storm-petrel *Oceanodroma castro* (Monteiro *et al.* 1996) and it was still considered to

be extremely abundant in the 17th century (Chagas 1645–1650). Following the formal description of the Madeiran Storm-petrel from Madeira in the 19th century (Harcourt 1851), the first record from the Azores islands was in 1887 (Bannerman & Bannerman 1966). However, breeding was not confirmed in the Azores until almost 100 years later (Le Grand *et al.* 1984). Subsequently, Luís Monteiro, carrying out research for his doctoral thesis on eco-toxicology of the seabird assemblage in the Azores in the 1990s,

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discovered two seasonally segregated breeding populations of storm-petrels (Monteiro *et al.* 1996, Monteiro & Furness 1998), similar to those previously described from the Galápagos islands (Harris 1969). Data on the occurrence and development of brood patches among mist-netted birds, incubation periods and chick body size suggested breeding populations were out of phase by 4–5 months, and overlapped at the breeding colony only in August and early September. Substantial differences in morphometrics and the quantities of mercury in both regurgitated food items and in the plumage of these seasonal populations suggested differences in their feeding ecology and the possibility of ecological isolation of the two groups (Monteiro & Furness 1998, Monteiro *et al.* 1998). More recently, Nunes (2003) and Bolton (2007) have found differences in the structure of burrow calls of the seasonal populations. Playback experiments have shown that hot-season birds prospecting for mates and nest sites do not respond to calls of cool-season individuals (Bolton 2007), although the response of cool-season birds to hot-season playback has not been examined in the Azores. Storm-petrels rely heavily on acoustic signals to locate potential mates when prospecting the colony at night (Allan 1962, Harris 1969), so the absence of vocal recognition between seasonally separated storm-petrel populations would act as a pre-mating isolating mechanism, preventing gene flow. The differences in calls between seasonal populations are clear to the human ear.

Analysis of mitochondrial DNA (comprising 266 bp of Domain I and 180 bp of Domain II of the control region) showed that the level of gene flow (number of females exchanged per generation) between sympatric seasonal populations of storm-petrels in the Azores did not differ significantly from zero (all values less than one female per generation between colony pairs) and there were significant levels of net sequence divergence (1.61–2.28%, Smith *et al.* 2007). Assuming a sequence divergence rate of 21% per million years (Wenink *et al.* 1993, though see Nunn and Stanley (1998) who suggest slower rates of mtDNA divergence for storm-petrels), seasonal populations in the Azores were estimated to have diverged 70 000–154 000 years ago. In contrast, much higher levels of gene flow (0.96 to 8.40 females per generation) and low levels of net sequence divergence (0.005–0.10%) were found between cool-season populations in the Azores and the Desertas islands, from where *O. castro* was first described (Smith *et al.* 2007). These results are also generally supported by microsatellite analyses (Friesen

*et al.* 2007) and indicate that whilst the cool-season storm-petrels breeding in Azores are conspecific with the nominate population from the Desertas islands, storm-petrels nesting in the Azores during the hot season are genetically distinct and genetically isolated from sympatric cool-season birds and those breeding in both the hot and cool seasons in the Desertas islands.

Here, we present previously unpublished data on the timing of breeding of the seasonal populations of the Azores and on the timing of moult of primary feathers. We also present updated information on the rate of exchange of individuals among seasonal populations and examine stable isotopes of nitrogen and carbon in storm-petrel flight feathers to compare foraging environments and trophic levels of the two populations. We conclude that the seasonal populations should be considered two distinct species and propose a new specific name for the summer-breeding population. We evaluate its current conservation status in the light of its taxonomic affinity to populations of Madeiran Storm-petrels in the both the Atlantic and Pacific Oceans.

## METHODS

Fieldwork was carried out on Praia Islet, Graciosa, Azores (39°03'N, 27°57'W), between 20 February 2000 and 10 September 2001 to establish the timing of breeding of the seasonal populations. Nest sites were located by searching the islet at night for storm-petrels singing within nest crevices, by inspection of potential nest holes and by playback of sound recordings during daylight. In addition, artificial nest boxes were installed during 2000 and natural nest sites and boxes were inspected daily to determine occupancy, and the timing of laying, hatching and fledging (see Bolton *et al.* 2004 for full details). Adults occupying nest sites were ringed and so could be individually recognized if trapped subsequently away from the nest. Mist-netting was carried out in the colony on 71 nights covering all months of the year. Individuals were examined to determine whether the cloaca was enlarged (indicating recent egg-laying), the stage of development of the brood patch (Monteiro & Furness 1998) and the amount of wear and stage of moult of the primary feathers. The extent of moult of the 10 primaries was recorded according to Ginn and Melville (1983), where a value of zero represents a bird with worn primaries that has yet to commence moult and a value of 50 represents a bird that has completed moult of all primaries. Intermediate values

refer to birds in active primary moult. The first author also measured body mass, wing, tarsus, combined head and bill, bill length (to feathering), bill depth (at the gonys), tail length and tail fork, following methods detailed in Monteiro and Furness (1998). Data were examined for homoscedasticity and normality. Where significant departures from normality occurred, data were analysed using the nonparametric Wilcoxon two-sample test, approximated to a normal distribution, due to large sample size. Procedures were implemented in SAS® v9.1 (SAS Institute 2007).

Further fieldwork was carried out on several days and nights during each breeding season from June 2002 to December 2007 to ring nestlings and adults and to recapture individuals ringed in previous seasons to assess patterns of colony attendance and exchange of individuals between seasons. Mist netting and ringing were also carried out on Vila Islet (36°55'N, 25°10'W), also situated in the Azores some 300 km from Praia Islet, to assess the extent of movements between colonies within the archipelago; Vila only holds cool-season Madeiran Storm-petrels (Monteiro *et al.* 1999). When later recaptures of birds examined previously allowed a more reliable assessment of population membership (for example if individuals were later retrapped with a developed brood patch or in a nest with an egg or chick), the latter assessment of breeding season was used in all analyses.

Information on the foraging environment and trophic level of seasonal populations of storm-petrels was obtained from analysis of stable isotopes of carbon and nitrogen in flight feathers. Inshore and benthic habitats are characterized by relatively higher ratios of  $^{13}\text{C}$  to  $^{12}\text{C}$  compared with offshore and pelagic environments (France 1995, Kelly 2000) and  $^{15}\text{N}$  enriches relative to  $^{14}\text{N}$  at higher trophic levels due to preferential incorporation into body tissues (Minagawa & Wada 1984, Owens 1987). We examined the  $^{13}\text{C}/^{12}\text{C}$  ( $\delta^{13}\text{C}$ ) and  $^{15}\text{N}/^{14}\text{N}$  ( $\delta^{15}\text{N}$ ) ratios in the innermost primary feather, which will reflect the diet when it is grown at the close of the breeding season (Cherel *et al.* 2000, Bearhop *et al.* 2002), and the eighth secondary feather, which is generally grown at the end of the moult cycle (Scott 1970, Arroyo *et al.* 2004) and will reflect the diet in the latter part of the non-breeding season. Feather samples were obtained, under licence, from the hot- and cool-season populations on Praia Islet ( $n = 92$  and  $34$  respectively) and the cool-season population on Vila Islet ( $n = 70$ ) between 2002 and 2004. Feathers were cleaned in a solution of NaOH (0.25 M), oven dried at 40 °C, and homogenized. Isotopic analyses were

carried out by EA-IRMS (elemental analysis-isotope ratio mass spectrometry) by means of a ThermoFinnigan Flash 1112 elemental analyser coupled to a Delta isotope ratio mass spectrometer via a CONFLOIII interface (Serveis Científico-Tècnics, University of Barcelona). Data were tested for normality and examined using multivariate analysis of variance (MANOVA) for repeated measures. Wilks' lambda was calculated to compare values for each isotope ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) between primary and secondary feathers and between sampled colonies (two cool colonies and one hot). Significant effects were further investigated using *post hoc* pairwise comparisons with Bonferroni corrections to control for Type I errors.

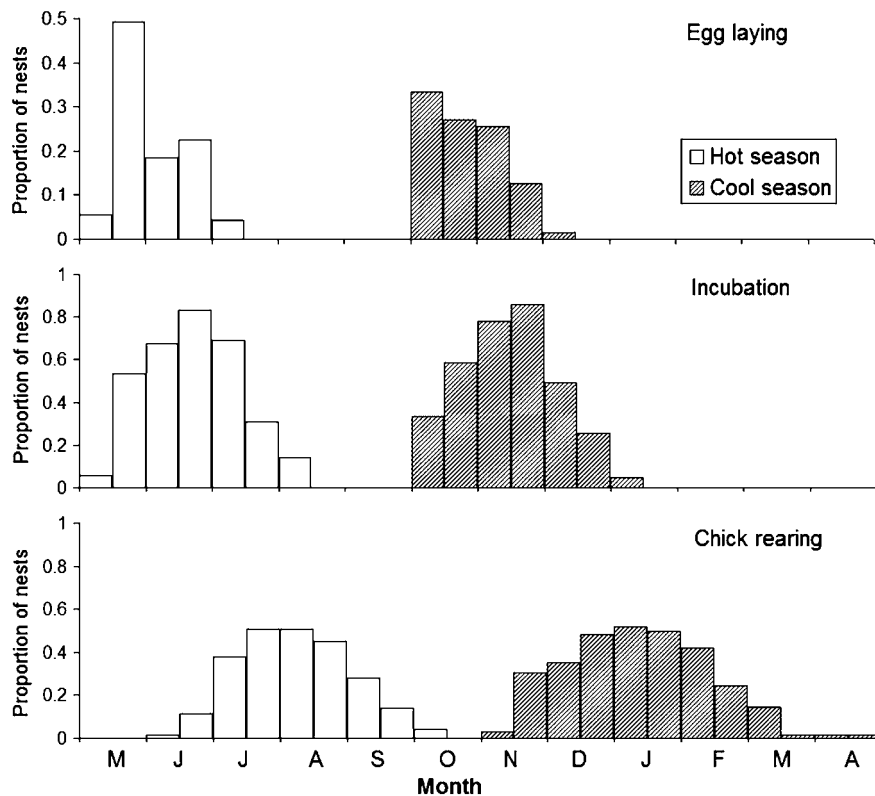
## RESULTS

### Timing of breeding

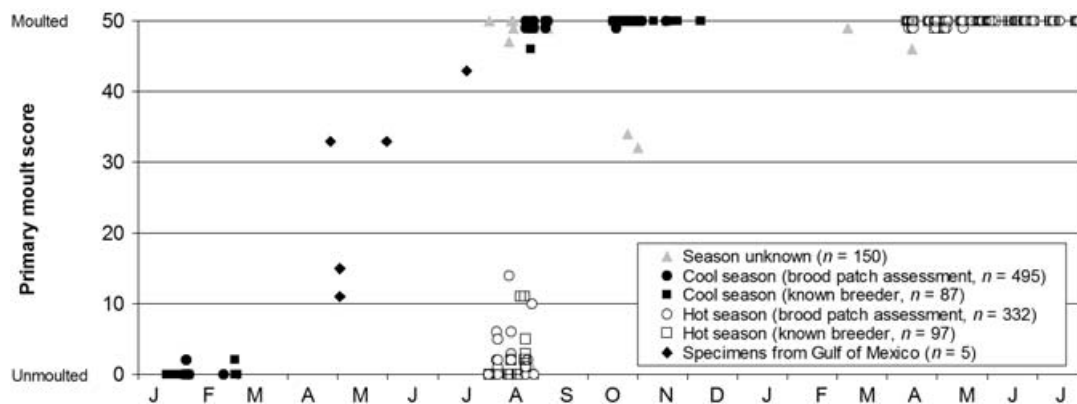
Daily inspection of both natural nest sites and nest boxes confirmed that egg-laying occurred in two discrete periods: May to early July ('hot season') and October to early-December ('cool season'; Fig. 1). Many nest cavities were used for breeding in both seasons. Incubation extended until early August for the summer population and to early January for the winter birds. The first hot-season chicks hatched in early June and the last fledged by early October, whereas the chick rearing period was far more protracted during the cool season, extending from early November until the second half of April. The protracted nature of the winter fledging period was due to very slow growth by some chicks that endured considerable periods without feeds (up to 10 consecutive days on occasion).

### Timing of primary moult

Among cool season birds, the earliest occurrence of primary moult was noted on 29 January, when two of 12 individuals examined had begun to moult the two innermost primaries (Fig. 2). Most cool-season chicks were well-grown at this time. Among 36 cool-season birds returning to the breeding colony in August and examined for moult, eight were still in the final stages of re-growing their outermost primaries. The latest occurrence of primary moult among cool-season birds was noted on 17 October (two individuals among 31 examined on that night). It is difficult to obtain information on the progression of moult of cool-season birds between April and July as they do



**Figure 1.** Timing of egg laying (bars show the proportion of nests at which an egg is laid in each time period); incubation (nests where incubation is in progress) and chick-rearing periods of Madeiran Storm-petrels on Praia Islet, Azores, during the hot and cool seasons ( $n = 120$  and  $103$  nests, respectively).



**Figure 2.** Timing of primary moult of individuals from seasonal populations of Madeiran Storm-petrels in Azores. Note the x-axis covers 19 months to embrace the complete moult cycle of both populations. Data on primary moult of five specimens collected from the Gulf of Mexico between April and July presented by Woolfenden *et al.* (2001) are also plotted.

not attend the colony during these months. However, Madeiran Storm-petrels are seen off the east coast of the USA at this time (Sangster 1999) and a cool-season individual with a fully developed brood patch ringed on Praia Islet on 25 September

1993 was subsequently captured alive on a fishing boat in the Gulf of Mexico on 27 April 1998, when it was in active primary moult (score *c.* 33, Woolfenden *et al.* 2001; Fig. 2). A further four individuals collected from the Gulf of Mexico between May and July were

all in active primary moult (Woolfenden *et al.* 2001; Fig. 2), indicating they were also cool-season, not hot-season, breeders.

Among hot-season birds, commencement of primary moult was first noted on 5 August, when hot-season chicks were well grown (Fig. 2). The last date on which a hot-season bird was still in primary moult was 17 May (one individual of 14 examined on that date). Examination of the timing of moult of individuals that can be reliably ascribed to a seasonal population indicates that moult of primary feathers extends from the latter stages of one breeding season to the start of the next and can therefore be used to determine population membership of adults at any time of year. For example, two individuals trapped in late October partway through primary moult (Fig. 2) were judged to belong to the hot season population, whose members would be expected to be at this stage of primary moult in late autumn, in contrast to the many cool-season individuals caught at this time, which had all recently completed primary moult. This identification was confirmed from biometrics for both individuals.

### Exchange of individuals between seasons

A fuller understanding of the timing of breeding seasons and the use of moult patterns to establish the population membership of individuals, have revealed a greater period of overlap in colony attendance of the seasonal populations than was previously recognized. The earliest attendance of a cool-season bird (assessed on the state of the brood patch, primary wear and moult) was 13 August and the latest attendance of a hot-season bird (similarly assessed) was 30 October. Between late August and early October, cool-season

birds may share nest sites during daylight with well-grown hot-season chicks. However, despite colony attendance by both populations during the summer months, we have found only one instance of switching seasonal colony attendance among 1339 recaptures (1122 on Praia, 217 on Vila) involving 728 individuals (568 on Praia, 160 on Vila) from a total of 4447 individuals ringed between 1990 and 2007. The single occurrence relates to an individual ringed as a hot-season nestling on Praia Islet in July 2003, recaptured by mist-net on Vila Islet during the cool season (18 November 2005). However, there was no evidence that this individual was breeding during the cool season. Additionally, all 1050 (900 on Praia, 150 on Vila) recaptures of 458 (353 on Praia, 105 on Vila) birds known to have made at least one breeding attempt, including 27 birds ringed as nestlings (25 on Praia, 2 on Vila) and later found breeding, have been within the same season.

### Biometrics

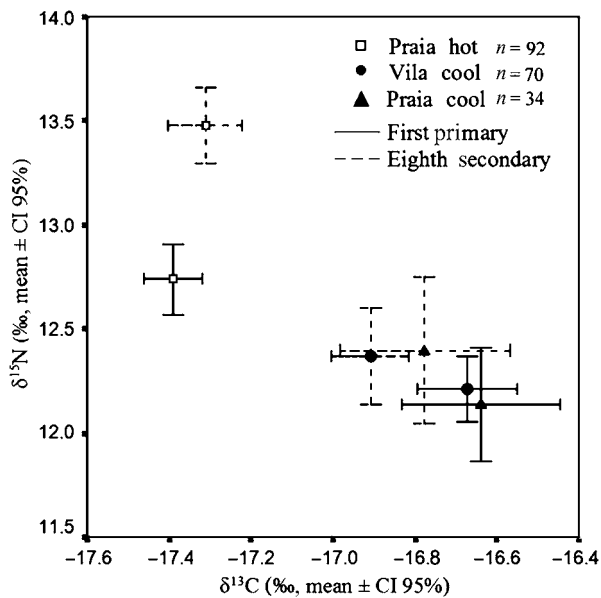
We found highly significant differences between seasonal populations in all body measures examined, except wing length (Table 1). On average, hot-season Storm-petrels are smaller in terms of body mass, and have longer, more deeply forked tails, smaller heads and shorter thinner bills than Storm-petrels nesting in the cool season.

### Foraging environment and trophic level

There were clear differences in both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  between Storm-petrels breeding in the hot-season and those breeding in the cool-season (Fig. 3, Wilks'  $\lambda$ ,  $F_{2,196} = 33.38$ ,  $P < 0.001$  and  $F_{2,196} = 37.27$ ,  $P < 0.001$ , respectively). Additionally, among the cool-season

**Table 1.** Biometrics of Storm-petrels breeding in the cool and hot seasons on Praia Islet, Graciosa, Azores. Mean  $\pm$  sd (min – max,  $n$ ). Significance was determined either with two-sample  $t$ -tests (where † indicates samples with unequal variances), or non-parametric Wilcoxon two-sample tests for those variables whose distribution departed from normality (tail length, tail fork, bill depth and tarsus length).

Variable	Cool season	Hot season	Significance
Wing length (mm)	158.44 $\pm$ 3.54 (149–166, 129)	159.21 $\pm$ 3.63 (150–169, 209)	$t_{336} = -1.91$ , $P = 0.057$
Weight (g)	47.28 $\pm$ 3.06 (38.5–55.1, 115)	44.57 $\pm$ 4.01 (34.8–56.1, 227)	$t_{289} = 6.93$ †, $P < 0.0001$
Tail length (mm)	72.35 $\pm$ 2.53 (66–79, 124)	74.71 $\pm$ 3.34 (62–84, 206)	$Z = 6.73$ , $P < 0.0001$
Tail fork (mm)	3.53 $\pm$ 1.47 (0–7, 124)	7.81 $\pm$ 2.30 (1–14, 205)	$Z = 13.56$ , $P < 0.0001$
Bill length (mm)	15.14 $\pm$ 0.49 (13.8–16.4, 117)	14.90 $\pm$ 0.55 (13.7–16.2, 207)	$t_{322} = 4.03$ , $P < 0.0001$
Bill depth (mm)	5.20 $\pm$ 0.27 (4.6–6.2, 117)	5.09 $\pm$ 0.23 (4.6–5.8, 207)	$Z = 3.76$ , $P = 0.0002$
Head and bill length (mm)	41.62 $\pm$ 0.81 (39.4–43.4, 125)	40.31 $\pm$ 0.87 (37.6–42.5, 208)	$t_{331} = 13.63$ , $P < 0.0001$
Tarsus length (mm)	23.57 $\pm$ 0.76 (21.5–25.2, 112)	23.27 $\pm$ 0.77 (21.4–24.7, 205)	$Z = 3.06$ , $P = 0.002$



**Figure 3.** Ratios of stable isotopes of carbon and nitrogen in primary and secondary feathers of seasonal populations of storm-petrels nesting on Praia Islet and Vila Islet in the Azores.

breeders there were differences between primary and secondary feathers in carbon ( $F_{1,104} = 12.59$ ,  $P < 0.05$ ) but not nitrogen signatures. Among hot-season breeders the reverse pattern was found: primary and secondary feathers differed in nitrogen ( $F_{1,92} = 38.31$ ,  $P < 0.001$ ) but not in carbon signatures.

### Taxonomic recommendation

All available evidence indicates that the seasonally segregated populations of storm-petrels breeding in the Azores should be regarded as distinct species by either the biological or phylogenetic species concepts (Helbig *et al.* 2002). Specifically, the taxa are both diagnosable (see below) and likely to retain their genetic and phenotypic integrity in the future. As the genetic evidence shows that the Azores cool-season population is conspecific with the nominate *O. castro* from the Desertas, for the Azores hot-season population we propose the name:

*Oceanodroma monteiroi*, sp. nov.

Monteiro's Storm-petrel

**Holotype:** adult male, American Museum of Natural History AMNH 528602 collected 25 April 1903 from a rock crevice on 'Praya' Islet, Graciosa, procured by W.R. Ogilvie-Grant during his expedition to the Azores islands (Hartert & Ogilvie-Grant 1905). Previously identified as *O. castro*.

### Description of the holotype

**Measurements:** Head and bill length 39.5 mm; bill length to feathering 13.9 mm; bill depth at gonys 5.2 mm; wing length 157 mm; tarsus 22.5 mm; outer tail feather length 73 mm; central tail feather length 60 mm; tail fork 13 mm (all measurements taken by M.B.).

**Bare parts:** Iris dark brown; bill, legs and feet black.

**Plumage:** Colour descriptions follow Smithe (1975). Plumage all one generation, no feather moult in progress. Primaries fresh with no sun-bleached 'shadows'.

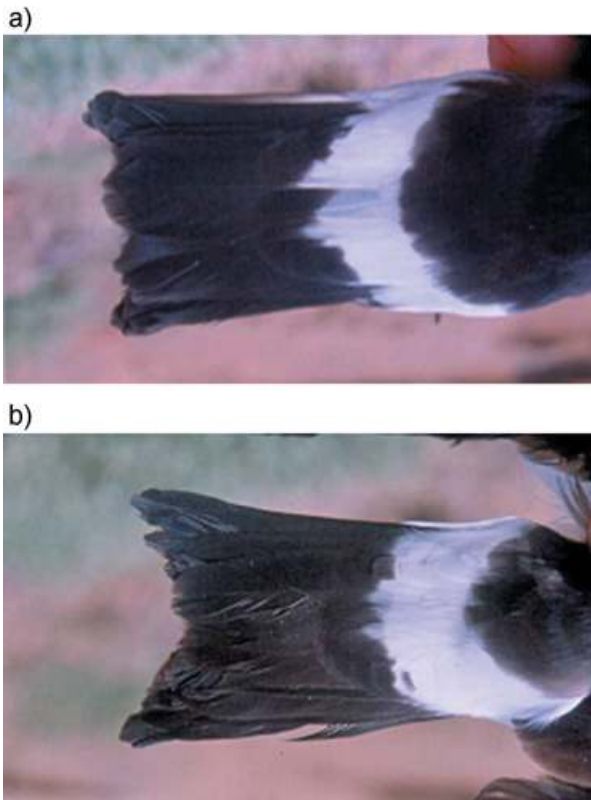
**Upperparts:** Entire head, mantle, scapulars, back and upper rump and upper tail sooty brown-black (Sepia, Colour 119). Nape, mantle and scapulars, back and upper rump with grey wash in good light. Longest scapulars thinly edged very pale grey. Upper tail coverts white (white feather shafts) forming a white rump band *c.* 15 mm wide in the centre and *c.* 20 mm wide at the sides. Lower 10 mm of upper tail coverts tipped black, concolorous with upper tail. Bases of outer three tail feathers white, extending 33 mm from feather base on outmost tail feather.

**Underparts:** Chin and throat slightly paler than upper headparts. Breast, belly, upper flanks, central undertail coverts noticeably browner than upperparts (Fuscous, Colour 21). Lower flanks and bases of outer undertail coverts white, forming a contiguous white band with rump, so the white rump 'wraps around' the flanks, but not joining ventrally. Underside of tail feathers brown-black (very similar to underparts) with silvery sheen. Undertail coverts extending almost to tail tip centrally.

**Wing:** Lesser coverts, carpal coverts, primary coverts, primaries and secondaries uniformly sooty brown-black (Sepia, Colour 119). Noticeable Light-Drab (Colour 119C) diagonal wing bar extending from tertials (and inner secondary), across the greater and median coverts, to the outer lesser coverts, almost reaching the leading edge of the wing. The outer three greater coverts have outer lower edge concolorous with the primary coverts. It was not possible to carry out a detailed examination of the underwing, but it appeared wholly dark, similar in colour to underparts.

### Diagnosis

Monteiro's Storm-petrel *O. monteiroi* is some 5–10% smaller in terms of body mass than the Madeiran Storm-petrel. Monteiro's Storm-petrel is proportionately longer-winged and has on average a longer, more deeply forked tail (Monteiro & Furness 1998;



**Figure 4.** Difference in the extent of the tail fork between the Madeiran Storm-petrel (a) and Monteiro's Storm-petrel (b). Photographs taken in August, when both species are present at the breeding colony. At this time, Monteiro's Storm-petrels are tending large chicks and have worn plumage (note brown tinge to tail feathers), whereas Madeiran Storm-petrels are prospecting for nest sites and have fresh plumage having recently completed the annual moult.

Table 1 and Fig. 4) and a shorter thinner bill, although there is overlap in all these measurements.

Vocalizations are the single most useful diagnostic feature of Monteiro's Storm-petrel, which enables separation from all populations of Madeiran Storm-petrel examined so far. Burrow calls of Monteiro's Storm-petrel are diagnostically different from those of Madeiran Storm-petrels nesting in the Azores, Cape Verde and the Galapagos Islands, in both the duration and structure of the breath notes that punctuate the purr phrases (see Bolton 2007 for sonograms). The breath note of Monteiro's Storm-petrel is shorter and contains fewer syllables than the corresponding phrase of the Madeiran Storm-petrel, a difference which is easily discernible to the human ear.

Due to the differences in the timing of breeding of Monteiro's and Madeiran Storm-petrels in the

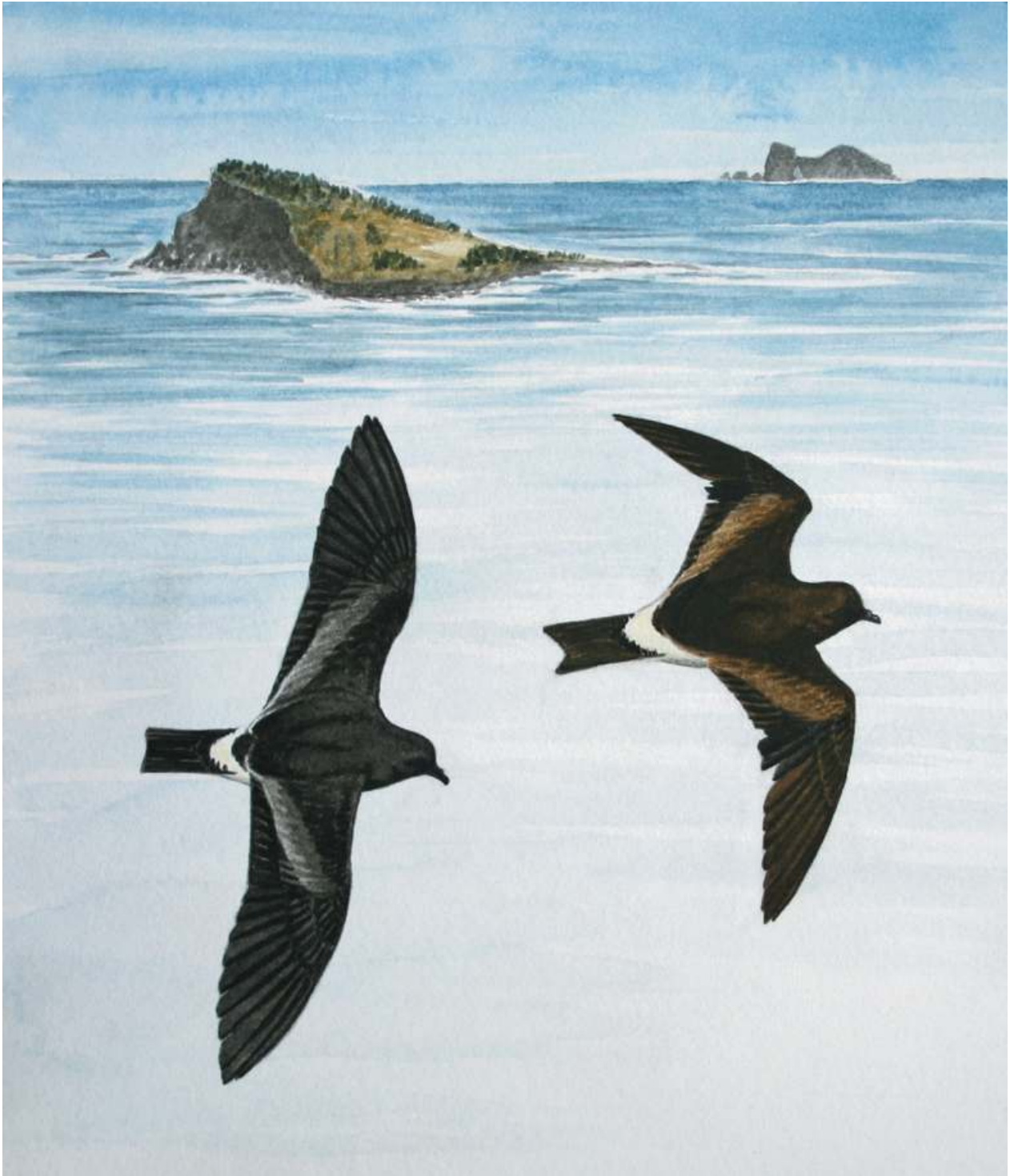
Azores islands, there are similar differences in the timing of wing moult, which commences towards the end of the breeding season and is completed towards the onset of the following breeding season. The difference in the timing of primary moult is currently the most useful single diagnostic criterion outside the breeding season, and may assist the identification of individuals at times of the year when both species attend the colony (principally August, with some Monteiro's Storm-petrels remaining as late as October; Figs 1 & 2). At this time, Monteiro's Storm-petrels have worn primary feathers and are in active primary moult, beginning with the innermost feathers. In contrast, Madeiran Storm-petrels nesting in the Azores complete primary moult in August, and consequently the outermost feathers are very fresh, having been replaced relatively recently (Fig. 5).

The use of primary moult as an identification feature for individuals away from colonies will be complicated by the existence of summer-breeding Madeiran Storm-petrels elsewhere in their Atlantic range (e.g. the Desertas Islands) which must presumably share a similar moult cycle to Monteiro's Storm-petrel. Immature individuals and failed breeders may also commence moult earlier than successful breeders. Away from the breeding colonies, field identification of Monteiro's Storm-petrel is likely to present similar challenges to the separation of Zino's Petrel *Pterodroma madeira* and Fea's Petrel *Pterodroma feae*. The biometric differences noted above are slight and unlikely to be perceptible under field conditions.

### Etymology

The specific name *lugubris* is available for any new taxon split from *O. castro*, following misidentification of a holotype specimen *Procellaria lugubris* Bonaparte, 1845 now held at the Naturhistorisches Museum Wien (NMW 40.989, Bauernfeind & Schifter 2003). The specimen is obviously not *Hydrobates pelagicus*, with which it was previously synonymized, and agrees well with *O. castro* (Bauernfeind & Schifter 2003). If this specimen were found to belong to the taxon newly described here, the specific name *lugubris* would take precedence. Although the precise location and date of collection are unknown, body measurements show that it does not belong to the taxon we describe: the exposed culmen of the *lugubris* holotype (16.4 mm) lies outside the range for the Azores species





**Figure 5.** Monteiro's Storm-petrel *Oceanodroma montei* (right) and Madeiran Storm-petrel *Oceanodroma castro* in flight off the only two known breeding islets of the former: Praia Islet (foreground) and Baixo Islet, Graciosa, Azores. The figure illustrates the differences in plumage wear and moult that are apparent in August, when both species attend the colonies in large numbers. Monteiro's Storm-petrels show faded plumage and have commenced moult of the inner primaries, whereas Madeiran Storm-petrels have relatively fresh plumage and have recently completed moult.



(Table 1). Additionally, the tail of the *lugubris* holotype is not forked (central tail feathers equal in length to the outer tail feathers, which may account for the original misidentification as *H. pelagicus*). The nominate *O. castro* can exceptionally show an unforked tail (three individuals among 124 examined by M.B., Table 1), but no instance of an entirely unforked tail was found among 205 individuals of the proposed new species. We therefore propose the specific name *monteiroi*, which acknowledges the huge contribution to the discovery of this species made by the late Dr Luís Monteiro, who first described the seasonal populations of storm-petrels in the Azores and who worked tirelessly for their conservation. We follow the recommendations of ICZN (1999) in the formation of the specific name.

## DISCUSSION

### Population size, distribution and foraging

On current knowledge, Monteiro's Storm-petrel is known only from the Azores islands and appears to have diverged between 125 000 and 300 000 years ago from populations in the Pacific and between 70 000 and 350 000 years ago from other populations within the North Atlantic (Friesen *et al.* 2007, Smith *et al.* 2007). Within the Azores, the species is known to breed only on two small (*c.* 12-ha) islets, some 5 km apart, lying off the inhabited island of Graciosa. The combined breeding population at these two sites has been estimated at 200 pairs (Monteiro *et al.* 1996, 1999). Further small colonies, possibly holding a few tens of pairs, are suspected on other islets lying off Graciosa, Flores and Corvo (Monteiro *et al.* 1999). The total breeding population is therefore estimated at between 250 and 300 pairs, but there is a clear need for more accurate and up-to-date information on population size and demography.

The distribution of Monteiro's Storm-petrel outside the breeding season is currently unknown, although the capture of two individuals on Praia Islet in late October and a further individual on Vila Islet in mid November suggests that it remains in the vicinity of the breeding grounds, rather than dispersing into the western Atlantic, as does the Madeiran Storm-petrel. The analysis of carbon isotopes supports this suggestion, as for Monteiro's Storm-petrel there were no differences in  $\delta^{13}\text{C}$  between feathers grown in the summer and winter months, suggesting a similar geographic origin of these feathers, whereas for the Madeiran

Storm-petrel there were significant differences in carbon signatures between the primary and secondary feathers. Whilst the diets of the Madeiran Storm-petrel and Monteiro's Storm-petrel are currently poorly known, Monteiro *et al.* (1998) found considerably higher levels of mercury in both the regurgitated prey and body feathers of cool-season Madeiran Storm-petrels than hot-season storm-petrels, and suggested that the cool-season birds had a higher dependence on mesopelagic prey. Analysis of  $\delta^{13}\text{C}$  data presented here indicates that the diet of Monteiro's Storm-petrel has much less of a benthic component than that of the Madeiran Storm-petrel. Even during the late winter (February–March) when both species are present in waters around the Azores, they appear to show dietary differences: we found considerable differences in both  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  of Madeiran Storm-petrel primary feathers and Monteiro's Storm-petrel secondary feathers, which would both be growing around this time. Analysis of  $\delta^{15}\text{N}$  suggests that Monteiro's Storm-petrel generally feeds at a higher trophic level than the Madeiran Storm-petrel and shows a dietary shift to higher trophic levels during the winter months.

### Conservation threats

In common with other members of the Order Procellariiformes, Monteiro's Storm-petrel lays a single egg and annual productivity is low due to interspecific competition with other, larger, burrowing Procellariiformes. Productivity averaged just 0.16 fledglings per pair over 2 years (2000–2001) on Praia Islet (Bolton *et al.* 2004). The species therefore has limited potential for population growth and consequently low resilience to adverse effects. Identified threats include high predation rates by Long-eared Owls *Asio otus* that are resident in the Azores. Up to 40 adult Storm-petrels are killed in some seasons, including some known from ring recoveries to be breeders (M. Bolton pers. obs.). The two known breeding islets are currently free of ground predators, but their close proximity (*c.* 1 km offshore) to the inhabited island of Graciosa, and the large numbers of visitors to one islet during summer means that the introduction of rodents is a possibility. Both islets lie within 2 km of the main shipping route for large passenger ferries and container ships docking on Graciosa. A cargo ship containing livestock ran aground on one of the breeding islets in 2000, leading to concerns over pollution and rodents escaping ashore.

Both breeding islets are designated under European legislation as Special Protection Areas and are assigned

a full-time warden based on the island of Graciosa. Recent work to reduce interspecific competition for nest cavities with other larger procellariiform species through the installation of nest boxes has met with considerable success, leading to large increases in annual productivity (Bolton *et al.* 2004). Nest boxes and natural sites are monitored annually to determine occupancy and breeding productivity. In 2007, 22 young fledged from 56 breeding attempts in nest boxes and a further 12 pairs reared four young in monitored natural nest sites.

The early 16th and 17th century accounts from the Azores of a small black and white seabird that was killed nightly by the thousands, relate that it had young in the nest in September–October (Fructuoso 1561, Chagas 1645–1650), which accords more closely with the breeding phenology of Monteiro's Storm-petrel than the Madeiran Storm-petrel. It seems likely therefore that these early descriptions of a seabird so abundant it was knocked from the air using sticks, almost certainly relate to the species newly described here. In comparison with its former, virtually unimaginable, abundance, Monteiro's Storm-petrel currently survives by a very slender margin indeed, and work must now be undertaken to establish an action plan to ensure its continued existence.

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## REFERENCES

- Allan, R.G. 1962. The Madeiran Storm Petrel *Oceanodroma castro*. *Ibis* **103b**: 274–294.
- Arroyo, B., Mínguez, E., Palomares, L. & Pinilla, J. 2004. The timing and pattern of moult of flight feathers of European Storm-petrel *Hydrobates pelagicus* in Atlantic and Mediterranean breeding areas. *Ardeola* **51**: 365–373.
- Bannerman, D. & Bannerman, W.M. 1966. *Birds of the Atlantic Islands, Vol. III. A History of the Birds of the Azores*. Edinburgh: Oliver & Boyd.
- Bauernfeind, E. & Schiffer, H. 2003. *Oceanodroma castro* (Harcourt, 1851) – nomen protectum. *Bull. Brit. Orn. Club* **123**: 280–283.
- Bearhop, S., Waldron, S., Votier, S.C. & Furness, R.W. 2002. Factors that influence assimilation rates and fractionation of nitrogen and carbon stable isotopes in avian blood and feathers. *Physiol. Biochem. Zool.* **75**: 451–458.
- Bolton, M. 2007. Playback experiments indicate absence of vocal recognition among temporally and geographically separated populations of Madeiran Storm-petrels *Oceanodroma castro*. *Ibis* **149**: 255–263.
- Bolton, M., Medeiros, R., Hotherhall, B. & Campos, A. 2004. The use of artificial breeding chambers as a conservation measure for cavity-nesting procellariiform seabirds: a case study of the Madeiran Storm Petrel (*Oceanodroma castro*). *Biol. Conserv.* **116**: 73–80.
- Chagas, D. 1645–1650. *Espelho Crystalino em Jardim de Varias Flores*, published in 1989, ed. A.T. Matos. Angra do Heroísmo, Azores: Secretaria Regional da Educação e Cultura.
- Cherel, Y., Hobson, K.A. & Weimerskirch, H. 2000. Using stable-isotope analysis of feathers to distinguish moulting and breeding origins of seabirds. *Oecologia* **122**: 155–162.
- France, R.L. 1995. Carbon-13 enrichment in benthic compared to planktonic algae: foodweb implications. *Mar. Ecol. Progr. Ser.* **124**: 307–312.
- Friesen, V.L., Smith, A.L., Gómez-Díaz, E., Bolton, M., Furness, R.W., González-Solís, J. & Monteiro, L.R. 2007. Sympatric speciation by allochrony in a seabird. *Proc. Natl Acad. Sci. U S A* **104**: 18589–18594.
- Fructuoso, G. 1561. *Saudades da Terra*, 2nd edn published in 6 volumes from 1978 to 1983, ed. J.B.O. Rodrigues. Ponta Delgada, Azores: Instituto Cultural de Ponta Delgada.
- Ginn, H.B. & Melville, D.S. 1983. *Moult in Birds*. BTO Guide 19. Tring: British Trust for Ornithology.
- Harcourt, E.V. 1851. *A Sketch of Madeira*. London: John Murray.
- Harris, M.P. 1969. The biology of storm petrels in the Galapagos Islands. *Proc. Calif. Acad. Sci.* **37**: 95–165.
- Hartert, E. & Ogilvie-Grant, W. 1905. On the birds of the Azores. *Novit. Zool.* **12**: 80–128.
- Helbig, A.J., Knox, A.G., Parkin, D.T., Sangster, G. & Collinson, M. 2002. Guidelines for assigning species rank. *Ibis* **144**: 518–525.
- ICZN 1999. *International Code of Zoological Nomenclature*, 4th edn. London: International Trust for Zoological Nomenclature.

- Kelly, J.F.** 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. *Canadian Journal of Zoology* **78**: 1–27.
- Le Grand, G., Emmerson, K. & Martin, A.** 1984. The status and conservation of seabirds in the Macaronesian Islands. In Croxall, J.P., Evans, P.G.H. & Schreiber, R.W. (eds) *Status and Conservation of the World's Seabirds*: 377–391. Cambridge, UK: International Council for Bird Preservation, Tech. Publ. No. 2.
- Minagawa, M. & Wada, E.** 1984. Stepwise enrichment of  $\delta^{15}\text{N}$  along food chains: further evidence and relation between  $\delta^{15}\text{N}$  and animal age. *Geochim. Cosmochim. Acta* **48**: 1135–1140.
- Monteiro, L.R. & Furness, R.W.** 1998. Speciation through temporal segregation of Madeiran Storm-petrel (*Oceanodroma castro*) populations in Azores? *Phil. Trans. R. Soc. Lond. B* **353**: 845–953.
- Monteiro, L.R., Granadeiro, J.P. & Furness, R.W.** 1998. Relationship between mercury levels and diet in Azores seabirds. *Mar. Ecol. Prog. Ser.* **166**: 259–265.
- Monteiro, L.R., Ramos, J.A., Pereira, J.C., Monteiro, P.R., Feio, R.S., Thompson, D.R., Bearhop, S., Furness, R.W., Laranjo, M., Hilton, G., Neves, V.C., Groz, M.P. & Thompson, K.R.** 1999. Status and distribution of Fea's Petrel, Bulwer's Petrel, Manx Shearwater, Little Shearwater and Band-rumped Storm-petrel in the Azores archipelago. *Waterbirds* **22**: 358–366.
- Monteiro, L.R., Ramos, R.A. & Furness, R.W.** 1996. Past and present status and conservation of the seabirds breeding in the Azores archipelago. *Biol. Conserv.* **78**: 319–328.
- Nunes, M.** 2003. Contributo das Vocalizações de Ninho para a Distinção das Populações de Período-frio e Período-quente de Angelito *Oceanodroma castro* (Harcourt 1851). Masters Thesis, Portugal: University of Coimbra.
- Nunn, G.B. & Stanley, S.E.** 1998. Body size effects and rates of cytochrome b evolution in tube-nosed seabirds. *Mol. Biol. Evol.* **15**: 1360–1371.
- Owens, N.J.P.** 1987. Natural variations in  $^{15}\text{N}$  in the marine environment. *Adv. Mar. Biol.* **24**: 389–451.
- Sangster, G.** 1999. Cryptic species of storm-petrels in the Azores? *Dutch Birding* **21**: 101–106.
- SAS Institute.** 2007. *SAS for Windows 9.1.3*. Cary, NC: SAS Institute Inc.
- Scott, D.A.** 1970. The Breeding Biology of the Storm Petrel *Hydrobates pelagicus*. DPhil Thesis, University of Oxford.
- Smith, A.L., Monteiro, L.R., Hasegawa, O. & Friesen, V.L.** 2007. Global phylogeography of the Band-rumped Storm-petrel (*Oceanodroma castro*; Procellariiformes: Hydrobatidae). *Mol. Phyl. Evol.* **43**: 755–773.
- Smithe, F.B.** 1975. *Naturalist's Colour Guide*. New York: American Museum of Natural History.
- Wenink, P.W., Baker, A.J. & Tilanus, M.G.J.** 1993. Hypervariable-control-region sequences reveal global population structuring in a long-distance migrant shorebird, the Dunlin (*Calidris alpina*). *Proc. Natl Acad. Sci. U S A* **90**: 94–98.
- Woolfenden, G.E., Monteiro, L.R. & Duncan, R.A.** 2001. Recovery from the northeastern Gulf of Mexico of a Band-rumped Storm-petrel banded in the Azores. *J. Field Orn.* **72**: 62–65.

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