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ORIGINAL ARTICLE

On the extinction of the Dune Shearwater (*Puffinus holeae*) from the Canary Islands

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Abstract Insular ecosystems have been subjected to severe hardship during the last millennia. Large numbers of insular bird species have undergone local disappearances and full extinctions, and a high number of insular birds are currently categorised as endangered species. In most of these cases, extinction—or endangerment—is in direct relation to the arrival of 'aboriginal' and/or imperialist waves of human settlement. Insular bird extinction events have been documented to have occurred at times corresponding to aboriginal settlement at many archipelagos and isolated islands, such as the Hawaiian Islands, New Zealand, the West Indies or the tropical Pacific Islands. However, no bird extinctions could be attributed to the first settlers of the Canary Islands—until now. The first accelerator mass spectrometer radiocarbon (^{14}C) dating of collagen from a bone of the Dune Shearwater *Puffinus holeae* (3395 ± 30 year BP), an extinct bird from the Canary Islands, indicates a late Holocene extinction event. This relatively recent date, together with some features of this bird (large body size, breeding areas situated at very accessible places) and the absence of its bones from the entire archaeological record suggests that the extinction occurred close to the time that the first human settlement occurred on the islands.

Keywords AMS ^{14}C · Canary Islands · Dune Shearwater · Extinction · *Puffinus holeae*

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Introduction

A high number of local and total extinctions of seabirds have occurred on islands and archipelagos around the world (see Olson and James 1982; Quammen 1996; Worthy and Holdaway 2002; Rando 2003; Steadman 2006). In addition, many of the remaining seabirds on these islands are considered to be endangered at the species or population level (IUCN 2007).

In most cases, extinction—or severe decimation—is directly related to the arrival of 'aboriginal' and/or imperialist waves of human settlers (Olson and James 1982; Quammen 1996; Worthy and Holdaway 2002; Steadman 2006). On the Canary Islands, both types of settlement waves have occurred: the 'aboriginal' human settlers (known as 'Guanches') arrived from northwest Africa some time before 2000 years ago (Navarro et al. 1990; Atoche et al. 1995), while the imperialist wave consisted of Europeans who began to colonize the islands during the early fourteenth century (Castellano and Macías 1997). Although the occurrence of insular bird extinctions in aboriginal times has been documented elsewhere in the world (e.g., Hawaii, New Zealand and other Pacific Islands; Olson and James 1982; James 1995; Worthy and Holdaway 2002; Steadman 2006), no bird extinctions have been definitely attributed to the first settlers of the Canary Islands—until now.

Four species of the genus *Puffinus* are known as breeders on the Canary Islands: the Manx Shearwater *P. puffinus*, Little Shearwater *P. baroli*, Lava Shearwater *P. olsoni* and Dune Shearwater *P. holeae*. The former two are extant species, while the last two are extinct taxa.

The Lava Shearwater was intermediate in size between the Little and Manx Shearwater (170–225 and 375–459 g, respectively; Snow and Perrins 1998), whereas the Dune Shearwater was intermediate between the Manx and Cory's Shearwater *Calonectris diomedea* (800–1,100 g; Snow and Perrins 1998).

Both extinct species inhabited the Eastern Canary Islands (Lanzarote, Fuerteventura and surrounding islets, Fig. 1; McMinn et al. 1990; Walker et al. 1990) and had very different breeding behaviours. Bones of the Lava Shearwater are abundant in caves located in lava fields (known locally as 'malpaíses') (McMinn et al. 1990), whereas remains of the Dune Shearwater, including egg shells and bones of young individuals, are frequently found in several dune fields (known locally as 'jables') (Walker et al. 1990; Michaux et al. 1991; Sánchez Marco 2003). Material of the Dune Shearwater (13 bones) has also been recorded at the Mousterian levels (levels 2–4) and at an as yet undated upper level (level 1, yielding mixed materials belonging to different periods) of Figueira Brava, a cave located on the west coast of the Iberian Peninsula (Mourer-Chauviré and Antunes 2000).

Similar to their extinct fellow *Puffinus* species, the two extant species have different breeding areas. The Little Shearwater breeds on islets and inaccessible cliffs, whereas the Manx Shearwater favours remote scarped hills in laurel forests that are sometimes several kilometers inland and up to 1000 m a.s.l. (Martín and Lorenzo 2001). Both extant species are considered to be endangered species (EN) under Canarian Islands Law and according to International Union for Conservation of Nature (IUCN) criteria (Martí and Del Moral 2003).

The extinction of the Lava Shearwater took place during the last Millennium. Bones of this species bearing evidence of human consumption (i.e. cutting and burning marks) are a common find in archaeological sites of Fuerteventura (Rando and Perera 1994). The overlap of the temporal interval for the last occurrence of this species (thirteenth to fifteenth century) and the first European presence at the archipelago suggests an association between these events (Rando and Alcover 2008). Walker et al. (1990) and Mourer-Chauviré and Antunes (2000) propose that the extinction of the Dune Shearwater could have been human mediated, but until now no bones of this species were known from the Canarian Holocene, not even in archaeological contexts (see also Sánchez Marco 2003). The aim of our study was to explore the chronology and more probable causes of extinction of the Dune Shearwater.

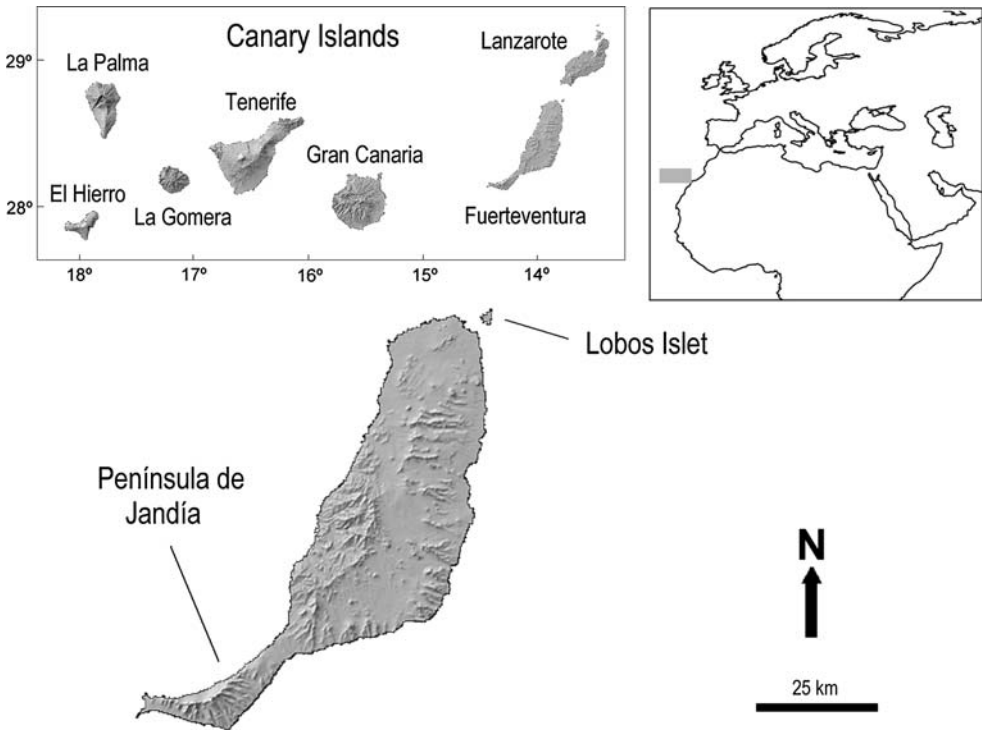

Fig. 1 Map of the Canary Islands showing the location of Lobos Islet and Península de Jandía at Fuerteventura

Materials and methods

Palaeontological prospection of the western Canary Islands in a search for vertebrate extinction events resulted in the detection of a humerus of Dune Shearwater of very recent aspect at the surface of the top of a little hill on the islet of Lobos (north of Fuerteventura Island; Figs. 1 and 2). The collagen of this bone was extracted at the Laboratory of the Royal Institute for Cultural Heritage (Brussels, Belgium) and directly dated for radiocarbon (^{14}C) by accelerator mass spectrometry (AMS).

The ^{14}C age is expressed as 2σ intervals (i.e., $p = 95.45\%$), and its interpretation is based exclusively on the extreme values of this interval (in order to have a $p > 95.45\%$ indicating that the true age of the dated material is more recent than the lower extreme value of the 2σ interval and, independently, it is more ancient than the upper extreme value of the 2σ interval) (see Tuggle and Spriggs 2000; Alcover et al. 2001; Zilhâo 2001; Ramis et al. 2002; Bover and Alcover 2003; Rando and Alcover 2008). Dates derived from the calibration of radiometric results are reported here as 'cal (calendar) year BC'.

Radiocarbon samples from species that obtain their carbon from a source (or reservoir) other than atmospheric carbon, such as seabirds, will yield radiocarbon dates that are excessively old and require the application of a correction factor. The average difference between the radiocarbon date of a terrestrial bone and a marine sample is about 400 radiocarbon years (Stuiver and Braziunas 1993).

The ages were calibrated using the software program OxCal v4.0 (Bronk Ramsey 2006), a marine ^{14}C calibration curve and a marine reservoir effect of 400 years. We also present a reservoir correction of $\Delta R = 275 \pm 67$ derived from the available closest marine samples to the Canary Islands (four samples from Algarve, Portugal, with a mean reservoir value of 630 years). Reservoir corrections for the world oceans can be found at the Marine Reservoir Correction Database (http://calib.qub.ac.uk/marine/).

Fig. 2 Humeri of *Puffinus holeae* from Isla de Lobos (**a**) and Istmo de la Pared, Fuerteventura (**b**, **c**). *Bar*: 4 × 1 cm

Results and discussion

The radiocarbon ages obtained directly on the Dune Shearwater material by AMS are given in Table 1. The date obtained from the bone found on the Islet of Lobos (3395 ± 30 year BP) is around tenfold younger than that obtained previously from an egg shell found at on the Península de Jandía (Fig. 1) (32,100 ± 1,100 year BP; Walker et al. 1990). The new date clearly points to a late Holocene extinction event, excluding climatic factors, as possible causes for this extinction. The 2σ calibration interval of this date, using the marine 04.14C calibration curve, falls inside the first half of the second millennium BC (1409–1230 cal year BC). The lower value (1409 cal year BC) is the most recent available evidence for the occurrence of the Dune Shearwater, and it provides a provisional and minimum estimate for the extinction date. To refine this date, we performed a new calibration using $\Delta R = 275 \pm 67$, which was obtained from the closest available marine samples to the Canary Islands (four samples from Algarve, Portugal, between 566 and 726 years, with a mean reservoir value of 630 years). The new 2σ calibration interval (1159–790 cal year BC) indicates that the 1409 cal year BC age for the last occurrence should be considered as a minimum estimate, with the extinction having occurred very probably later than 1159 cal year BC (Table 1).

This last 2σ calibration interval (1159-790 cal year BC) is very close to the temporal range proposed for the arrival of the House Mouse *Mus musculus* to the Canary Islands, which was introduced by humans (756 cal year BC–313 cal year AD; Alcover et al. 2009), and fits well with the chronology of the first human settlement of the islands (before 2000 years ago; Navarro et al. 1990; Atoche et al. 1995). The closeness between these two temporal intervals could indicate a relation between both events: the aboriginal arrival and extinction of the Dune Shearwater.

Three features of the Dune Shearwater lend support to this hypothesis: (1) Its attractive size (as a food source),

Table 1 Radiocarbon dates of Dune Shearwater *Puffinus holeae*

Reference	Lab code	Site	Sample	C/N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Radiocarbon age (year BP)	2σ calib. interval marine04.14C (cal year BC)	2σ calib. interval marine04.14C $\Delta R = 275 \pm 67$ (cal year BC)
This paper	KIA-36249	Islet of Lobos	Humerus	3.3	−11.51	13.57	3,395 ± 30	1,409–1,230	1,159–790
Walker et al. 1990	–	Jandía peninsula	Egg shell	–	–	–	32,100 ± 1,100	–	–

C/N, Carbon nitrogen ratio

Radiocarbon age (year BP) and three 2σ calibration intervals (cal year BC) are given. The 2σ calibration intervals have been calculated using software program OxCal v4.0, the marine0.4.14C calibration curve and $\Delta R = 275 \pm 67$ (reservoir correction), respectively. Calibration for dates older than 26 kyear BP is not possible

which was between that of the Cory's and Manx Shearwater (thus quite a bit larger than the Lava Shearwater, which was habitually hunted by the aboriginal populations; Rando and Perera 1994; Rando and Alcover 2008); (2) its very accessible breeding areas, on sand dunes, where the remaining members of this species are locally very abundant to this day, especially on the Península de Jandía (Fig. 1) (Walker et al. 1990; Sánchez Marco 2003). (3) *Puffinus* shearwaters are highly philopatric, and their colonies are at high risk from introduced predators. Consequently, this species should have been very vulnerable to aboriginal hunting. Outside of these breeding sandy areas, the occurrence of bones of this species is extremely rare. The location of breeding areas on islets and in locations relatively inaccessible to humans and other alien predators seems to be a crucial factor in explaining the survival of Little and Manx Shearwaters on the Canary Islands (Martín and Lorenzo 2001; Martí and Del Moral 2003).

An analysis of the extinction patterns of land and freshwater birds of the Hawaiian Islands indicates that prehistoric extinctions show a strong bias toward larger body sizes, ground-nesting and flightless species, with nest type being the primary risk factor for extinction. Boyer (2008) clearly identifies two characteristics that are associated with increased aboriginal extinction risk: ground nesting and large body size. Despite the Dune Shearwater being a seabird, based on Boyer's (2008) features, this species would be highly vulnerable to the effects of the first human arrival. The combination of all possible extinction risk features would explain its quick extirpation after human settlement on the islands. No remains of the Dune Shearwater have ever been found at archaeological sites, whereas bones of other extinct species are abundant (i.e. Lava Shearwater, Lava Mouse *Malpaisomys insularis*, or Giant Rat from Tenerife *Canariomys bravoi*; Hutterer et al. 1988, Rando and Perera 1994; Galván et al. 1999; Rando and Alcover 2008; Rando et al. 2008). The current absence of evidence for the coexistence of the Dune Shearwater and the aboriginal population should not be interpreted as a taphonomic marker of an absence of contact. It is possible that the first human settlement led to an extirpation of the Dune Shearwater that was so swift as not to leave any archaeological or palaeontological trace. Data from other archipelagos indicate that aboriginal loss of a species can occur within a very short time interval (a century or less) (e.g. Steadman et al. 2002; Steadman 2006).

In contrast to other extinct endemic vertebrates, such as the Lava Shearwater and the Lava Mouse, which survived until they came into contact with the wave of European settlers (Rando and Alcover 2008; Rando et al. 2008), the data presented here indicate that the Dune Shearwater was still present on the Canary Islands shortly before the first aboriginal arrival. The absence of later evidence supports the hypothesis that this species is a firm candidate for being considered to have been directly eradicated by the 'Guanches' during the early stages of human settlement of the Canary Islands.

Zusammenfassung

Über das Aussterben des Kanarischen Sturmtauchers (Puffinus holeae) auf den Kanarischen Inseln

Insel-Ökosysteme haben während der letzten Jahrtausende stark unter Druck gestanden. Enorme Anzahlen von Vogelarten auf Inseln sind lokal verschwunden oder vollständig ausgestorben, und auch heutzutage sind eine große Anzahl von Vogelarten auf Inseln vom Aussterben bedroht. Die meisten dieser Fälle, - Aussterben oder vom Aussterben bedroht – stehen in direkter Beziehung zu menschlichen Ansiedlungen, - einheimischer oder kolonialer. Von vielen Archipelen und isolierten Inseln, darunter Hawaii, Neuseeland, der Karibik und von tropischen Inseln im Südpazifik, wurde von aussterbenden, endemischen Arten berichtet. Andererseits jedoch konnten bis heute keine Aussterbeereignisse von Vogelarten den ersten Siedlern der Kanarischen Inseln zugeordnet werden. Die erste 14C Radiokohlenstoffdatierung einer heute ausgestorbenen Vogelart von den Kanarischen Inseln datierte Kollagen

eines Knochens des Kanarischen Sturmtauchers auf 3395 ± 30 Jahre vor heute. Dies deutet darauf hin, dass diese Art im späten Holozän ausgestorben ist. Dieses Datum, zusammen mit weiteren Charakteristika dieser Art (große Körpergröße, Brutgebiet sehr zugänglich), und das Fehlen von Knochen in allen archäologischen Aufzeichnungen weist darauf hin, dass der Zeitpunkt des Aussterbens sehr dicht bei dem Zeitpunkt der ersten Besiedlung der Inseln durch den Menschen lag.

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