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Abstract

Insular ecosystems have been highly punished during the last millennia. Huge numbers of local disappearances and full extinctions of insular birds have been recorded elsewhere, and currently a high number of insular birds are categorised as endangered species. In most of these cases, extinction -or endangerment- is in direct relation with the 'aboriginal' and/or imperialist waves of human settlement. Insular bird extinction events, during aboriginal times, have been documented at many archipelagos and isolated islands, such as the Hawaiian Islands, New Zealand, the West Indies or the tropical Pacific Islands. However, in a different way, no bird extinctions could be attributed to the first settlers of the Canary Islands until now. The first accelerator mass spectrometer (AMS) ^{14}C date of collagen from a bone of the Dune Shearwater *Puffinus holeae* (3395 ± 30 yr BP), an extinct bird from the Canary Islands, indicates a late Holocene extinction event. The obtained 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 first human settlement at the islands.

Keywords

Canary Islands - Dune Shearwater - *Puffinus holeae* – AMS ^{14}C – extinction

Introduction

A high number of local and total extinctions of seabirds have occurred on islands and archipelagos around the world (see Olson and James 1982b; Quammen 1996*;* Worthy and

Holdaway 2002; Rando 2003; Steadman 2006). Otherwise, 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 1982b; Quammen 1996*;* Worthy and Holdaway 2002; Steadman 2006). On the Canary Islands, both settlement waves have occurred: the 'aboriginal' (known as "Guanches"), arrived from northwest Africa some time before 2000 years ago (Navarro et al. 1990; Atoche et al. 1995); and the Europeans, who began to colonize the islands in the early 14th century (Castellano and Macías 1997). Although the occurrence of insular bird extinctions in aboriginal times has been documented elsewhere (e.g., Hawaii, New Zealand and other Pacific Islands; Olson and James 1982b; 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: 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 the Manx Shearwater (170-225g and 375-459g respectively, Snow and Perrins 1998), whereas the Dune Shearwater was intermediate between Manx and Cory`s Shearwater *Calonectris diomedea* (800-1100 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 behaviour. Bones of the Lava Shearwater are abundant in caves located at lava fields (known locally as "malpaíses") (McMinn et al. 1990), whereas remains of the Dune Shearwater are frequent at several dune fields (known locally as "jables") (Walker et al. 1990; Michaux et al. 1991; Sánchez Marco 2003). In the latter case, egg shells and bones of young

individuals have been frequently recovered. Material of the Dune Shearwater (13 bones) has been recorded also at the Mousterian levels (levels 2-4) and a not yet dated upper level (level 1, yielding mixed materials belonging to different periods) of Figueira Brava, a cave placed on the west coast of the Iberian Peninsula (Mourer-Chauviré and Antunes 2000).

Like their extinct fellows, 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 forest, sometimes placed several kilometers inland and up to 1000 meters above see level (Martín and Lorenzo 2001). Both extant species are considered as Endangered Species (EN) under the Canarian Islands Laws, and according to IUCN criteria (Martí and Del Moral 2003).

The extinction of the Lava Shearwater took place during the last Millennium. Its bones, showing evidence of human consumption (i.e., cutting and burning marks), are common in archaeological sites of Fuerteventura (Rando and Perera 1994). The overlap of the temporal interval for the last occurrence of this species (13-15th centuries) and the first European presence at the archipelago, suggests a relation between both events (Rando and Alcover 2008). Walker et al. (1990) and Mourer-Chauviré and Antunes (2000) already considered 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 this paper is to explore the chronology and more probable causes of extinction of the Dune Shearwater.

Materials and methods

During a palaeontological prospection of the western Canary Islands in order to investigate vertebrate extinction events, a humerus of Dune Shearwater of very recent aspect was found at the surface of the top of a little hill at the islet of Lobos (north of Fuerteventura Island; Fig. 1 and Fig. 2). The collagen of this bone was directly dated by accelerator mass spectrometer (AMS) ^{14}C at the Laboratory of the Royal Institute for Cultural Heritage (Brussels, Belgium).

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 will appear as 'cal yr BC'.

Radiocarbon samples from species that obtain their carbon from a source (or reservoir) different to atmospheric carbon, such as seabirds, will yield radiocarbon dates 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 program OxCal v4.0 (Bronk Ramsey 2006), a marine ^{14}C calibration curve, and a marine reservoir effect of 400 years. Additionally, we present a reservoir correction of ΔR = 275 ± 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/).

Results and discussion

The currently available radiocarbon ages directly obtained on Dune Shearwater material are given in Table 1. The date obtained from the bone of Islet of Lobos (3395 ± 30 yr BP) is around ten times younger than the previous age obtained from an egg shell at Península de Jandía (Fig. 1) (32100 ± 1100 yr 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 II millennium BC (1409-1230 cal yr BC). The lower value (1409 cal yr BC) is the most recent available evidence for the occurrence of the Dune Shearwater, and it offers a provisional and minimum estimate for the extinction date. To refine this date, we performed a new calibration using a $\Delta R = 275 \pm 67$ 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 yr BC) indicates that the 1409 cal yr BC age for the last occurrence should be considered as a minimum estimate, the extinction having occurred very probably later than 1159 cal yr BC (Table 1).

This last 2σ calibration interval (1159-790 cal yr 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 yr BC – 313 cal yr AD, Alcover et. al. in press), 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 the Dune Shearwater extinction.

Three features of the Dune Shearwater might lend support to this hypothesis: (1) Its attractive size, between Cory`s and Manx Shearwaters [thus quite bigger than the Lava

Shearwater, which was habitually gathered by the aboriginal populations (Rando and Perera 1994; Rando and Alcover 2008)]; (2) Its very accessible breeding areas, at sand dunes, where nowadays remains of this species are locally very abundant, specially at Península de Jandía (Fig. 1) (Walker et al. 1990; Sanchez Marco 2003). (3) *Puffinus* Shearwaters are highly philopatric, and their colonies are at high risk under introduced predators. Consequently, this species should be 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 at islets and in inaccessible places –to humans and other alien predators- seems crucial to explain the survival of the Little and Manx Shearwaters at 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 showed a strong bias toward larger body sizes, ground-nesting and flightless species, 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. In spite of the Dune Shearwater being a seabird, these features derive in a high vulnerability to the first human arrival. The combination of all these facts would explain its quick extirpation after human settlement on the islands. In spite of the intensive field work developed in the last decades, 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 so swift as for not to leave any

archaeological or palaeontological trace. Data from other archipelagos indicate that aboriginal loss of species could have occurred within a very short time interval (a century or less) (e.g., Steadman et al. 2002; Steadman 2006).

In an opposite way to other extinct endemic vertebrates, like the Lava Shearwater and the Lava Mouse, that survived until the European contact (Rando & Alcover 2008; Rando et al. 2008), the data presented herein indicate that the Dune Shearwater was still present on the Canary Islands shortly before the human arrival. The absence of later evidence promotes this species as a firm candidate to be considered as 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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The authors declare that all the works performed during this project comply with current Spanish laws

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

Figure 2. Humeri of *P. holeae* from Isla de Lobos (A) and Istmo de la Pared, Fuerteventura (B, C). Bar: 4 x 1 cm

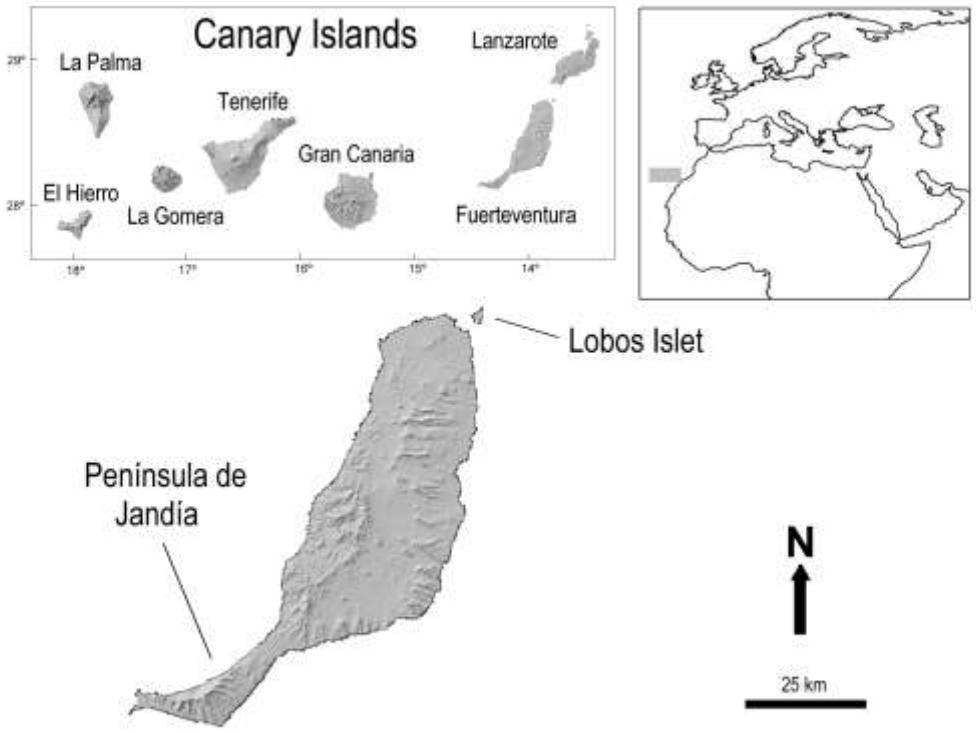
Canary Islands
La Palma
Tenerife
Lanzarote
Gran Canaria
El Hierro
La Gomera
Fuerteventura
29°
28°
18°
17°
16°
15°
14°
Lobos Islet
Peninsula de
Jandia
N
25 km

Table 1. Radiocarbon dates of dune shearwater (*Puffinus holeae)*. Radiocarbon age (yr BP) and three 2σ calibration intervals (cal yr BC) are given. The 2σ calibration intervals have been calculated using intcal04.14C, marine04.14C calibration curve and ΔR = 275±67, respectively. C/N, carbon nitrogen ratio; Rc, carbon recuperation rate. 1, this paper; 2, Walker et al. 1990. Calibration for dates older than 26 kyr BP is not possible.

Ref	Lab code	Site	Sample	C/N	$\delta^{13}C$ (o/oo)	$\delta^{15}N$ (o/oo)	Radiocarbon age (yr BP)	2σ calib. interv. marine04.14C (cal yr BC)	2σ cal marin ΔR = (cal
1	KIA-36249	Islet of Lobos	humerus	3.3	-11.51	13.57	3395±30	1409-1230	115
2	-	Jandía peninsula	egg shell	-	-	-	32100±1100	-	