

Short communication

Evidence for a second western Palaearctic seabird extinction during the last Millennium: the Lava Shearwater *Puffinus olsoni*

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Among western Palaearctic seabirds, only the Great Auk *Pinguinus impennis* is known to have become extinct in the past 1000 years (Fuller 2000). There have been no supporting data for other putative historical seabird extinctions in the region. However, bones of the extinct endemic Lava Shearwater *Puffinus olsoni* (McMinn *et al.* 1990) have been found in archaeological sites of unknown age (although presumably dating to before European colonization in the 15th century) on Fuerteventura (Canary Islands, eastern Atlantic Ocean; Fig. 1). Some of these bones were burned, broken and had cut marks, which indicate consumption by humans (Rando & Perera 1994, Fig. 2A,B), but until now no radiocarbon ages have been measured on bone collagen of this species.

The Lava Shearwater was intermediate in size between the Little Shearwater *P. assimilis* and Manx Shearwater *P. puffinus* (170–225 g and 375–459 g, respectively; Snow & Perrins 1998). It was described from materials obtained in Fuerteventuran caves and has been recorded from deposits on Lanzarote, Fuerteventura and adjacent islets (McMinn *et al.* 1990, Rando 2003), its remains being especially abundant in sites in the recent lava fields, known locally as 'Malpaís'.

Understanding the Lava Shearwater extinction requires an accurate chronology of the event, with the most recent date being a key datum (e.g. MacPhee & Flemming 1999). We set out to obtain ¹⁴C ages of samples of Lava Shearwater bones to determine the time of extinction. The ages were measured on samples found in Fuerteventuran caves after

the exploration of several sites in 2006, and on samples curated in the scientific collection of the Departamento de Zoología, La Laguna University (DZUL). Specimens for dating were selected according to the following criteria: (1) unquestionable taxonomic identity, (2) overall quality of bone preservation, (3) stratigraphic position in the deposits, (4) presence of cut marks and (5) putative association with other organic materials. The first direct datings on bone collagen of new material from two caves on Fuerteventura have made it possible to establish a *termini post quem* for the extinction of the Lava Shearwater.

MATERIALS AND METHODS

Two bones were selected to be dated from a pool of potential samples (Table 1). They came from two archaeological sites (Cueva de La Laguna and Cueva de Las Moscas), both at Malpaís Grande, a lava field in the southeast of Fuerteventura Island, in the municipality of Tuineje (Fig. 1). A fragment of femur from the first site and a sternum from the second were dated via accelerator mass spectrometer (AMS) ¹⁴C. Both samples fulfilled our selection criteria 1–3. In addition, on the proximal part, the former has human-made cut marks (criterion 4; Fig. 2B). One of these cuts was deep, with parallel walls, and appears to have been made by a slender metallic knife (J.F. Navarro pers. comm.). This bone was divided, the distal part being used for dating, and the proximal part (with cut marks) being preserved as a voucher specimen. This bone was labelled in its distal part with ink and varnish (Fig. 2B). These products were removed by scraping. Later, the distal site was treated with acetone and hexane in an ultrasonic bath for 5 min, and finally rinsed with water. An infrared image of the

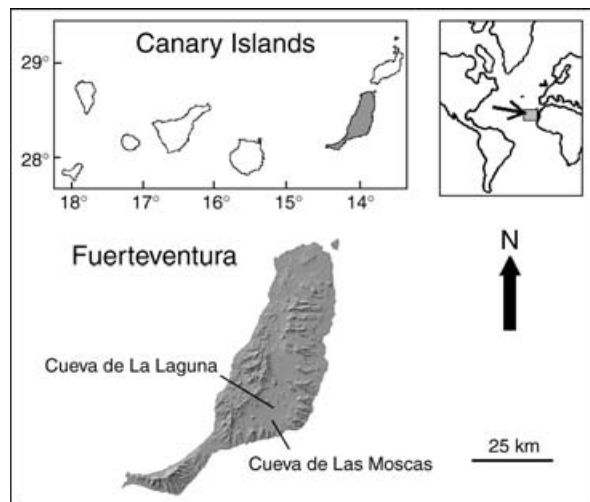


Figure 1. Map of the Canary Islands indicating the location of Cueva de Las Moscas and Cueva de La Laguna in Fuerteventura.

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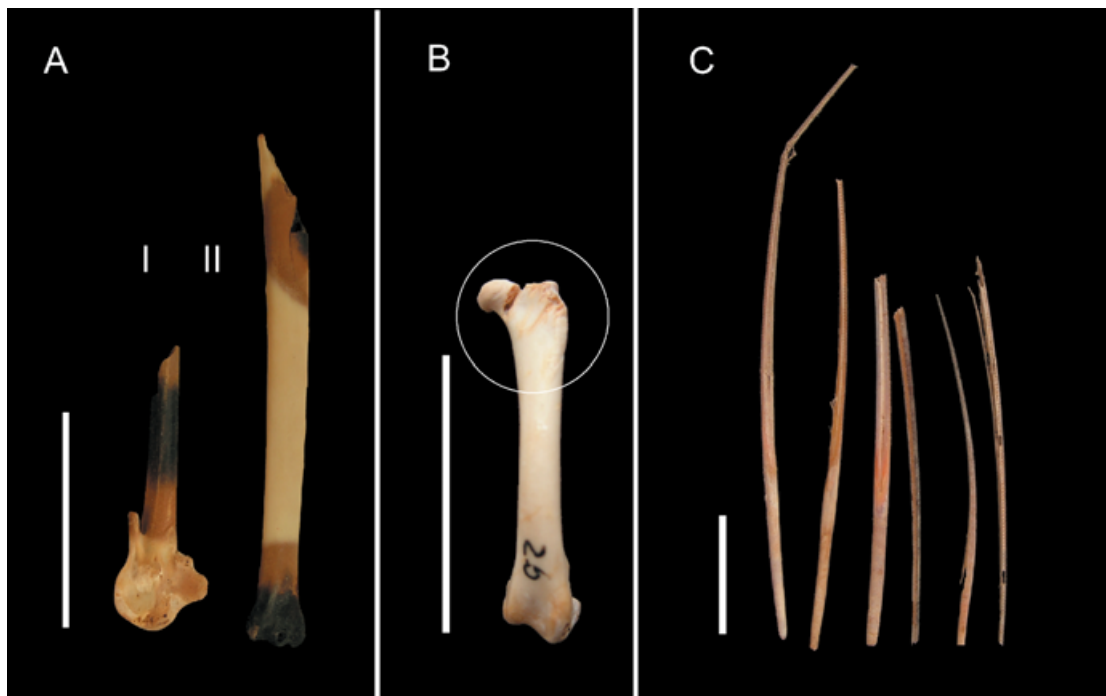


Figure 2. Bird remains from archaeological sites of Fuerteventura. (A) Burned bones of Lava Shearwater *Puffinus olsoni* from Cueva de Las Moscas; (I) proximal fragment of carpometacarpus, ventral view; (II) ulna without proximal fragment, cranial view. (B) Femur of Lava Shearwater from Cueva de La Laguna showing cut marks at the proximal side (circle), cranial view. (C) Feather remains, presumably of Lava Shearwater, from Cueva de Las Moscas. Scale: white vertical line = 2 cm.

Table 1. Sites and description of available bones of Lava Shearwater *Puffinus olsoni*.

Site	Description
Cueva de Las Moscas*	Materials burned, broken with cuts. In association with feather remains. White.
Cueva de La Laguna*	Materials from surface some of them with cuts. White.
Cueva de Las Palomas	Materials from fissures. Brownish.
Cueva Pequeña*	Materials from surface. White.
Malpaís de La Arena	Materials from surface in an old owl nest. Brownish.
Lobos Islet	Materials from surface. Brownish.

*Archaeological site.

collagen yield was taken and no traces of varnish or ink were detected. At Cueva de Las Moscas, some rachides from feathers presumably belonging to Lava Shearwater were found together with the dated sternum (criterion 5; Fig. 2C). Radiocarbon ages were measured at the ^{14}C Laboratory of the Royal Institute for Cultural Heritage (Brussels, Belgium).

The ^{14}C ages are expressed as 2σ intervals (i.e. $P = 95.45\%$), and their interpretation is based exclusively on the extreme values of this interval so as 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 (e.g. Tuggle & Spriggs 2000, Alcover *et al.* 2001, Zilhão 2001, Ramis *et al.* 2002, Bover & Alcover 2003). Calibrated calendar ages derived from the radiometric results are given as 'cal years AD'.

Radiocarbon samples that obtain their carbon from a source (or reservoir) different from atmospheric carbon, such as marine bird bones, will yield a radiocarbon date that is excessively old. Marine samples have a different radiocarbon reservoir from that of the radiocarbon in the biosphere and therefore an accurate radiocarbon age

requires that a correction be made to account for it. The average difference between a radiocarbon date of a terrestrial bone and a marine sample is about 400 radiocarbon years (Stuiver & Braziunas 1993). A reservoir correction must therefore be made to any conventional marine dates to account for this difference.

The ages were calibrated using the program OxCal v4.0 (Bronk Ramsey 2006), using a marine ^{14}C calibration curve, and a marine reservoir effect of 400 years. Additionally, we present a reservoir correction of $\Delta R = 275 \pm 67$ obtained from the closest available marine samples (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 conventional radiocarbon ages measured on the samples are given in Table 2. The most recent date is 1265 ± 25 years BP. Using the marine04.14C calibration curve, this date falls inside the II millennium AD (1060–1220 cal years AD). The lower value (1060 cal years AD) is, at the moment, the most recent occurrence of the Lava Shearwater, and is a provisional and minimum estimate of the extinction date (MacPhee & Flemming 2001). No data exist on the values of the marine reservoir effect at the Canary Islands. The closest region for which data are available is the Algarve (southern Portugal), with four estimates of between 566 and 726 years (mean 630 years) and a $\Delta R = 275 \pm 67$. Using this ΔR value for the marine reservoir correction in the Canary Islands yields more recent calibrated ages than the OxCal 2004 marine ^{14}C calibration curve. Thus, the 1060 cal year AD age for last occurrence should be considered to be a minimum estimate, with the true age of the sample (and the extinction of the species) probably being later than 1270 cal years AD (Table 2).

The femur displaying cut marks provides the earliest age (535–675 cal years AD, using OxCal 2004 marine ^{14}C curve). The sole evidence of metallic artefacts in the aboriginal culture from the Canary Islands (only nine samples, of Roman origin) came from Lanzarote, the closest (11 km) island to Fuerteventura. Stratigraphic information places some of these artefacts to about the beginning of the Common Era (Atoche *et al.* 1995). Although no metallic tools have been found at archaeological sites on Fuerteventura, similar artefacts could have produced the cut on the femur.

A premaxillar bone referable to the genus *Puffinus* was found at the archaeological site of La Aldea, Gran Canaria Island (Alcover & Florit 1989). This bone may be from a Lava Shearwater and could perhaps indicate that aboriginals on the Canary Islands hunted these birds at breeding areas, as is the case with other Procellariidae (Rando *et al.* 1996, 1997).

Table 2. Radiocarbon dates of Lava Shearwater *Puffinus olsoni* bones from two archaeological sites from Fuerteventura.

Lab. code	Site	Sample	Collagen yield (%)	C/N ratio	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	R_C	Conventional radiocarbon age (years BP)	2 σ calib. interv. intcal04.14C (cal years AD)	2 σ calib. interv. marine04.14C $\Delta R = 275 \pm 67$ (cal years AD)	2 σ calib. interv. marine04.14C $\Delta R = 275 \pm 67$ (cal years AD)
KIA-29159	Cueva de las Moscas	Sternum	12.50	2.73	-13.56	+14.65	0.92	1265 ± 25	670–810	1060–1220	1270–1475
KIA-30991	Cueva de La Laguna	Femur	23.29	2.8	-13.61	+13.70	–	1805 ± 30	130–325	535–675	710–1020

Radiocarbon age (years BP) and three 2 σ calibration intervals (cal years AD) are given. The 2 σ calibration intervals have been calculated using intcal04.14C, marine04.14C calibration curve and $\Delta R = 275 \pm 67$, respectively. C/N, carbon nitrogen ratio; R_C , carbon recuperation rate.

People arrived at the Canary Islands from North Africa before 2000 years BP (Navarro *et al.* 1990, Atoche *et al.* 1995). The present work suggests that there was an overlap of more than 1000 years between aboriginal inhabitants and the Lava Shearwater on Fuerteventura. The 2σ interval for the sample from Cueva de Las Moscas (1060–1220 cal years AD) sets it close to the arrival of the first Europeans at the Canary Islands at the beginning of 14th century AD (Castellano & Macías 1997). Thus, the extinction of the Lava Shearwater may be directly linked to this last event instead of the arrival of aboriginals, but it is also likely that the earlier inhabitants had reduced the populations significantly.

Among shearwaters of the genus *Puffinus*, only five Late Pleistocene – Holocene extinctions have been reported: *P. spelaeus* (Holdaway & Worthy 1994) from New Zealand; *P. parvus* from Bermuda (Olson 2004); *Puffinus* undescribed species from 'Eua (Kingdom of Tonga; Steadman 2006), and *P. holeae* (Walker *et al.* 1990) and the Lava Shearwater from the Canary Islands. *P. spelaeus* became extinct early in the New Zealand Polynesian record, its most recent radiocarbon age being c. 600 cal years BP. It was probably exterminated by the introduced Pacific Rat *Rattus exulans* (Worthy & Holdaway 2002). *P. parvus* was apparently exterminated after human arrival in Bermuda (Olson 2004) in the 16th century.

The effect of the introduction of alien mammals on native oceanic islands species is both dramatic and well known (e.g. Quammen 1996, Worthy & Holdaway 2002, Steadman 2006). At present, this continues to be one of the most important causes of biodiversity loss. Species such as the Black Rat *Rattus rattus* and Cat *Felis catus* are among the worst invasive alien taxa (Courchamp *et al.* 2003), especially for seabirds. Both were introduced to the Canary Islands by Europeans. The House Mouse *Mus musculus* was present in Fuerteventura from at least 1730 ± 50 years BP (Carrascosa & López-Martínez 1988), and the 2σ interval for this age (140–420 cal years AD) pre-dates by at least 600 years the last known occurrence of the Lava Shearwater (1050 cal years AD). The House Mouse would have been a relatively inefficient predator of birds the size of the Lava Shearwater, but could have damaged eggs and killed chicks, contributing perhaps to a long-term decline of the shearwater.

The Lava Shearwater from the Canary Islands is therefore the second extinction of a western Palaearctic seabird in the past millennium, the Great Auk being the first. The most probable scenario is that both species were exterminated during the expansion of Europeans. Initial declines may, however, have been precipitated by hunting by earlier inhabitants and perhaps some predation by the House Mouse, which accompanied them to the Canary Islands (Carrascosa & López-Martínez 1988).

Direct hunting is the most probable cause of the extinction of the Great Auk. Despite its wide distribution, it bred historically in only a few localities. The species is likely to

have been reduced significantly by prehistoric hunting, as its bones have been found along much of the Atlantic coast of Europe. On land it was clumsy and slow, and, because it was also large (75 cm), people hunted them wherever they could be reached (Fuller 2000). The small size of the Lava Shearwater and the location of its colonies in remote caves and inhospitable lava fields may have assisted its survival until Europeans reached the Canary Islands. The introduction of alien mammals – especially Black Rats and Cats – appears as the most probable cause of the extinction of the Lava Shearwater, with human hunting a significant contributing factor.

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