


# New insights into the historical translocation of the Algerian hedgehog and pine marten throughout the Balearic Islands (Western Mediterranean): refining the radiocarbon-based chronology

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## Keywords

*Atelerix algirus*; historical ecology; *Martes martes*; species colonisation; species translocation; Western Mediterranean; Zooarchaeology.

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Editor: Andrew Kitchener

Received 29 May 2021; revised 3 September 2021; accepted 9 September 2021

doi:10.1111/jzo.12932

## Abstract

In this paper, we refine the colonisation timeframe of pine marten (*Martes martes*) and Algerian hedgehog (*Atelerix algirus*) to the Balearic Islands synthesising their occurrence records and providing an accurate chronology through new directly <sup>14</sup>C dated archaeological bone samples. The new dates are significantly earlier than previously reported finds; therefore, both cases currently represent the earliest records for the human-mediated translocation of these species in Europe. These new data not only provide further accurate resolution for previous historical translocation hypothesis but also expand the geographical scope throughout the archipelago. The sequence and timing of introduction events are embedded in different historical timeframes. The time of arrival of the pine marten is now established in the early Roman period, a period that supported a huge wave of introduced alien species into the Balearics. For the Algerian hedgehog, the new records further support the hypothesis that the Almohads were responsible for its introduction to these islands. Both examples illustrate how important it is to connect past translocation records to tighter radiometric chronologies through direct dating on bones of the implicated species.

## Introduction

The current distribution of mammalian species has been often mediated, to some extent, by humans. This human involvement is not only a result of the ongoing globalisation process but has also been repeatedly recorded in the past (e.g. Boivin, 2017; Giovas, 2019; Hofman & Rick, 2018). The archaeological record provides an opportunity to uncover not only some features of the past human-animal interactions but also to better understand the role played by ancient cultures in the diffusion of species and the construction of current landscapes. These past movements can be more clearly reflected through the zooarchaeological record of some islands that, by their inescapable geographical characteristics, provide an ideal framework to work with these topics (DiNapoli & Leppard, 2018).

This is especially the case of the Balearic Islands, an archipelago on the western edge of the Mediterranean Sea located in a strategic crossroad used since the late prehistory as a stepping stone between the East-West and North-South trading

routes. Depending on the historical period, the transference of technology, ideas, culture, commodities and animals came from one or another area of the Mediterranean Basin. The Balearic Islands comprises four large islands divided into two groups: the westernmost group of Pityusic Islands (i.e. Eivissa and Formentera) and the easternmost group of Gymnesic Islands (i.e. Mallorca and Menorca). Although there are differences in the geology, ecology and even faunal composition of each of these islands, they share a similar component, that is the introduction of all their extant non-flying terrestrial mammals has been human mediated (Alcover, 1979, 2010).

Currently, one of the aspects most discussed and that is extensible both to islands and the European mainland is whether the faunal introductions occurred constantly along several centuries or were concentrated in short periods irregularly scattered along time and separated by long periods without new faunistic incorporations (i.e. gradual vs. punctuated approaches; Boivin, 2017; Giovas et al., 2012). In the case of the Balearic Islands, the latest research points that after the arrival of the first humans with their transported fauna, there

are at least two waves of multiple introductions before the current one produced by globalisation (e.g. Alcover, 2010). The first took place at the end of the first millennium BC having the Punics (i.e. western Phoenicians from Cartago) and Romans as vectors and their region of origin as the main source for the transfer of new species to the islands. Only in the case of mammals, the initial package of domestic and wild animals already present (i.e. sheep *Ovis aries*, goat *Capra hircus*, pig *Sus scrofa*, dog *Canis familiaris*, cattle *Bos taurus*, wood mouse *Apodemus sylvaticus* and garden dormouse *Elomys quercinus*) now incorporated the cat *Felis catus*, rabbit *Oryctolagus cuniculus*, hare *Lepus granatensis*, black rat *Rattus rattus*, domestic mouse *Mus musculus*, deer *Cervus elaphus*, fallow deer *Dama dama*, lesser white-toothed shrew *Crocidura suaveolens*, weasel *Mustela nivalis*, pine marten *Martes martes*, stone marten *Martes foina* and, probably, the North African white-toothed shrew *Crocidura pachyura*, Algerian mouse *Mus spretus*, horse *Equus caballus* and ass *Equus asinus* (Valenzuela, 2015). When it has been possible to investigate the phylogenetic affiliation of these species, generally the Western Mediterranean is considered the source region, although some genetic inputs from the Eastern part have been claimed for fallow deer (Valenzuela et al., 2016). The second wave of multiple introductions occurred within the Islamic occupation of the islands between the 10th and 13th centuries. This short temporal span involved at least the arrival of the genet (*Genetta genetta*) and Algerian hedgehog (*Atelerix algirus*) from North Africa (Valenzuela, 2015).

Within this framework, there are still many gaps concerning the accurate dating and extent of these two identified ancient episodes of introductions. For some species (i.e. equids, cats and rats), there are only available circumstantial data pointing to its relative time of introduction. The limitations of such associations can lead to potential errors, therefore, failing to achieve valid interpretations, as has been illustrated elsewhere (e.g. Lyman, 2012; Valenzuela & Alcover, 2013a; West et al., 2016). Hence, translocation records need to be connected to tighter radiometric chronologies through direct dating of non-native animal remains to establish the sequence and timing of introduction events.

This paper focuses on furnishing new direct  $^{14}\text{C}$  evidence for the introduction to the Balearic Islands of two terrestrial mammals (i.e. pine marten and Algerian hedgehog) that, despite differing in their provenance and arrival time, both represent the earliest records of their human translocation in Europe.

## Materials and methods

### The pine marten

The pine marten (*Martes martes*) is a medium-sized (c. 0.9–2.2 kg) member of the Mustelidae family. It has a slim body, prominent rounded ears and a long tail, with its dark brown fur contrasting with a creamy-yellow throat patch. The European pine marten not only inhabits coniferous woodland such as pine forests but is also found in deciduous and mixed woodlands, as well as scrub (Herrero et al., 2016). The

geographical range of pine marten extends widely in the west and central Palaearctic, across most of Europe, Asia Minor, northern Iran, the Caucasus and in westernmost parts of Asian Russia (Western Siberia). In the Iberian Peninsula, it is found in the northern mountainous strip formed by the Cantabrian Mountains and its foothills in Galicia, and the Pyrenees (López-Martín, 2007). In a large area of Europe, this mustelid lives in sympatry with another closely related mustelid, the stone marten (*Martes foina*), similar in terms of their morphology, feeding and behaviour (Reig, 2007).

In the Balearic Islands, the two species of the genus *Martes* were translocated by humans and have an allopatric distribution (Alcover, 1979, 2010). In Eivissa, the only known mustelid present is the stone marten (*M. foina*), although it is currently considered to be nearly extinct (Delibes & Amores, 1986; Samblás & Martínez, 2015). Conversely, the pine marten (*M. martes*) only inhabits Mallorca and Menorca. The differences in size between the specimens of the Menorcan population and the rest allowed describing the subspecies *M. m. minoricensis*, which also has a more robust face (Alcover et al., 1986). Although archaeological remains of *Martes* sp. have been recorded in other Mediterranean islands (Masseti, 1995), only the Balearic Islands accounts for direct radiometric evidence that supports its historical introduction (Valenzuela & Alcover, 2015). In that study, accelerated mass spectrometry (AMS) direct radiocarbon dates the presence of pine marten in Mallorca in the late Roman period and the stone marten in Eivissa since, at least, the seventh century AD (Valenzuela & Alcover, 2015: 3097). In the case of Menorca, the absence of archaeological remains precludes the timing of this species introduction synchronous to Mallorca. Moreover, the current status of subspecies for the Menorcan pine marten is particularly attractive to establish the introduction event as a proxy for its maximum time divergence.

For these reasons, further efforts were devoted to identifying archaeological bone remains of the Menorcan pine marten. A bone of pine marten was retrieved in So na Caçana (Alaior, Menorca) during the archaeological intervention of 2016 near the Eastern *taula* enclosure. The stratigraphical provenience of the bone was a sedimentary layer (SU 1016) of red sandy-clay soil dated by the cultural material content (i.e. mainly Punic pottery sherds) around the 2nd century BC (Cobos et al., 2016: 22). This specimen constituted the only available bone of the pine marten in Menorca and, according to its archaeological context, could be also evidence for the occurrence of the species prior to the Romans.

Further Marten remains were obtained in Mallorca and Eivissa (see Table S1) but, in both cases, their chronological context was equal to or later than the already attested time of introduction. Consequently, none of these was selected for direct radiocarbon dating.

### The Algerian hedgehog

The Algerian hedgehog is a small mammal (0.3–0.7 kg), with a head–body length of 19–25 cm and a tail length of 2 cm. As a member of the family Erinaceidae, the Algerian hedgehog

closely resembles the European hedgehog (*Erinaceus europaeus* Linnaeus, 1758) but is smaller and has a longer snout, ears and legs. Its face is light in colour, usually appearing to be white, and the legs and head are brown. The underbelly of this animal can vary in colour and is often either brown or white. The upper parts of the body are covered in soft spines, which are mostly white with darker banding, and they are separated in the head by a characteristic bare 'spine parting' about 7 mm wide and 15 mm long (Miller, 1912). Currently, the Algerian hedgehog is distributed across North Africa (Algeria, Libya, Morocco and Tunisia), on the east coast of the Iberian Peninsula, the Canary Islands and some Mediterranean islands such as Djerba, Malta, Mallorca, Eivissa, Formentera and Menorca. It was also introduced in some localities of Southern and Western France but currently appears to be extinct in these areas (Alcover, 2007). The Balearic hedgehog is smaller and paler than its North African counterpart and is recognised as a subspecies, *A. algirus vagans* (Thomas, 1901). The occurrence of *A. algirus* in continental Europe, the Canary Islands and some of the Mediterranean islands is the result of human introduction (Khaldi et al., 2016; Vigne, 1999). The exact dates of most of these introductions are unknown, but in the case of the Canary Islands, it is known that the species was introduced in 1892 (Hutterer, 1983). The species was also introduced in Puerto Rico, from where Peters (1877) described a new hedgehog species, '*Erinaceus krugi*', later synonymised to *A. algirus* (Cabrera, 1928; Hutterer, 1983). Its source region was probably Mallorca, from where there was much human immigration in the second half of the 19th century. The naturalisation of the species in Puerto Rico failed (de Vos et al., 1956: 185).

In Europe, the earliest evidence for the introduction of the Algerian hedgehog comes from Menorca. Morales and Rofes (2008) reported 13 bones, two of which were directly dated by AMS to between the 13th and 14th centuries AD (1289–1398  $2\sigma$  cal AD; see Table 1). The sampled bones were retrieved from Biniai Nou (Menorca – Fig 1), a megalithic tomb of the Bronze Age (Gómez, 2000). Therefore, despite the central chamber being built and used in the Bronze Age, the *A. algirus* remains derived from a natural intrusion occurred after the abandonment of the structure. In any case, these dated bones from Biniai Nou became important, not only because they constituted the oldest dated elements of the Algerian

hedgehog in the Balearic Islands (and in Europe), but also because that timeframe allowed to associate the introduction to the Almohads, a Berber confederation that created an Islamic empire in North Africa, Iberian Peninsula and the Balearic Islands between the second half of the 12th century AD and the early 13th century AD. Despite this evidence, a short temporal gap persisted between the end of the Islamic occupation in Menorca (1202–1287 AD) and the temporal range provided by the radiocarbon dates.

To critically evaluate the causal relationship between the Almohads and the introduction of the Algerian hedgehog in Menorca, we conducted a survey in the rest of the Balearic Islands to target new archaeological records of this species to be directly  $^{14}\text{C}$  dated. As the Almohad occupation of Mallorca (1203–1229) and Eivissa (1188–1235) were shorter and not fully synchronous to the occupation of Menorca, they provide an independent approach to test the early presence of the hedgehog on the Balearic Islands previous to the Catalan conquest of Menorca (1287).

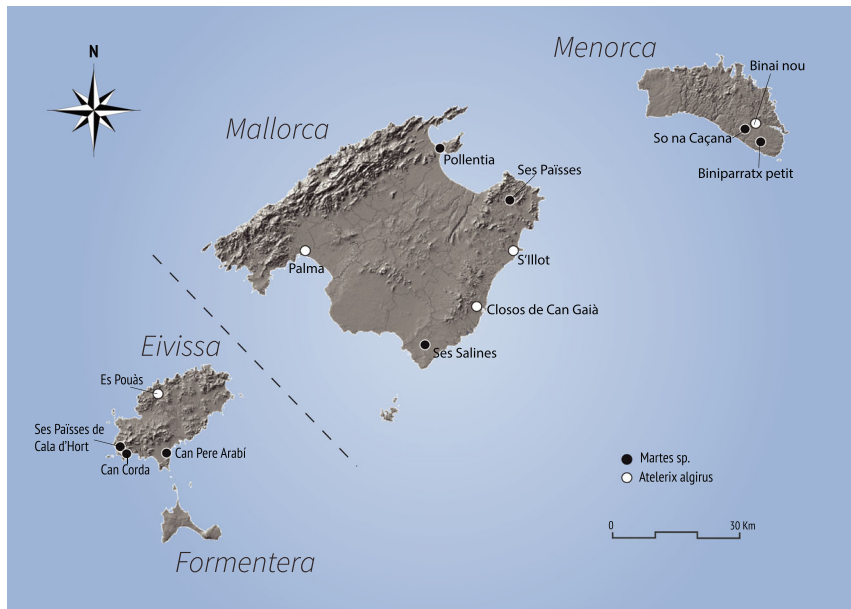
The survey for Algerian hedgehog archaeological remains was performed extensively throughout all the Balearic Islands, but we only attested new finds in the islands of Mallorca and Eivissa. Of all the sites where hedgehog remains were located (Fig. 1, Table S1), we selected one from each island based on those remains that presented the more reliable data of its archaeological context.

From Mallorca, the retrieved *A. algirus* remains came from the archaeological site of S'Illo, a megalithic settlement located on the east coast of Mallorca that was occupied from the Bronze Age to the Late Iron Age, then sporadically until the medieval times (Font & Valenzuela, 2018). The dated bone is a left mandible without teeth that presented some degradation in its surface by the action of the humic acids of the roots (Fig. 2b). It was retrieved in the SU 120, the upper archaeological level in the sequence of the building SN2 of the settlement. The cultural findings inside the stratigraphic unit point to a period from the Late Antique to medieval times, with some postmedieval intrusions (Valenzuela et al., 2019).

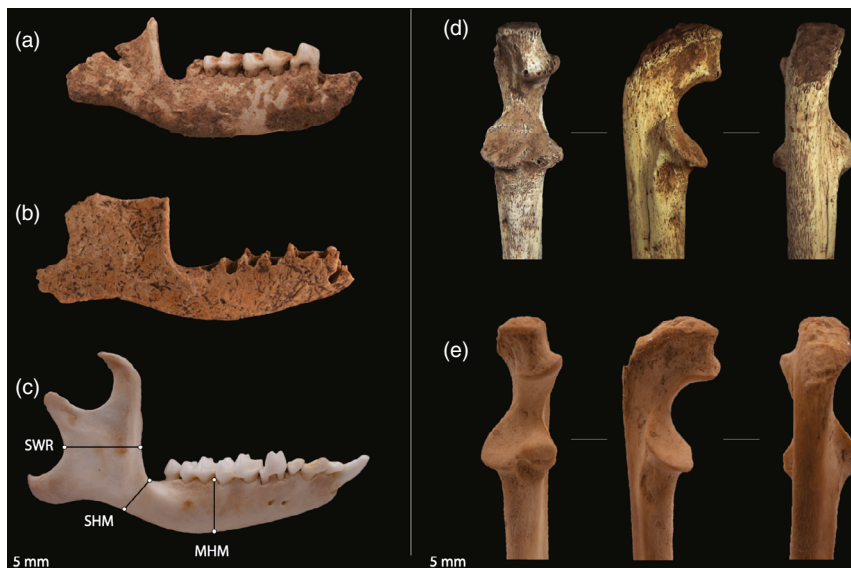
From Eivissa, the only available Algerian hedgehog was a partial right mandible with some preserved teeth retrieved from the excavations of Es Pouàs in Eivissa (Fig. 2a). The site is a karstic sinkhole partially excavated in 1989–1994 (Alcover

**Table 1** Direct accelerated mass spectrometry (AMS) dates of *Martes* spp. and *Atelerix algirus* from the Balearic Islands

Island	Site	Lab Code	Age BP	Cal AD ( $2\sigma$ )	References
<i>Martes martes</i>					
Mallorca	Pollentia	Wk-28569	1792 ± 30	205–353	Valenzuela and Alcover (2015)
Mallorca	Pollentia	RICH-20461	1838 ± 27	125–310	Valenzuela and Alcover (2015)
Menorca	So na Caçana	RICH-24984	1928 ± 30	25–205	Present paper
<i>Martes foina</i>					
Eivissa	Can Arabí	RICH-21400	1358 ± 30	609–774	Valenzuela and Alcover (2015)
<i>Atelerix algirus</i>					
Menorca	Biniai Nou	OxA-10469	634 ± 34	1289–1398	Morales and Rofes (2008)
Menorca	Biniai Nou	OxA-10487	355 ± 75	1424–1795	Morales and Rofes (2008)
Mallorca	S'Illo	RICH-24988	768 ± 28	1223–1281	Present paper
Eivissa	Es Pouàs	RICH-24998	303 ± 29	1495–1653	Present paper



**Figure 1** Locations of the archaeological sites where *Aterlix* and *Martes* remains have been reported. [Colour figure can be viewed at [zslpublications.onlinelibrary.wiley.com](https://zslpublications.onlinelibrary.wiley.com).]



**Figure 2** On the left, Algerian hedgehog mandibles from (a) Es Pouàs; (b) S'illot; compared with (c) reference Mallorcan specimen (IMEDEA-116) with the measurements taken (see Table S2). The specimen from s'illot is illustrated reversed to facilitate the comparison. On the right, anterior, medial and posterior views of (d) pine marten ulna from So na Caçana; compared with (e) reference juvenile pine marten ulna from Mallorca (IMEDEA-108831). [Colour figure can be viewed at [zslpublications.onlinelibrary.wiley.com](https://zslpublications.onlinelibrary.wiley.com).]

*et al.*, 1994; Florit *et al.*, 1989), with very large and complex stratigraphy that goes back to the Pleistocene. In particular, the dated remain of *A. algirus* was located in the square D4 at a depth of 80–100 cm. The relative chronology of this layer is uncertain, but it is clearly posterior to the first human arrival to Eivissa (i.e. c. <2350 cal BC; see Bover *et al.*, 2016). The bone was partially embedded in a layer of calcareous concretion giving it a very ancient appearance.

## Results

Collagen extraction was performed following Longin's (1971) method. All samples were transformed into graphite using the automatic graphitisation device AGE (Boudin *et al.*, 2019; Némec *et al.*, 2010; Wacker *et al.*, 2010), and <sup>14</sup>C concentrations were measured by AMS at the Royal Institute for Cultural Heritage (Brussels; Boudin *et al.*, 2015). Uncalibrated <sup>14</sup>C

results are expressed in BP (Before Present) according to Stuiver and Polach (1977). Calibration analysis was executed with the Oxcal 4.4 programme (Bronk Ramsey, 2009) using atmospheric data from Reimer *et al.* (2020). All bone collagen samples fell within the atomic C:N ratio range (2.9–3.6) regarded as uncontaminated (Ambrose, 1990; DeNiro, 1985).

Table 1 summarises the new and already existing direct radiocarbon dates for *Martes* spp. and *A. algirus* of the Balearic Islands. In the case of the dated pine marten from So na Caçana (RICH-24984), the obtained date (1928 ± 30 BP; 25–205 2σ cal AD) precedes the previously available evidence from Mallorca, whereas the new radiocarbon dates of the Algerian hedgehog from Mallorca are slightly earlier than the previously published radiocarbon date (OxA-10469) from Menorca. For Eivissa, the bone sample from Es Pouàs (RICH-24998) only attests that this species was present on the island at least from the 15th–17th century AD (1495–1653 2σ cal AD).

## Discussion

Until 15 years ago, the time of introduction of the pine marten and the Algerian hedgehog in the Balearic Islands was completely unknown. In absence of radiocarbon and stratigraphical evidence, both species were considered either a very early natural immigration previous to the human arrival (e.g. Colom, 1957; Comte Sart, 1968) or a very late anthropogenic translocation probably occurred in Modern times (Alcover, 1979). The recent revision and direct dating of archaeological remains of these species have provided a new perspective on their translocation events. In the case of *Atelerix*, the remains dated from Biniai Nou on the island of Menorca attested that the arrival of this hedgehog should be established around the 13th–14th centuries AD (Morales & Rofes, 2008). Additionally, the arrival of the pine marten in Mallorca is situated around the 2nd–3rd centuries AD and the stone marten in Eivissa in the 7th century AD (Valenzuela & Alcover, 2015).

In both cases, the cross-reference of new archaeological data with the phylogeographic information allowed the association of each translocation event with a significant turning point in the history of the Balearic Islands. Nonetheless, the lack of available data at that moment left some gaps and unanswered questions in relation to these historical translocations. For example, the open possibility that these events occurred simultaneously throughout the islands, reinforcing the idea that they were culturally motivated transportations. In the same vein, the chronological resolution achieved at that time still left room for improvement.

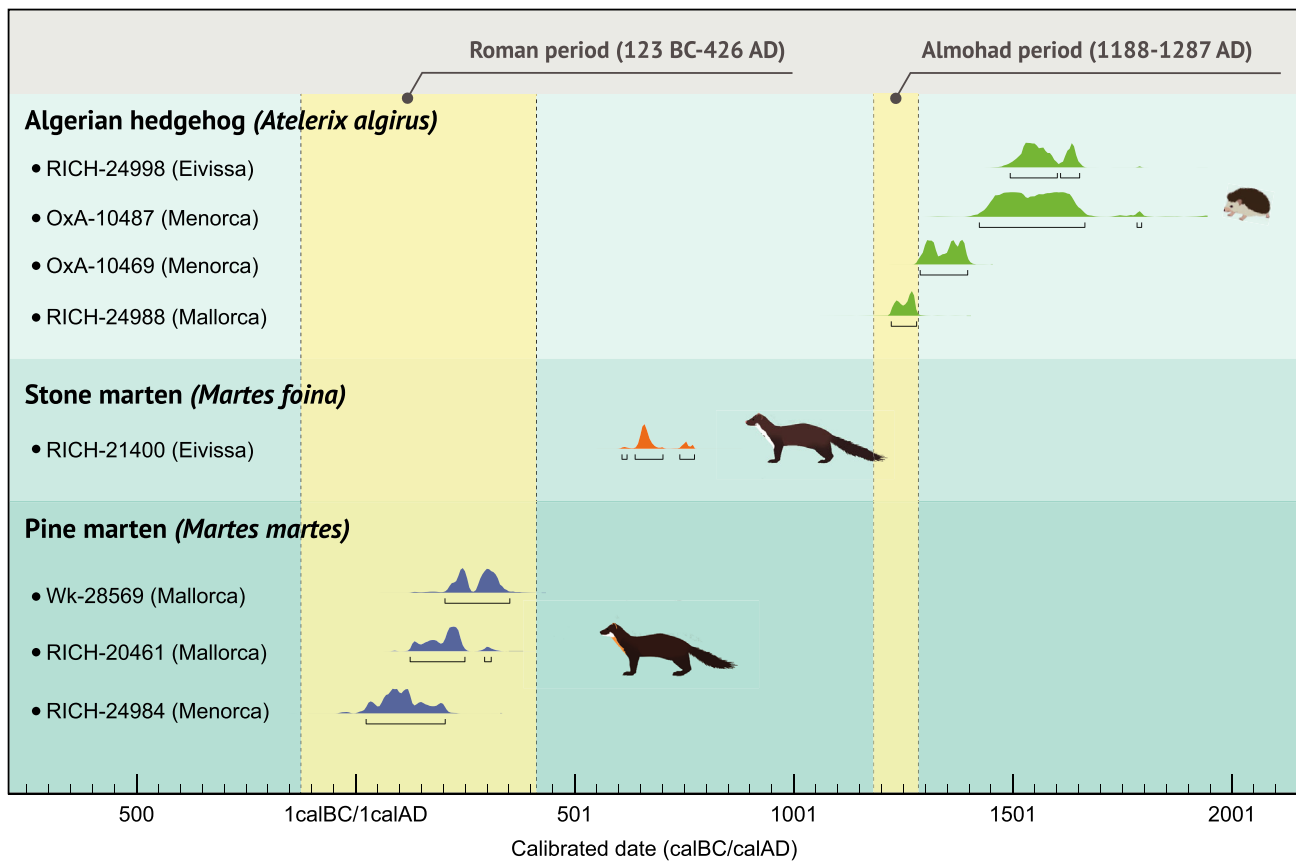
For example, Valenzuela and Alcover (2015) suggested that the introduction to the Balearic Islands of two species of the genus *Martes* took place during Roman times as part of a series of non-native species introduction events. However, the obtained data for *M. martes* pointed to a late introduction (2nd–4th cal. AD) within the long-time span of the Roman presence on the islands (2nd c. BC–5th c. AD). This in turn set a temporal gap of up to 200 years with the documented wave of multiple introductions (3rd c. BC–1st c. AD) (Valenzuela, 2015). With the dated specimen of So na Caçana, this

chronological offset is reduced and becomes more plausible to incorporate the martens as part of the wave of species translocated at the end of the first millennium BC (Fig. 3). New findings of fallow deer, camels, donkeys, mules and Egyptian mongoose in the Iberian Peninsula seems to be in line with this (Detry *et al.*, 2018; Lepetz & Yvinec, 2002; Pigièrre & Henrotay, 2012; Valenzuela *et al.*, 2016). Despite in some cases such as the Egyptian mongoose (Barros *et al.*, 2021) and donkey (Cardoso *et al.*, 2013), the new evidence indicates that this would not have been the first time that these species were introduced in the Iberian Peninsula.

The increasing frequency of species translocated and the propensity for these to occur over a relatively short period seems to be linked to the socio-cultural context of that moment. In the Mediterranean, the period from the Late Iron Age and the Early Roman period is marked by increased agricultural production, urban development and commercial interconnectivity fostered through the shipping routes opened by Phoenicians/Punics, Greeks and Romans (e.g. Hodos, 2009; Horden & Purcell, 2000). In this way, the extraordinary levels of mobility, interaction, commerce and cultural exchange evidenced in the historical and archaeological records of that period are the most probable driving factors for that ‘protoglobalised’ era (Boivin, 2017).

In the case of *Atelerix*, Morales and Rofes (2008) argued, with the support of multiple circumstantial data, that the most likely scenario for the introduction of the Algerian hedgehog was during the brief Almo had period (1202–1287 AD). The mean of the calibrated <sup>14</sup>C ages of OxA-10469 (634 ± 34 BP; 1289–1398 2σ cal BC; Morales & Rofes, 2008) and RICH-24988 (768 ± 28 BP; 1223–1281 2σ cal BC; present paper) differs 90 years, pointing to greater antiquity for the new sample. Both radiocarbon dates display a small degree of overlap, but they are not coeval, as the OxCal R\_Combine function indicates ( $\chi^2$ :  $T = 9.2$ ,  $< 3.8$  for d.f. = 1). This offers additional robustness to the hypothesis of an Almo had introduction of the species. The new radiocarbon date constitutes not only the earliest evidence of *A. algirus* in the Balearics but also in Europe (Fig. 3). Furthermore, this new evidence strongly supports a potential causal relationship between the distribution of the Algerian hedgehog in Europe and the expansion of the Almo had during the 12th–13th century AD.

The arrival of the Algerian hedgehog to the Balearic Islands belongs to the second wave of multiple introductions initiated during the early medieval period. Following the Muslim conquest of Iberia (711 AD), the Balearic Islands were conquered in 902 AD. This conquest had profound consequences for the archipelago, not only because of the arrival of a new human contingent but also by implementing new ways to exploit the environment such as the irrigation systems and the establishment of an agricultural economy based on orchards and wasteland (Kirchner, 2009; Tello *et al.*, 2018). This new era of Balearic history had four major phases. The Balearic Islands administratively depended on the Emirate/Caliphate of Córdoba (902–1010 AD) in the first phase, followed by a period of a series of independent-ruled municipalities called *taifa* (1010–1116 AD) and the arrival of two successive North African dynasties: the Almoravids (from 1116 to 1188 on Eivissa, to



**Figure 3** Chronology of introduction of *Martes* spp. and *A. algirus* on the different islands of the Balearics based on calibrated AMS radiocarbon  $^{14}\text{C}$  dates (see Table 1). Relevant historic periods are shaded in a light-yellow colour. [Colour figure can be viewed at [zslpublications.onlinelibrary.wiley.com](https://zslpublications.onlinelibrary.wiley.com).]

1202 AD on Menorca and to 1203 AD on Mallorca) and the Almohads (from 1188 to 1235 in Eivissa, from 1203 to 1229 in Mallorca, and from 1202 to 1287 in Menorca).

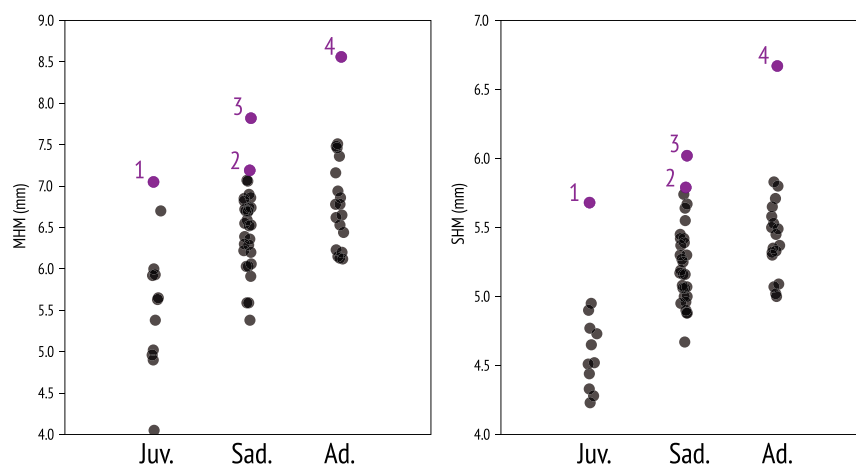
In the last years, the evidence pointing the Almohads as active agents in the translocation of African faunas into Europe has grown. For example, the introduction in the Iberian Peninsula of dromedaries (*Camelus dromedarius*) as beasts of burden for the armies (Morales *et al.*, 1995) and the genet (*Genetta genetta*) has long been associated with the Almohad Berber dynasty (Delort, 1978). The latter case relies on solid ground as it has been supported by direct radiocarbon dating (Delibes & Carrasco-Rus, 2015; Morales, 1994) although recent evidence demonstrates that previous introduction events took place (Delibes *et al.*, 2019). Moreover, the new dated finds of *A. algirus*, taken together with dates from a previous study (Morales & Rofes, 2008), constitute an additional species within the large-scale animal translocation phenomenon of that period.

Another aspect worth considering is the extent of dispersion. All the current terrestrial non-volant mammal fauna of the Balearic Islands has been introduced through human intervention, whether intentional or unintentional. In the case of unintentional translocations, these are accidental introductions in which an animal can stow away on a boat and disembark in a

new place. This is especially true for rodents, but for species such as the pine marten and the Algerian hedgehog, it is very unlikely that they went unnoticed as stowaways. Furthermore, the socio-cultural values and human uses documented for these species are well known (e.g. MacKinnon, 2014), making their historical dispersal strongly linked to intentional human movement.

However, one way to clearly define whether that process was truly intentional is examining whether it was temporally and geographically consistent. In the two cases studied here, the new data provide further support that the introduction of each species was intentional and relatively simultaneous throughout the Gymnesic Islands (i.e. Mallorca and Menorca). The odds that each introduction event happened in isolation and by chance in both islands are very remote. In the case of Eivissa, the introduction of the stone marten and Algerian hedgehog are currently documented slightly later than the rest of the Balearic Islands. However, in this case, we presume that this time lag has more to do with the sparse zooarchaeological record available than a true historical phenomenon.

The introduction of mammals to islands often undergo body size evolutionary changes as a result of the adaptation of the species to the new ecological conditions (e.g. Case, 1978; Foster, 1964; Lomolino, 2005). Although most island body size



**Figure 4** Morphometric analysis of mandibles of *A. algirus*. MHM: maximum height of the mandible; SHM: smallest height of the mandible (see Fig. 2C; Table S2). Shaded in grey extant Algerian hedgehog specimens from the Balearic Islands. In purple, the archaeological specimens of (1) Santa Bàrbara; (2) S'Illot; (3) Can Oleo; (4) Es Pouàs. [Colour figure can be viewed at [zslpublications.onlinelibrary.wiley.com](https://zslpublications.onlinelibrary.wiley.com).]

changes among mammals are reported for herbivores, predators are not excluded from such evolutionary changes. Introduced predators not only suffer body changes as a result of their island adaptation, but they are also key drivers of the evolution of island ecosystems: concurrently with the body change in an introduced predator, there is an ecosystemic change to reach a new equilibrium in which the new predation pressure is incorporated. Although there is a record of body size change in predators once achieved the new ecosystemic equilibrium, little information exists on the period necessary to achieve the new body size on islands, especially in mammals.

The new  $^{14}\text{C}$  ages presented herein allows exploring the pace of change at which the insular evolutionary body occurred. Assuming North Africa as the source region for the Algerian hedgehog of the Balearic Islands (e.g. Khaldi et al., 2016), the current presence on these islands of populations of small-sized individuals suggests a local evolutionary body size reduction. Morphometric analysis was performed to explore this feature (Table S2), and three linear measurements were taken (Fig. 2c). Of them, only the MHM and SHM have been considered here, as they present a lower coefficient of variation (Simpson et al., 1960). Partitioning the results by tooth wear and eruption age classes (see Table S2), the size of the four archaeological specimens (including the two here dated) falls above the range of measurements of the extant population of *A. algirus vagans* of the Balearic Islands (Fig. 4). In spite of the small sample of ancient *A. algirus*, these results seem to indicate that size reduction did not take place just after introduction, rather it was delayed at least two centuries.

In the case of the pine marten, the specimen of So na Caçana belonged to a juvenile individual in the initial growth phase, thereby precluding any in-depth morphometric analysis. However, despite its lesser degree of osteological development, the archaeological specimen has a slightly wider breadth across the coronoid process (BPC = 6.38 mm; after Von den Driesch, 1976: 79) than the extant comparison Mallorcan specimen IMEDEA-108831 (BPC = 6.11 mm). This suggests (but

definitely does not prove) that the larger body size of the extant pine marten population *M. martes minoricensis* could have already been achieved at the time when the archaeological specimen was dated (1st–2nd c. AD). Further research is needed to confirm this.

Body size is a plastic feature derived by different selection pressures, such as climate, availability of resources, predation and concurrence pressures. The combined effect of all the potential drivers on the body size changes is still poorly understood. On islands, body size changes are one of the most conspicuous results of island evolution (Lomolino, 1985), which can occur immediately after the colonisation (usually in a fast and abrupt way; e.g. Gray et al., 2015; van der Geer, 2018; van der Geer et al., 2018) or can be delayed and started long after the colonisation event (e.g. Sanders & Reumer, 1984). The body size change in *Hemorrohis hipocrepis* on Eivissa and *Lampropeltis californiae* on Gran Canaria are recent examples of an abrupt body size change occurring immediately after the colonisation event (Fisher et al., 2019; Hinckley et al., 2017). According to the available data, the body size of the garden dormouse (*Eliomys quercinus*) and the wood mouse (*Apodemus sylvaticus*) seems to have been unaltered on Mallorca and Menorca presumably from their first archaeological records (c. 2000 BC) until the introduction of the weasel on the islands. Only since then both rodents exhibited a very quick body size reduction (Sanders & Reumer, 1984; Valenzuela & Alcover, 2013b). Although the in-depth examination of the underlying causes of these body size changes is beyond the scope of this paper, it is interesting to note that the attested delayed start in the case of the Algerian hedgehog seems to fit into the reference pattern of these rodents (i.e. a change preceded by a long stasis).

## Conclusions

The presented Algerian hedgehog and pine marten remains were recovered in allegedly much older deposits, several

centuries than the previous obtained dates and their accurate dating was only possible through direct AMS analysis. Given the tiny bone size of both species, it is not surprising to find that these remains were, in fact, later intrusions in the archaeological contexts from where they were retrieved. This is true even though neither the martens nor the Algerian hedgehogs are burrowing species. Consequently, this paper emphasises that caution should be applied when interpreting undated, putatively ancient animal bones, independently of their size, physiology and ethology. Increasing awareness has already been attested for other introduced mammals to the continent (e.g. Delibes & Carrasco-Rus, 2015; Giovas, 2019; Valenzuela & Alcover, 2013).

Both examples illustrate, in a generalised way, a translocation event embedded in different historical timeframes (Roman and Islamic conquests), with opposite dispersal directions (southward for the pine marten and northward for the Algerian hedgehog) but with a common output: the successful human-mediated introduction of a new non-native species. Unravelling the timing and mode of dispersal of these processes is only possible through a rigorous and detailed analysis of the remains of long-term records, such as the zooarchaeological record, providing an explanation for why, when and where societies deliberately chose to relocate animals.

## Acknowledgements

This work was funded by the Agencia Estatal de Investigación (Ministerio de Economía, Industria y Competitividad/Fondo Europeo de Desarrollo Regional (FEDER) as part of the research project: ‘Cambios holocénicos en la biodiversidad animal de las islas de la Macaronesia y de Baleares. II (CGL2016-79795-R)’. AV was funded by the postdoctoral contract Vicenç Mut postdoctoral fellowship (CAIB PD/022/2019). The archaeological excavation carried out in So na Caçana has been financed by the Consell Insular de Menorca. Finally, we would also like to express our gratitude to Joan Ramon (Ses Païsses de Cala d’Hort), Alberto Dorado (So na Caçana), and Bernat Font (S’Illot) by allowing us access to the dated specimens.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Archaeological specimens of pine marten and Algerian hedgehog surveyed. In dating methods, ‘Indirect’ refers to the fact that the remains were dated indirectly by association through the typology of the ceramic contained in the same context.

**Table S2.** Age and linear metric results of *Atelerix* mandibles. Three age classes based on eruption of teeth and tooth wear stages have been identified: Juvenile (Juv.), Subadult (Sad.) and Adult (Ad.). The identification of juveniles is based on the presence of deciduous teeth. The remaining two age categories are based on the tooth wear stages as defined by Kahmann & Vesmannis (1977): subadults integrates stages I-III and adults, stages IV-V. The measurements taken were the maximum height of the mandible (MHM), the smallest height

of the mandible, at the level of the mandibular ramus meets coronoid process (SHM), and the smallest width of the mandibular ramus (SWR) as are illustrated in the Fig. 2c. Asterisk marks the archaeological specimens

**Table S3.** Summary statistics of the measurements taken on *Atelerix* mandibles. CV, coefficient of variation.

**Figure S1.** Summary statistics of the measurements taken on *Atelerix* mandibles. CV, coefficient of variation.

**Appendix S1.** Supplementary references.