Both introduced and extinct: the fallow deer of Roman Mallorca

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Abstract

The archaeological record concerning the distribution and timing of fallow deer translocation across the Mediterranean has been growing in the last years. This knowledge has provided important insights into the movement, trade patterns and ideology of past societies. Unfortunately, the dispersal of fallow deer to the western part of the Mediterranean is insufficiently understood. To fill this gap, this article presents the results of a multidisciplinary investigation (combining the zooarchaeological evidence with AMS radiocarbon dating, isotope analyses and preliminary aDNA results) from a set of remains recovered from archaeological sites on Mallorca (Balearic Islands, Western Mediterranean). The purpose is to explore the timing, circumstances and meaning of the fallow deer's introduction to this island, as well as their subsequent management and extirpation. The results of these proxies confirm the arrival of the fallow deer during the Roman period and, after a short expansion with the establishment of *vivaria*, its disappearance after the Byzantine period.

Keywords: Fallow deer, Roman, AMS dating, Stable isotopes, Genetics, Osteometrics, Western Mediterranean.

1. Introduction

All islands in the Mediterranean have witnessed dramatic shifts in the composition of their mammalian inhabitants, with humans representing the greatest agents of change (Vigne and Alcover, 1985; Dobson, 1998; Masseti, 2009; Vigne et al., 2014). Since the Neolithic, the actions of people have, directly or indirectly, resulted in the eradication of some autochthonous species and the introduction of other allochthonous fauna (Vigne and Alcover, 1985; Groves and Di Castri, 1991; Vigne et al., 2014). Human-instigated species turnover is seen no more clearly than in the Balearic Islands. Across the archipelago the endemic mammalian fauna – which consist solely of *Myotragus balearicus*, *Hypnomys morpheus* and *Nesiotites hidalgo*, inhabiting exclusively Mallorca, Menorca and surrounding islets – was brought to extinction shortly after the arrival of farming communities at the end of the third millennium BC (Alcover, 2008; Bover and Alcover, 2003; 2008). All of the terrestrial mammals found on these islands today derive from anthropogenic imports and, as such, the modern species spectrum can be viewed as a direct record of human migration and trade. In recent years, there have been an increasing number of studies investigating the ancient processes by which native species became extinct on the Balearic Islands (e.g. Bover and

Alcover, 2003, 2008; Bover et al., submitted). Other researchers have examined the timing and impact of the introduced fauna, for instance, Valenzuela and Alcover (2013a, 2013b; 2015) have considered how the arrival of domestic dogs and the three mustelids species (*Mustela nivalis, Martes foina, Martes martes*) that now inhabit the island chain may have influenced the fortunes of the native vertebrates.

Whilst most studies of Balearic fauna focus upon species that are either 'extinct' or 'introduced', there are some animals, notably fallow deer (*Dama dama*), that occupy both positions. The fallow deer is native to the eastern Mediterranean, to where its range was restricted during the last glacial maximum: Figure 1 shows the natural range of the two *Dama* sub-species, the European fallow deer (*Dama dama dama*) and the Persian fallow deer (*Dama dama mesopotamica*). The modern distribution of *Dama* is almost entirely the result of human activity, with translocations beginning in the Neolithic and continuing in waves up to the present day. Archaeological evidence indicates that fallow deer were imported to Mallorca in antiquity, most probably during the Roman period; however, their establishment must have been transient, as they are no longer part of the island's fauna. Because of their ephemeral association with the Balearics, fallow deer have received little attention from researchers. The extirpation of introduced species is largely irrelevant to conservation biologists who privilege the 'native' (Gippoliti and Amori, 2006) and fallow deer, as unsuccessful colonizers, are considered immaterial to those interested in modern biodiversity (Masseti et al., 2008).

Such stances, however, overlook three important aspects that render research into fallow deer, and other temporarily established species, worthwhile. The first is that by taking a purely ecological approach to animal introductions is to ignore their cultural significance. Recent research suggests that many ancient animal translocations were motivated not simply by economic concerns but also as social status symbols or even by spiritual or cosmological beliefs, whereby the diffusion of exotic animals often parallels the spread of religious cults and deities (Sykes, 2014). By understanding the timing and circumstances of ancient animal introductions we can, therefore, gain fresh insights into the ideology of the cultures responsible for their movement and management, as well as reconstructing the trade networks that facilitated this. Secondly, we can also begin to model the bio-cultural context and mechanisms involved in localized extinction processes – this is not without value for modern biodiversity management (e.g. Sykes et al. in prep). Finally, foregrounding the role of culture in ancient introduction/extinction processes will help to highlight the need for similar approaches to be adopted in modern biodiversity and conservation management, especially since it is becoming widely recognised that current policies are failing because they do not engage adequately with the cultural aspects that are critically entangled not only with animals but with the policy-creators themselves (Frawley and McCalman, 2014).

To these ends, this article presents the result of detailed investigation (combining zooarchaeological evidence with AMS radiocarbon dating, isotope analysis and preliminary ancient DNA results) that sets out to explore the timing, circumstance and meaning of the fallow deer's introduction to, as well as their subsequent management and extirpation on the island of Mallorca.

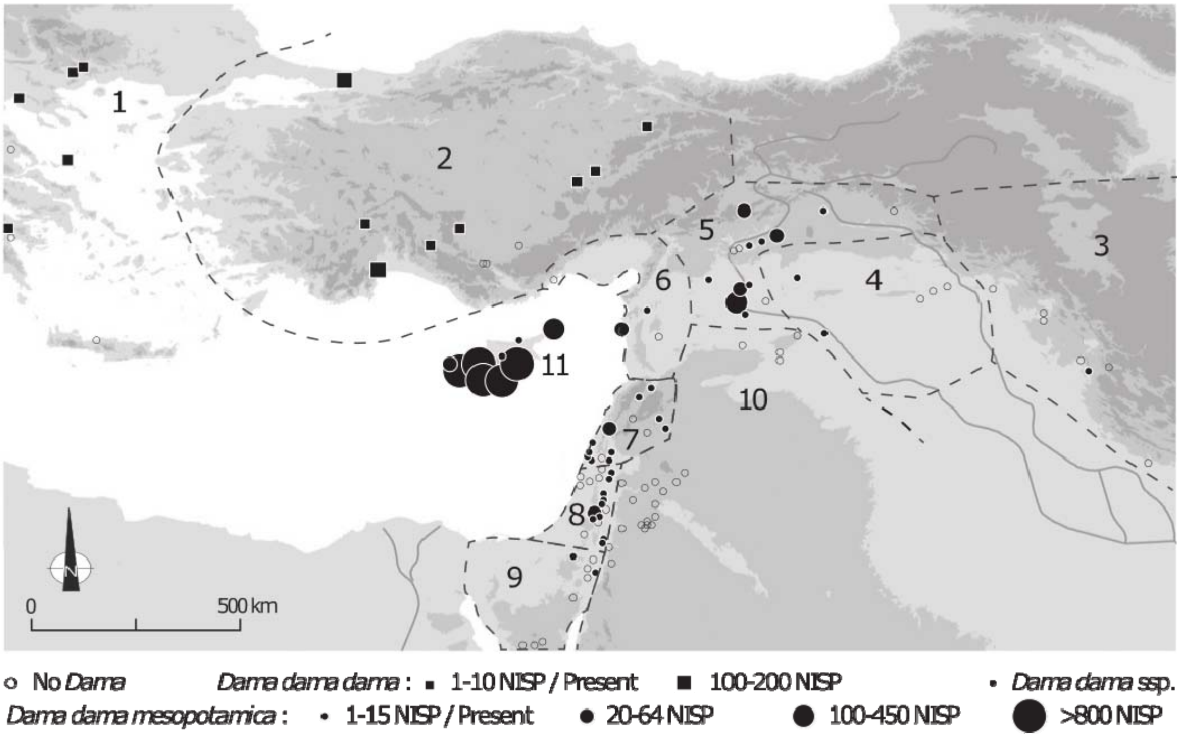

Fig. 1. Native range and early-translocated distribution of the European and Persian fallow deer in the eastern Mediterranean (after Vigne et al. 2015).

2. Materials and Methods

A previous review of fallow deer representation in Roman Europe (Sykes et al., 2011) highlighted one Roman site in Mallorca – S'Illot - purported to have yielded fallow deer remains. As part of the AHRC-funded *Dama* International project, further materials were located (see Table 1, Figure 2), including two large assemblages. The first is from the Roman city of *Pollentia*, located on the north of the island, on an isthmus separating the bays of Alcúdia and Pollença. The second is from Sa Mesquida, a Roman rural settlement situated in the west of Mallorca (e.g. Orfila et al., 1996; Mas et al. 2015). The assemblages from these two settlements are the focus of this paper, although data from the other sites detailed in Table 1 have been synthesised to consider changing patterns of representation through time.

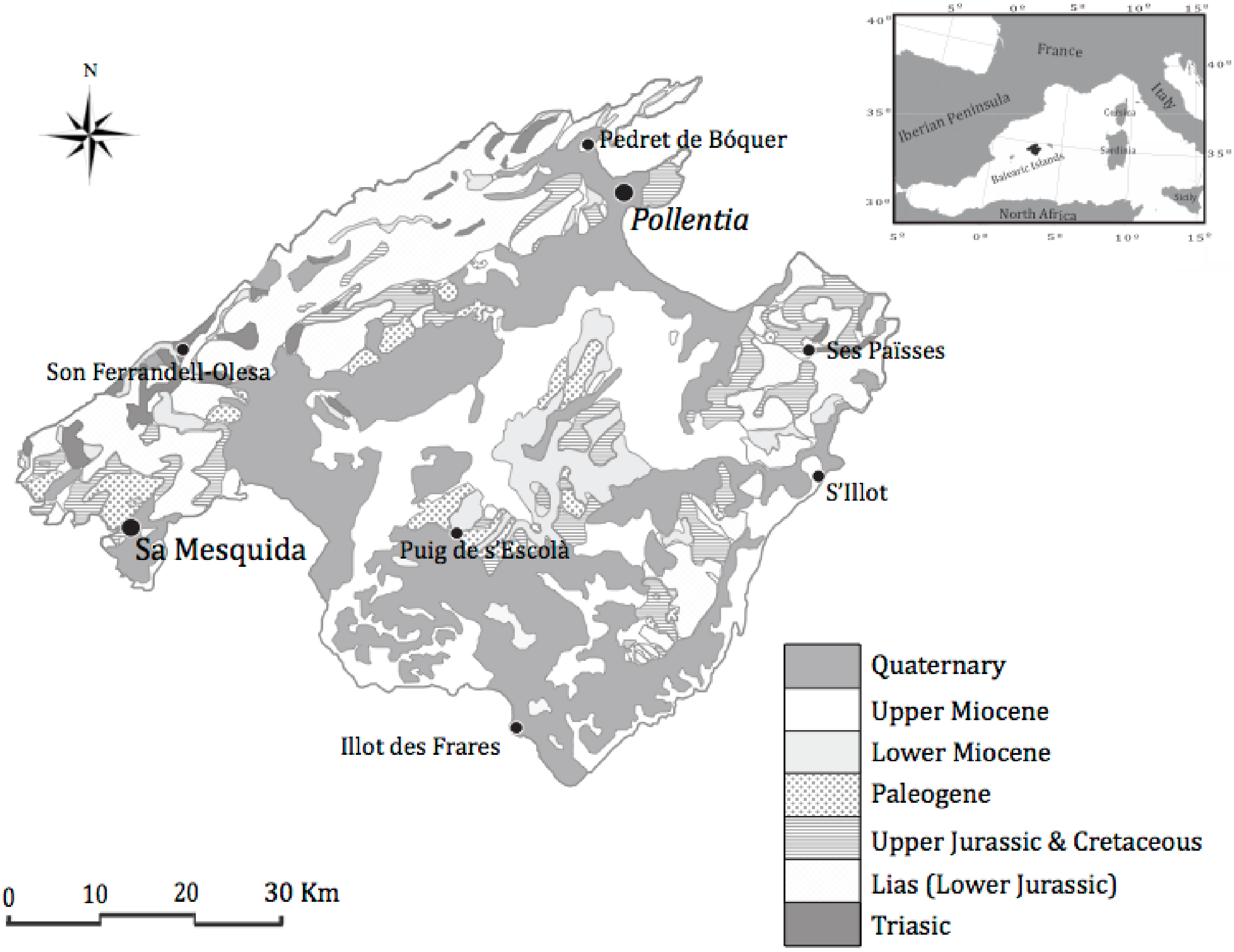

Fig. 2. Location of the sites named in the text on the geology map of Mallorca (from the European TRIANET agency).

Site	Date (AD)	Site	NISP			Assemblage Total	References
			Fallow Deer	Red Deer	Cervid		
Son Fornés	2nd-1st BC	Village	-	-	-	3559	Valenzuela, 2015
Son Espases	2nd BC	Military camp	-	-	-	18,262	Valenzuela, 2015
Pollentia	1st BC – AD 1st	Urban	-	-	-	7948	Valenzuela, 2015
Ses Païsses	Iron Age/ Roman	Rural settlement	1	2	13	3692	Ramis, 2005
Son Ferrandell-Olesa	Iron Age/ Roman	Rural settlement	4	-	-	3289	Chapman and Grant, 1989, 1997
S'Illot	Iron Age/ Roman	Rural settlement	16	24	-	10,456	Uerpmann, 1971
Pollentia	3rd-4th AD	Urban	212	12	81	6464	This paper
Pedret de Bóquer	4th-5th AD	Urban	13	-	-	151	Valenzuela, 2015
Sa Mesquida	4th-6th. AD	Villa	342	108	449	1746	This paper
Puig de S'Escolà	5th-7th AD	Rock-shelter	1	-	2	109	Aramburu, 2011
Illot des Frares	5th-7th AD	Islet/trade-post	2	-	1	114	Ramis, 2004
Son Peretó	6th-7th AD	Rural settlement	1	1	-	677	Valenzuela and Ramis, 2012

Table 1. Counts of deer bones from Roman and post-Roman sites in Mallorca. Counts are derived from Number of identified specimens (NISP).

2.1 Zooarchaeological methods

The relative frequencies of fallow deer were calculated for all of the sites listed above (Table 1). Metrical data were already available for Sa Mesquida and *Pollentia* and these can be accessed via the Dama International Project's on-line database http://www.nottingham.ac.uk/zooarchaeology/deer_bone/search.php In recognition that they could be made more meaningful if viewed against a baseline derived from modern animals of known age and sex, measurements from 227 fallow deer (119 male and 108 female) from Phoenix Park, Dublin, Ireland were used for comparison (also accessible at the above link).

All available epiphyseal fusion data were examined following Carden and Hayden (2006). Jaws from both sites were examined using Bowen *et al.*'s (2016) new dental ageing system (full details are presented in Supplementary information) and samples of tooth enamel were taken for oxygen and strontium isotope analyses.

2.2 Isotope analysis

In order to highlight temporal changes in human-fallow deer relationships and management strategies, multi-element isotope analyses were undertaken to provide a suite of information, often on the same specimens. Bone samples collected from a total of 52 samples (26 each from *Pollentia* and Sa Mesquida) were taken for carbon and nitrogen analysis. Twelve of the resultant collagen samples (six each from *Pollentia* and Sa Mesquida) were also selected for sulphur analysis. Six mandibles (three each from Sa Mesquida and *Pollentia*) were selected for strontium and oxygen analysis. Full details of the analytical methods can be found in the Supplementary Information.

2.3 Radiocarbon dating

Three specimens, one from *Pollentia* and two from Sa Mesquida, were submitted to the University of Oxford's Radiocarbon Accelerator Unit (ORAU). These were processed using the gelatinisation and ultrafiltration protocols described by Brock et al. (2010) and Bronk Ramsey et al. (2004a). They were then combusted, graphitised and dated by Accelerator Mass Spectrometry (AMS) as described by Brock et al., (2010), Dee and Bronk Ramsey (2000), and Bronk Ramsey et al. (2004b). ORAU maintains a continual programme of quality assurance procedures, in addition to participation in international inter-comparisons (Scott, 2003; Scott et al., 2010), which indicate no laboratory offsets and demonstrate the validity of the precision quoted.

2.4 Genetics

Full details of the analytical procedures are provided in the Supplementary information. Genetic analysis was undertaken on 19 specimens (six from Sa Mesquida and 13 from Pollentia) also submitted for isotope analysis. All DNA analyses were carried out at the School of Biological and Biomedical Sciences, Durham University.

The Mallorcan samples amplified for this study were aligned with reference data sets from available Persian fallow deer sequences from Stuttgart Zoo (N=7) (see Masseti et al., 2008) and Genbank (N=3) (see Supplementary information) and from ancient European fallow deer (amplified as part of the Dama International project). All samples were aligned using a consensus subsection (333bp) of the mtDNA control region. The relationship amongst haplotypes was examined by constructing a Neighbour Joining tree using the Tamura-Nei model and 1000 bootstrap replications in MEGA 5.2 (Kumar et al., 2008).

3. Results and discussion

New data were generated for a total of 75 specimens, the results of which are presented in detail in the Supplementary information. To place these in context, it is necessary to first consider the representation of fallow deer in the zooarchaeological record.

Whilst many zooarchaeological assemblages have been analysed for the island of Mallorca, no fallow deer have been positively identified within Prehistoric contexts (Alcover, 1979, 2010). A small number of *Dama* remains have been recovered from the 'indigenous' Iron Age settlements of Ses Païsses (Ramis, 2005), Son Ferrandell-Olesa (Chapman and Grant, 1989; 1997) and S'Illot (Uerpmann, 1971); finds that could suggest a pre-Roman introduction date for the species. However, in all three cases the fallow deer remains came from insecure contexts more likely associated with Roman activity (Figure 3).

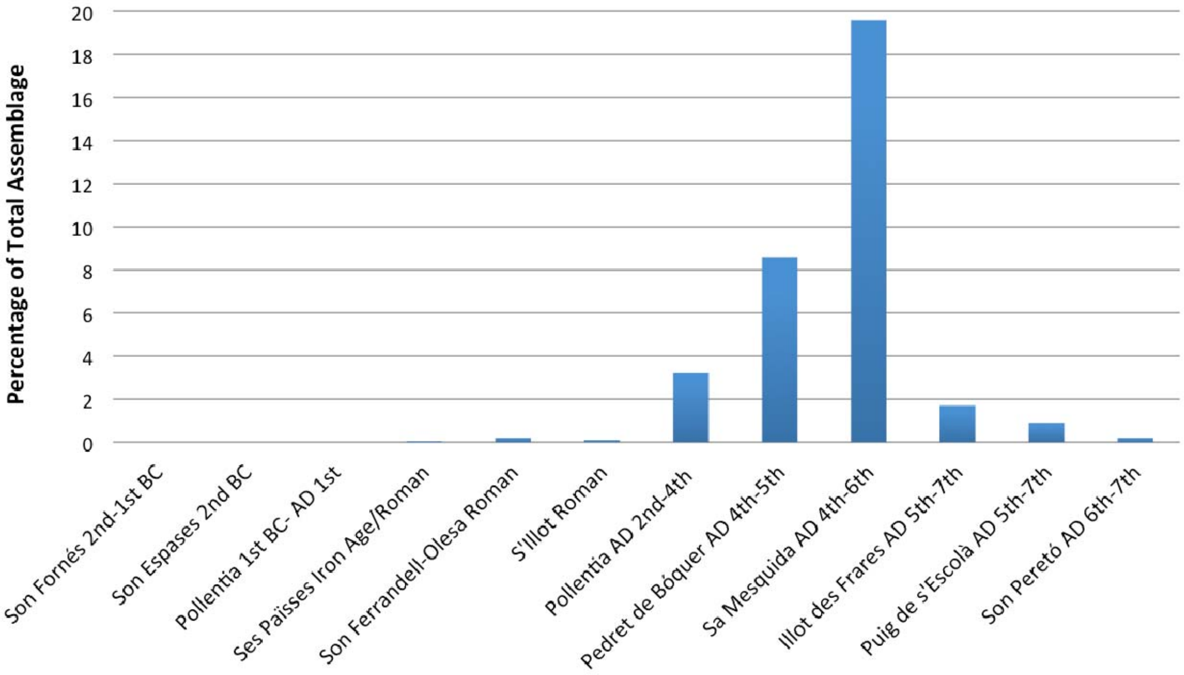

Fig. 3. Representation of fallow deer remains on Mallorcan sites through the time.

Based on spot-dating, the Roman city of *Pollentia* is the earliest site where fallow deer have been noted unequivocally. Written sources indicate the city was founded in 123 BC, although currently the earliest zooarchaeological material from this city comes from contexts dated to c.70-60 BC. Fallow deer remains are entirely absent before the 3rd century AD. All of the fallow deer bones from *Pollentia* come from fire destruction levels associated with the conflagration that damaged much of the city in AD 270/280 (e.g. Orfila et al., 1999; Orfila, 2000). The AMS radiocarbon date for *Pollentia* (OxA-27878: 1776 ± 26 BP; 142-336 2σ cal AD) is in agreement with this spot-date (see Figure 4).

Within *Pollentia*'s 3rd/4th century contexts, fallow deer comprise approximately three per cent of the total assemblage. This figure is far below the frequency seen at Sa Mesquida where fallow deer make up almost twenty per cent of the zooarchaeological material. The AMS radiocarbon dates for the cistern of Sa Mesquida, including spot dating of the fallow deer samples (OxA-27936: 1678 ± 25 BP, 260-420 2σ cal AD; and OxA-27937: 1726 ± 26 BP, 248-385 2σ cal AD), suggest that this deposit is contemporary or slightly later in date than the single date obtained for one deposit in *Pollentia* (OxA-27878, see above). The study of the pottery recovered in the cistern demonstrate that the vast majority of materials found are dated in the first half of the 5th century AD. The differences in both date and fallow deer representation between the different contexts in the two sites could feasibly suggest that, by the 4th-5th century *Dama* populations had increased significantly upon the island.

The data for the 4th- 5th-century AD urban site of Pedret de Bóquer, where the frequency of fallow deer sits between the *Pollentia* and Sa Mesquida values (Figure 3), could be informative on the population or management trends of fallow deer. If is accepted that the zooarchaeological representation is a reliable proxy of fallow deer population it would seem that, following an earlier expansion, their numbers declined substantially by the 6th-7th century AD: the frequencies for Illot des Frares (a trading post) and Puig de S'Escolà (a re-occupied rock shelter) are both under two per cent and in the early Christian site of Son Peretó, in contexts of the very late 6th and the 7th centuries AD, fallow deer are practically absent (Valenzuela and Ramis, 2012).

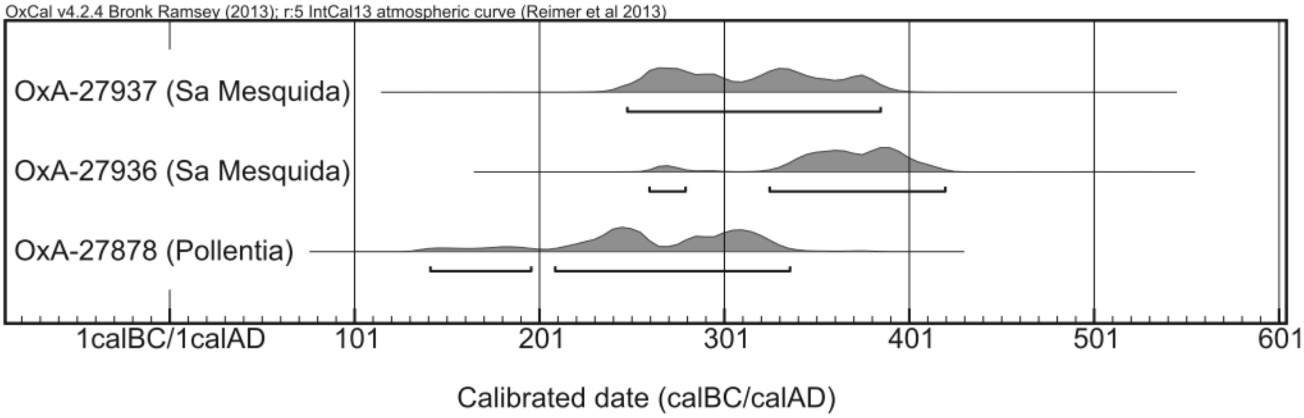

Fig. 4. AMS radiocarbon dates for *Pollentia* and Sa Mesquida.

With the fallow deer population apparently beginning to flourish by the 3rd/4th century, it is likely that the species had been established on the island for some time before *Pollentia*'s fire of AD 270/280 and we must, therefore, view the earliest radiocarbon date as a *terminum ante quem*. This is supported by the results of the strontium analysis: Figure 4 shows that the Sr values for *Pollentia*'s fallow deer provide no evidence for first-generation imports; instead they reflect the local geology, as shown by the bone value which reflects the post-depositional environment (Bentley, 2006). The same is true for the Sa Mesquida deer, which exhibit similar Sr values to those from *Pollentia* (Figure 5). This is perhaps unsurprising as the two sites are situated on rocks of comparable lithology (Figure 2). What the results do suggest is that none of the fallow deer featured in this sample have been translocated from populations established in other areas of the island of different geological substratum (Figure 2).

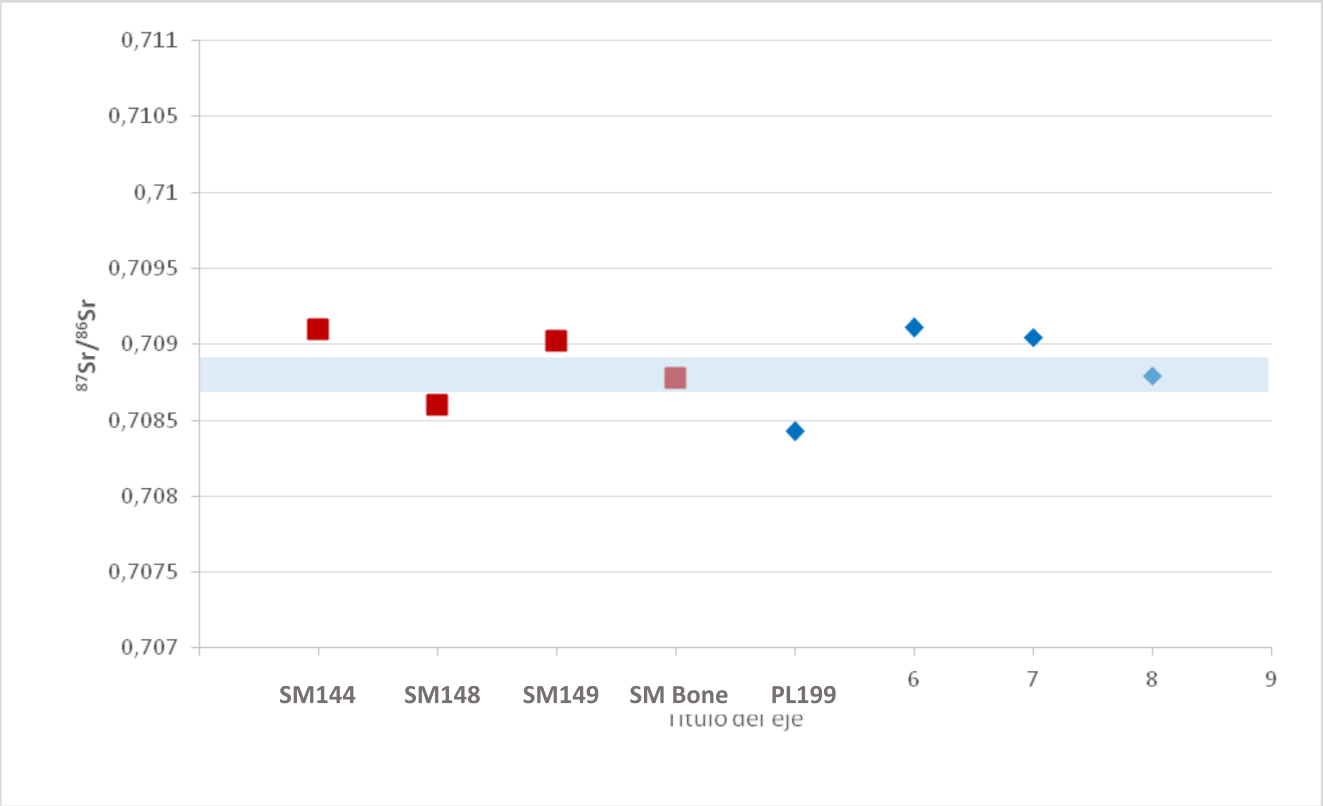

Fig. 5. Stable strontium isotope data from Sa Mesquida and *Pollentia*. Red squares indicate isotopic values from Sa Mesquida and blue diamonds from *Pollentia*.

The similarity of the results for the populations of deer at *Pollentia* and Sa Mesquida is also seen in the oxygen isotope values (Figure 6). While sample SM149 looks initially very different, the tooth of this individual was very worn, giving just 2mm of enamel for analysis. As such, this section of tooth probably reflects only one season of growth, rather than an average displayed by the other samples. Again this is more indicative of a resident rather than translocated population. Given the size of the island and the likely common sources of local meteoric water it is not possible to separate the *Pollentia*, Sa Mesquida and populations potentially coming from other sites, on this basis (Longinelli, 1984; Luz et al., 1984). Overall the $\delta^{18}O$ values for these samples are within in the range of those expected for Mediterranean populations, according to Miller et al.'s (in prep) oxygen baseline.

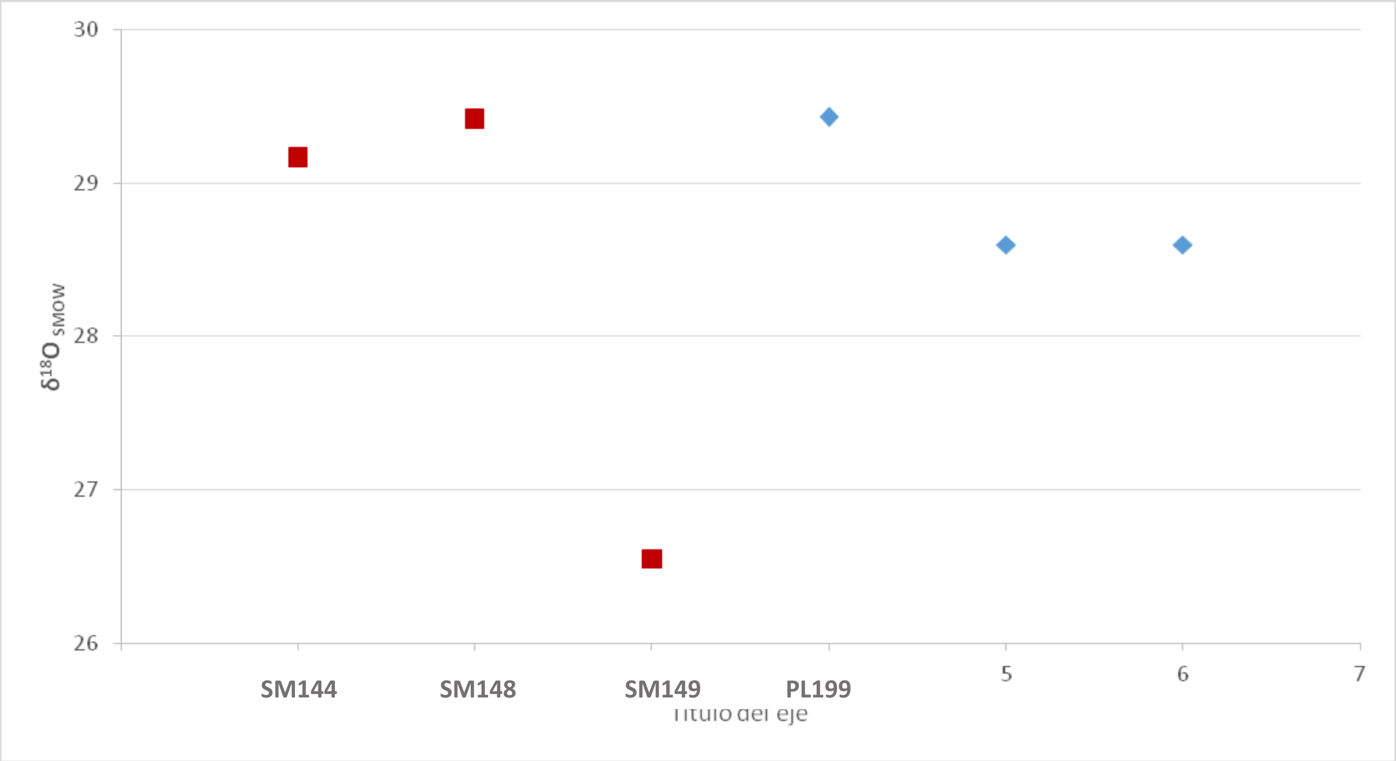

Fig. 6. Stable oxygen isotope data from Sa Mequida and *Pollentia*. Red squares indicate isotopic values from Sa Mesquida and blue diamonds from *Pollentia*.

With traditional provenancing isotopes (Sr and O) failing to tease out potential relationships between the *Pollentia* and Sa Mesquida fallow deer, it is particularly notable that the specimens from these two sites separate, almost completely, in terms of their carbon and nitrogen values (Figure 7). Although these dietary indicators are generally seen as poor gauges of provenance, fallow deer stable isotope ratios, particularly carbon, have been shown to vary significantly across wide geographical ranges (Miller et al., 2014; Sykes et al., accepted). In this case, the same may be true in specific environmental conditions.

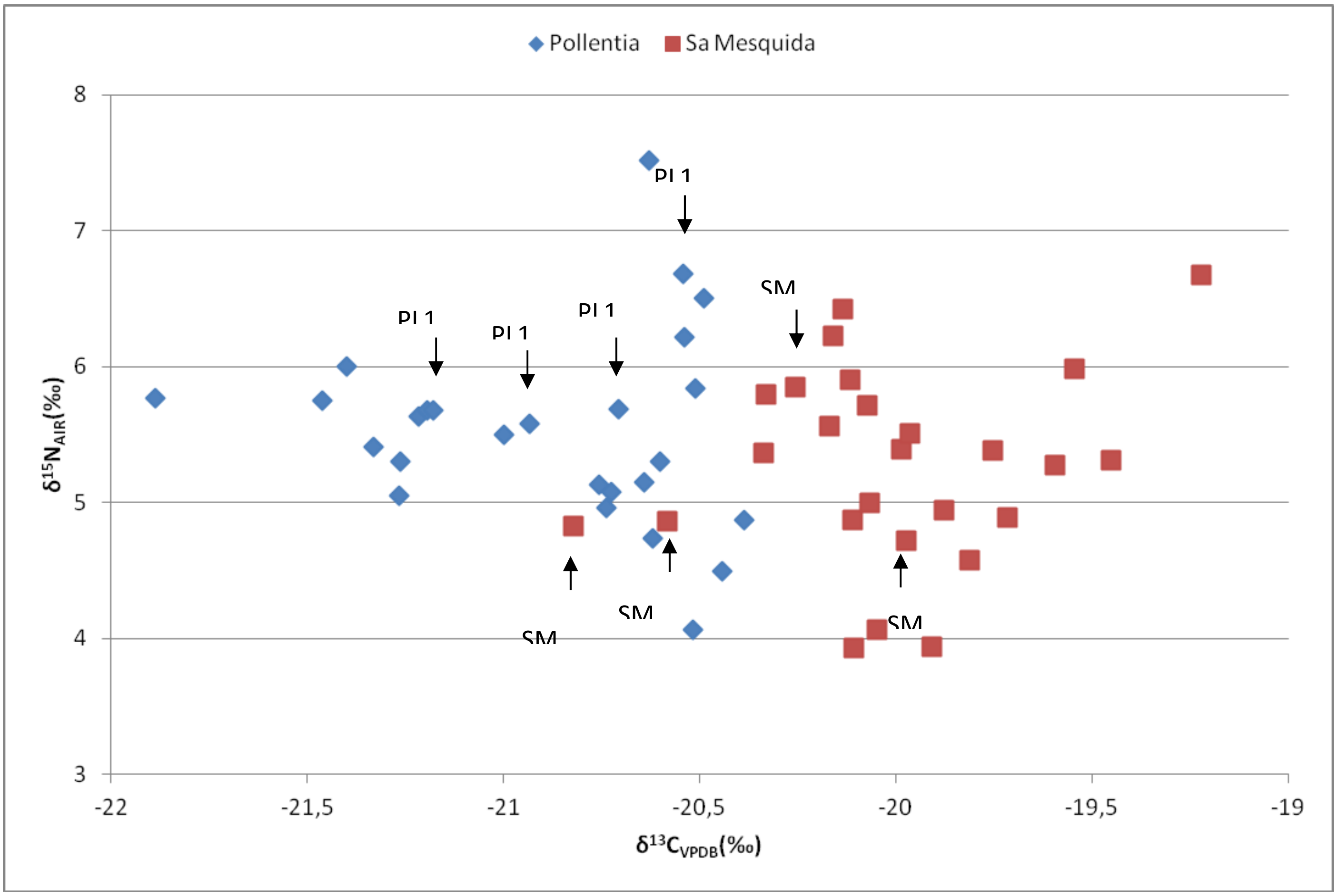

Fig. 7. Stable Carbon and Nitrogen isotope data from Sa Mesquida and *Pollentia*. Some of the samples are indicated with the accession number.

Sulphur isotopes were used to check if the difference seen in δ^{13}C values between Sa Mesquida and *Pollentia* fallow deer might be due to the effects of sea spray, influenced by local wind patterns. Currently, patterns of stronger winds in the area of *Pollentia* have a N -NNE component, while in the area of Sa Mesquida they are dominated by W-SW directionality (see Guijarro et al. 2015). Nothing is currently known about the intensity and direction of the prevailing winds in the past. The results of the sulphur study show that there is little difference between the values from the two sites (Figure 7), therefore both were equally affected by sea spray. This is likely because the wind regime of Mallorca is complex, with influential local systems that change from one area of the island to another.

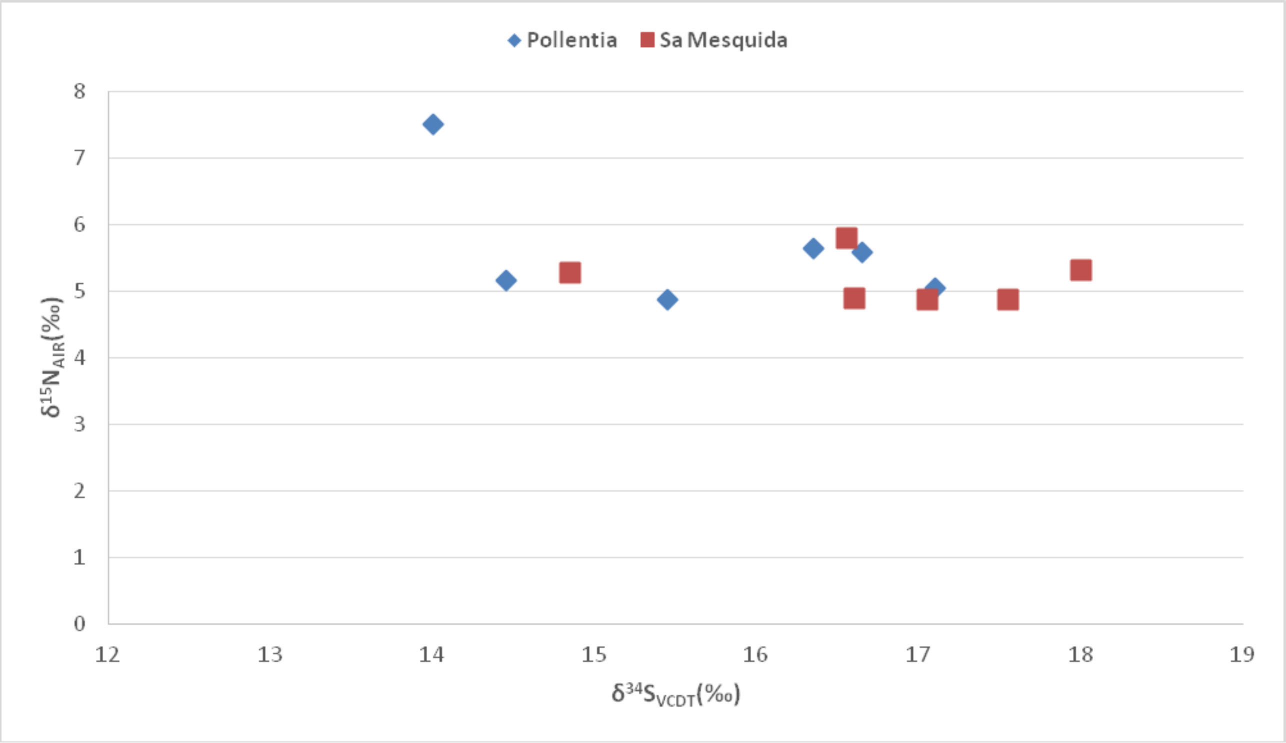

Fig. 8. Stable sulphur isotope data from Sa Mesquida and *Pollentia*.

Having ruled out sea spray as the cause for the difference in $\delta^{13}C$, and given the inconclusive nature of the traditional provenancing isotope data (Sr and O), it falls to the more conclusive, yet unconventional use of C/N data to look at management locality. As such, it is almost certain that the separation of fallow deer $\delta^{13}C$ and $\delta^{15}N$ from Sa Mesquida and *Pollentia* seen in Figure 7 reflects local variation in the animals' diet.

The mostly likely cause of this variation is the climate, and associated rainfall patterns, that distinguish the two sites (Figure 9). Sa Mesquida sees c.300 mm of rainfall annually, an amount that is likely to result in impoverished vegetation growth and the establishment of arid-tolerant species. As a result, relatively higher (less negative) $\delta^{13}C$ values at in fallow deer Sa Mesquida may be due to their diet consisting of C_3 plants that have modified their responses to the arid environment (Seibt et al., 2008, Kohn, 2010), or a small contribution of C_4 plants. Although Van Strydonck et al. (2005) have suggested that there were no C_4 plants on the Balearic Islands in Prehistory, Čarni and Mucina (1998) identified the C_4-trample weed taxa *Cynodonto-Heliotropietum curassavici* as being present in modern Mallorca (e.g., *Paspalum vaginatum*), and some no naturalized species are currently present in the Mallorcan marshes (e.g., *Sporobolus pungens*, *Salsola vermiculata*, *S.kali*, *S.soda*, *S. oppositiflora*; Gulías, pers. com.).

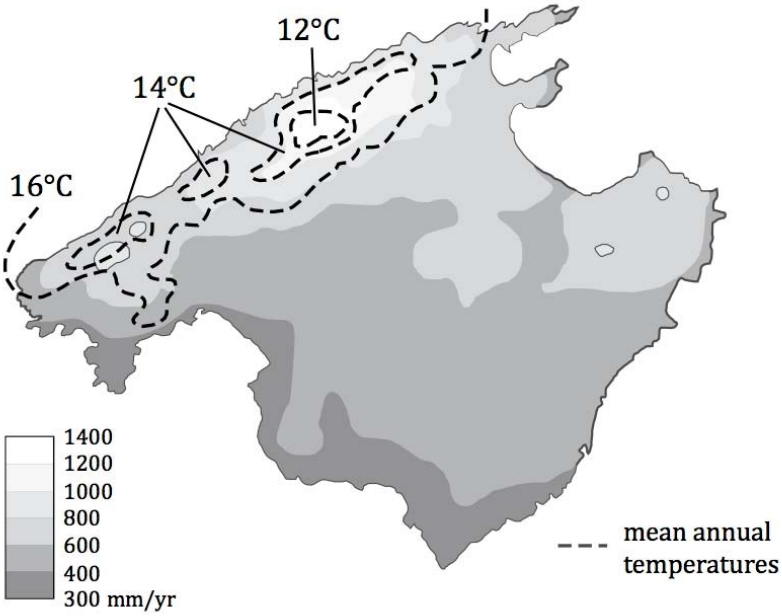

Fig. 9. Distribution of the average annual rainfall and temperature values. Modified after Ginés et al. 2012, 18.

More information on the environmental archaeological record of the Balearics in general, and Mallorca in particular, is necessary (Van Strydonck et al., 2005). However, the C/N results from Sa Mesquida and *Pollentia*, regardless of the precise reason for the difference in $\delta^{13}C$, make clear that only the local environments of the two sites are reflected in the diets of the adult deer.

While the home-range of fallow deer is not large by comparison to other cervid species – Borkowski and Pudelko (2007) estimate the average range of females and males to be 2 and10 km^2 respectively – it is very surprising that the C/N values show such little overlap between the two sites. Indeed, it would seem that these populations of fallow deer were restricted in their movement and it is tempting to suggest that this may have been because they were emparked. This would be in-keeping with the evidence for the rest of the Roman Empire: documentary sources recount the fashion for maintaining wild animals, in particular deer, within enclosures known as '*vivaria*' (e.g. Sykes et al., 2006). How these animals were managed within these *vivaria* has been examined for Roman Britain (Sykes et al., 2006; 2011; Madgwick et al., 2013; Miller et al., 2014), but the large size of the assemblages from *Pollentia* and Sa Mesquida permits a far more in-depth analysis using traditional zooarchaeological methods.

Figures 10a and 10b show the osteometric data for the two best-represented skeletal elements from both sites – the tibia and the astragalus – shown against measurements of modern European fallow deer, of known sex, from Phoenix Park in Dublin. In both cases the distribution plots for the ancient Mallorcan deer are consistent with the modern specimens: both have a similar size-range and indicate a clear bimodality that maps directly onto the modern male-female separation. There are, however, some differences between the two sites. Most noticeable is that whilst the fallow deer from *Pollentia* appear to show equal proportions of males and females, the Sa Mesquida deer show a much higher representation of females: only three of the eleven astragali (27%) from Sa Mesquida and just one of the 17 tibiae (6%) appear to be male.

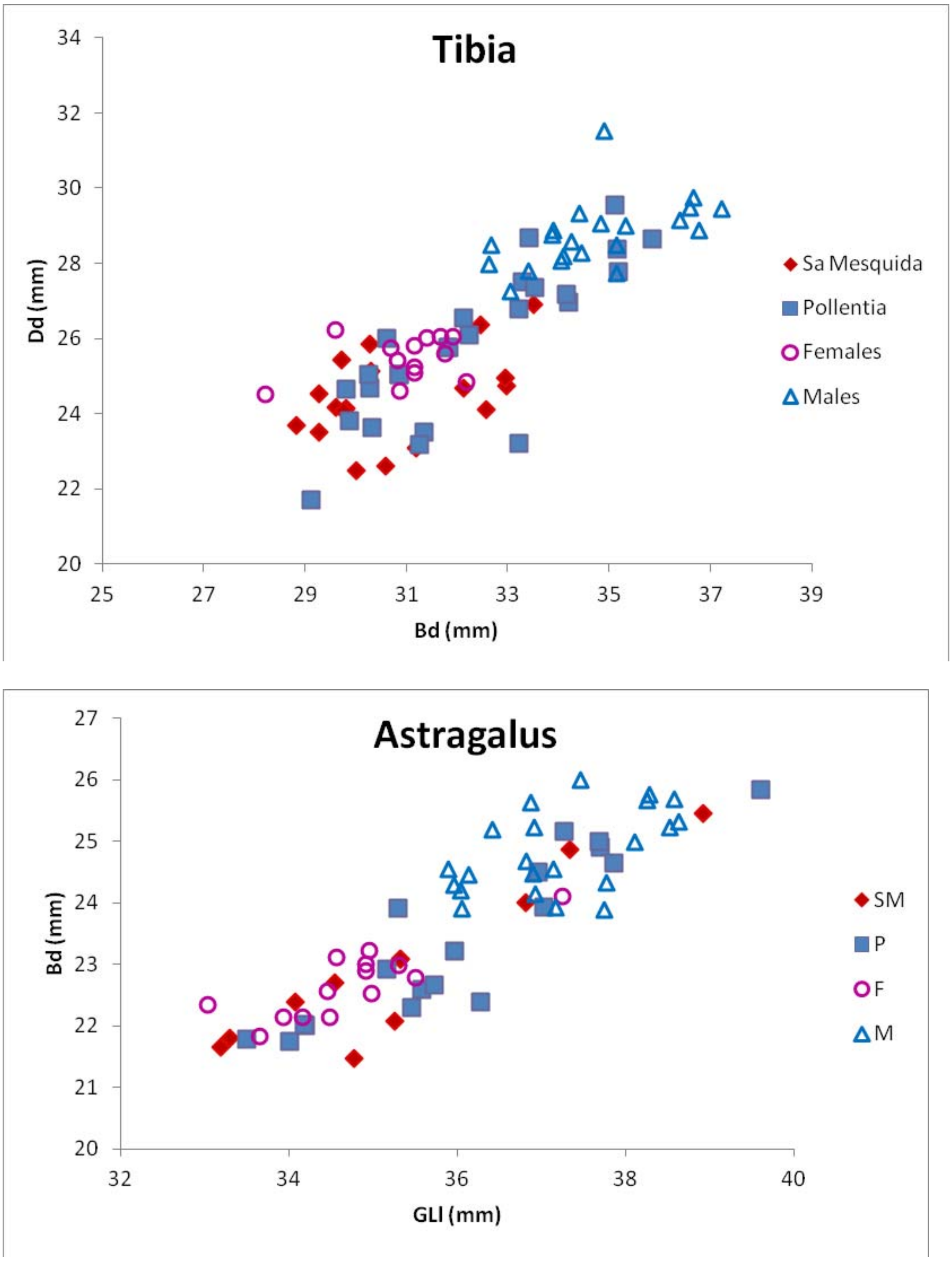

Fig. 10. Osteometric data for a) tibia and b) astragalus for Sa Mesquida (SM) and *Pollentia* (P), shown against modern animals of known sex (F= female; M= Male).

When these sexing data are combined with the ageing results for the two sites (Figures 11 and 12), the demographic profiles for *Pollentia* and Sa Mesquida become further differentiated. The female-dominated Sa Mesquida assemblage is skewed heavily towards very old individuals, the majority at mandible wear stage (MWS) J which equates to approximately 118-189 months. However, it also contains a noticeable representation of animals aged under 20 months, their presence indicated not only by the dental ageing (Figure 11) but also the epiphyseal fusion data (Figure 12). It is rare to find an abundance of female and juvenile animals in wild animal assemblages, as hunters tend to preferentially target the larger adult males. It is possible that Sa Mesquida's deer represent the hunting and capture of nursery herds, which would have this kind of demographic composition. If this were the case, it may explain why fallow deer numbers declined sharply in the 6/7th century because, in deer management terms, the targeting of females and juveniles is unsustainable and quickly erodes population size. However, the profile could equally be indicative of close husbandry on a ‘producer site’, with an over-representation of old breeding stock and infant fatalities (Zeder, 1988; Crabtree, 1996). This is in contrast to the age profiles for *Pollentia*, where the ageing data suggest that most of the animals at this site were between approximately 20 and 50 months. According to economic models (e.g. Zeder, 1988; Crabtree, 1996), this profile is suggestive of a ‘consumer site’, provisioned with prime age animals of both sexes. Whilst it is unusual to apply economic livestock models to wild animals, the demographics fit with the character of both settlements: Sa Mesquida a rural production estate and *Pollentia* an urban centre. Taken together, the evidence seems to suggest that, on Roman Mallorca, fallow deer were maintained within parks and actively managed to provide venison for the urban table.

However, the social value of fallow deer likely extended beyond their role as providers of meat. Across the Roman Empire there appears to have been a strong association between fallow deer and the Goddess Diana (Miller et al., in press) and, as a result, *Dama* was important in both Roman religion and medicinal practices (Miller et al., in press). Antlers in particular were sought after for use in zootherapy and many of the specimens from Mallorca do exhibit signs of having been worked/shaved, which could suggest they were used for this purpose (Figure 13).

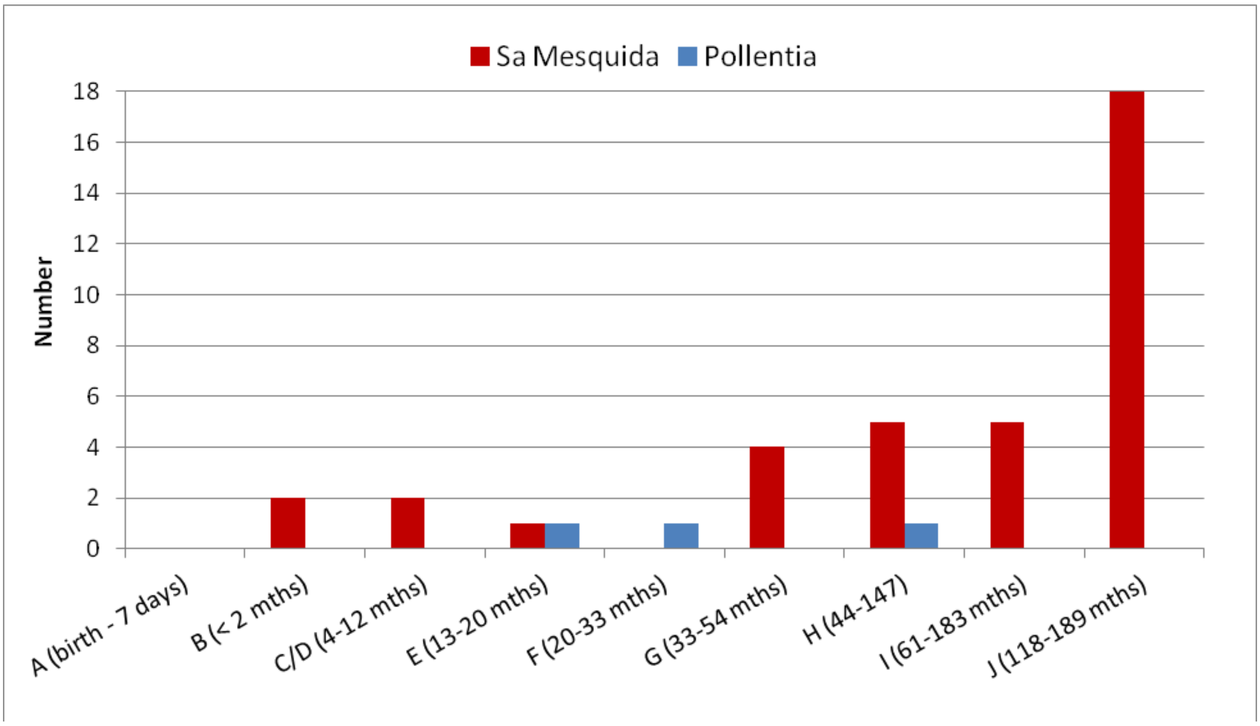

Fig. 11. Dental ageing (Bowen et al. submitted) for Sa Mesquida and *Pollentia* deer.

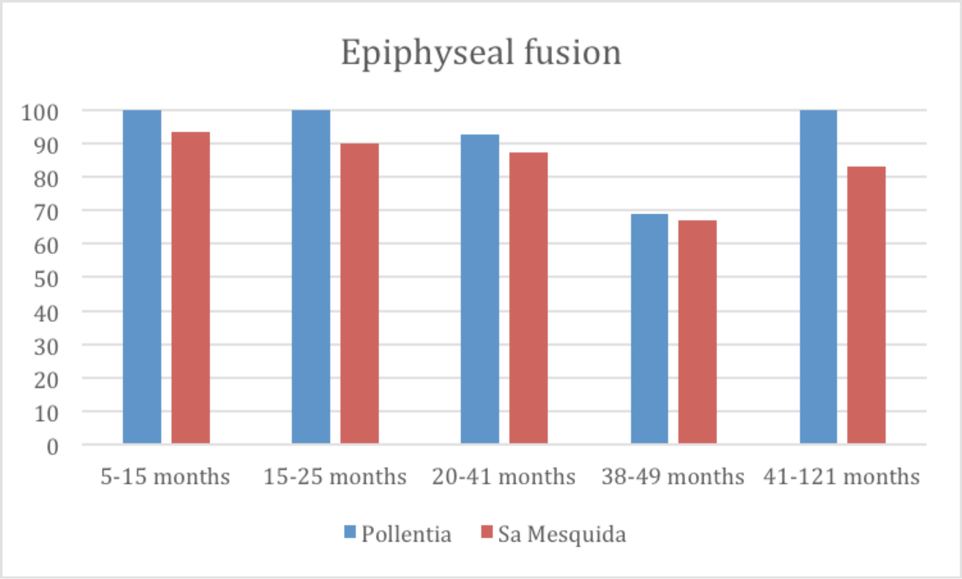

Fig. 12. Epiphyseal fusion data of fallow deer from *Pollentia* and Sa Mesquida.

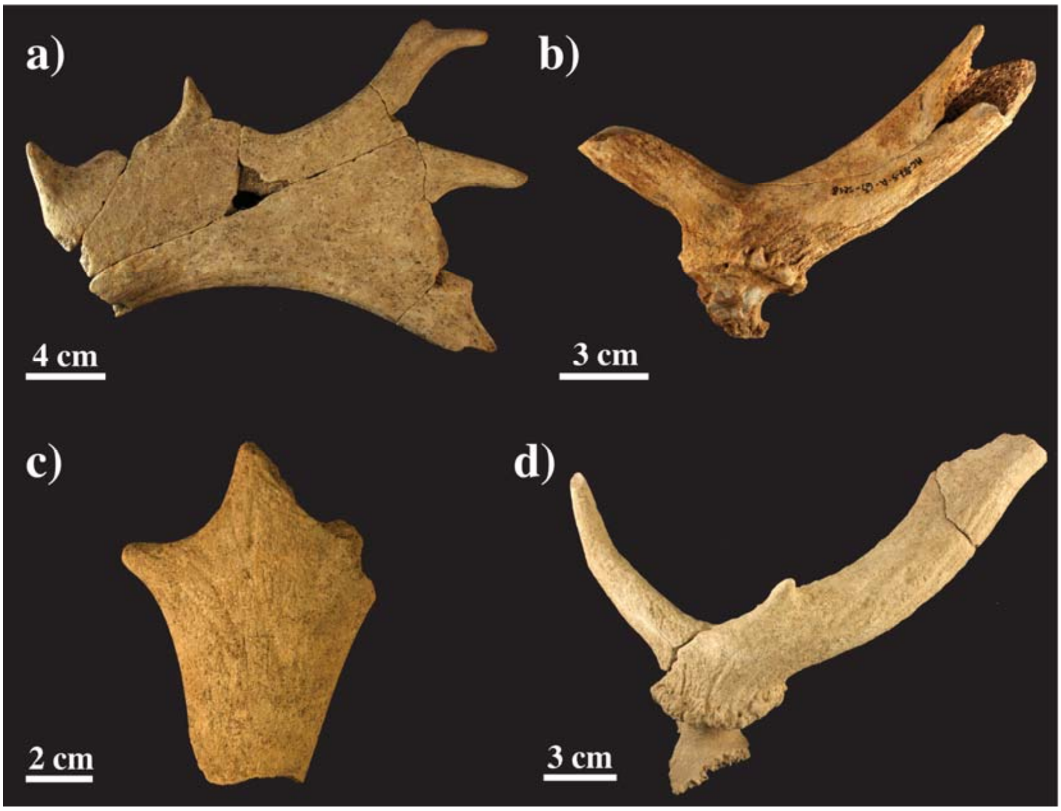

Fig. 13. Antler fragments from archaeological sites of Mallorca: a) Sa Mesquida (MC87-5B-56-5006); b) Sa Mesquida (MC87-5A-65-1218); c) Sa Mesquida (MC87-5B-56-502); d) Pedret de Bóquer (PB-525-143).

These antlers are interesting not only in terms of the evidence that they display for alteration but also, more generally, in terms of their shape. Antler morphology has traditionally been used as a key criterion for differentiating the European fallow deer (*Dama dama dama*) from the Persian fallow deer (*Dama dama mesopotamica*), another criterion being size, with Persian *Dama* generally larger than their European relative. All of the antlers from Roman Mallorca appear consistent with the expected morphology for *D. d. dama* (Figure 13) and the same is true of their post-cranial measurements (Figures 10a and 10b). However, the genetic results for the Sa Mesquida and *Pollentia* deer suggest a different story (Figure 14).

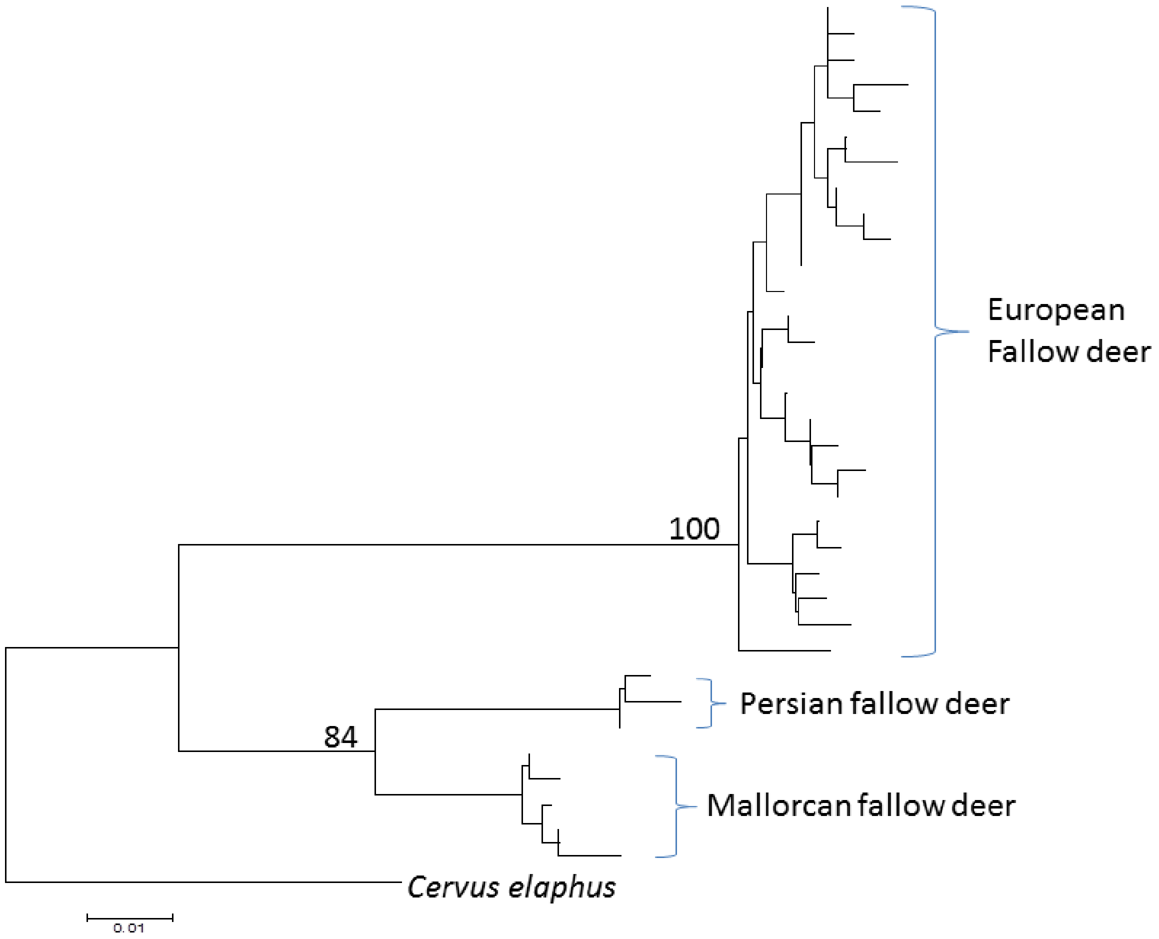

Fig. 14. NJ tree showing the different mtDNA haplotypes among ancient European, ancient Mallorcan and modern Persian reference sequences. The tree shows bootstrap values (based on 1000 bootstrap replications) and is rooted with a sequence of *Cervus elaphus*.

The genetic results show that the European and Persian fallow deer fall into separate, reciprocally monophyletic, lineages (Figure 14), which agrees with the conclusions of previous studies (Randi et al., 1998, Masseti et al 2008; Hassanin et al 2012; Fernandez-Garcia 2012). Interestingly, ancient Mallorcan samples cluster with the Persian (84% bootstrap support), rather than European fallow deer, though the Persian and Mallorcan lineages are also distinct, and no haplotypes are shared. Haplotypes from the ancient Mallorcan samples are shared between the two sites examined; Sa Mesquida and *Pollentia*, suggesting that the source populations of these deer could have been the same. The diversity of the European and Mallorcan populations is well enough sampled to indicate that a European origin for the Mallorcan population is unlikely. Comparisons with the modern Persian samples however are complicated by the recent demography of the Persian population. As a result of overhunting, modern native, wild Persian fallow deer are highly restricted to a small area in Iran, rendering this species as endangered (IUCN report; Werner et al., 2015). Therefore, contemporary population sizes and distributions do not reflect those of historic times (see Figure 1 for the historic distribution of the fallow deer). Though the sample sizes of the modern reference Persian sequences used in this study were small, the low diversity detected (see Supplementary information) likely reflects the general story for this species (see Masseti 2008 and Fernández-García 2012). Ancient Mallorcan haplotypes were not shared with any of the modern Persian references used and so if the Mallorcan population was founded from the Persian population, it is likely that historic diversity has been lost. Future studies could use ancient DNA samples from the historic range of Persian fallow deer to determine the geographic origin of ancient Mallorcan populations, as well as the wider movement of this species by humans.

Whatever the case, these results are highly surprising and have implications not only for our understanding of the ancient history and population dynamics of the Persian fallow deer but also for the reconstruction of trade networks. In the absence of the aDNA results, logic would suggest that the Mallorcan herds were established from populations previously translocated to the western Mediterranean: there is evidence that European fallow deer were already present across 1st-3rd century Italy, Sicily, Portugal and Spain as well as southern France. Yet none of these populations were the source of the Mallorcan deer. Instead, current data suggest that they probably derived from the home-range of the Persian fallow deer: Syria, Iraq or Iran. If Persian fallow deer was imported in Mallorca directly from the Middle East or though some stepping stone region (e.g. Northern Africa, areas of which remains insufficiently explored zooarchaeologically) is anunresolved question. However, the idea that fallow deer may have been brought from these regions is consistent with the material culture record for the island. From the 5th century onwards, alongside Western-oriented and Central Mediterranean imports, archaeological assemblages show the presence of goods from the Eastern-oriented Mediterranean (e.g. Orfila, 1989; Cau, 2003;). Our findings point in the same direction, recording that there was also some trade with the Eastern-oriented Mediterranean. It is gratifying that we may be able to demonstrate that live fallow deer formed part of this, highlighting that zooarchaeological studies can be as informative about trade interactions, if not more so.

4. Conclusion

This paper has presented the first scientifically informed study of the introduction and management of fallow deer in Mallorca. The zooarchaeological representation data, together with evidence from isotope analyses and AMS radiocarbon dating suggest that fallow deer were already well-established on the island by the 3rd century AD. The strontium and oxygen isotope results provide no indication that the *Pollentia* and Sa Mesquida assemblages contained first generation imports; indeed, the deer from these sites appear to have had rather restricted movement. Based on the carbon and nitrogen evidence, it seems likely that, as in other areas of the Roman Empire, the fallow deer were housed in parks or *vivaria*. Demographic analysis of the zooarchaeological *Dama* assemblages suggests that fallow deer were managed almost as livestock, husbanded to provide venison for the producer estates but also to supply urban sites.

Overhunting, or rather over-culling, of females and juveniles – as indicated by the 4th-5th century AD assemblage from Sa Mesquida – may have been a factor influencing the species' ultimate population collapse and extirpation. By the 6th-7th century AD, the representation of fallow deer was much reduced and no specimens have been found in assemblages post-dating the 7th century AD. The possibility that over-exploitation may have resulted in the local extinction of fallow deer on Mallorca serves as a warning to those managing modern island populations: similar extirpation events have happened repeatedly in the past (to Mallorca we can add the collapse of the fallow deer populations in Roman Britain, in Cyprus, Crete and on many of the other smaller Aegean islands) and could easily happen again.

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Both introduced and extinct: the fallow deer of Roman Mallorca

Supplementary Information

1. **Methodological information.**
2. **Radiocarbon and isotopes analysis data.**
3. **Genetic samples.**
4. **Dental ageing.**

1. Supplementary Information - Methods

Isotope Analysis

In order to highlight temporal changes in human-fallow deer relationships and management strategies, multi-element isotope analyses were undertaken to provide a suite of information, often on the same specimens.

Carbon and nitrogen isotopes are routinely measured in palaeodietary studies because they are assimilated in consumer tissues from dietary protein sources (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). At the most basic level, gross variations in bone collagen δ^{13}C values are thought to be influenced by the consumption of marine versus terrestrial protein (Schoeninger et al., 1983) or by the inclusion of arid C_4 plants in the diet (Voegl and Van der Merwe, 1977); whereas δ^{15}N values reflect the proportion of plant and animal protein in the diet, becoming enriched at each trophic level (Ambrose and Norr, 1993; Richards and Hedges, 1999). However, researchers are increasingly highlighting the complex range of variables – e.g. temperature (Stevens et al., 2006), water availability (Schwarcz et al., 1999), salinity and marine input (Guy et al., 1986a; 1986b; van Groenigen and van Kessel, 2002; Britton et al., 2008) – that can result in small scale variation in isotopic signatures.

Bone samples collected from a total of 52 samples (26 each from *Pollentia* and Sa Mesquida) were taken for C and N analysis. Collagen was extracted according to a modified Longin (1971) and Brown et al. (1988) method whereby, after the gelatinisation process, samples were filtered through 8 µm Ezee filters prior to freeze drying. Twelve of the resultant collagen samples (6 each from *Pollentia* and Sa Mesquida) were also selected for *sulphur analysis*. Similar to C/N analysis, the stable isotope composition of sulphur (δ^{34}S) in human and animal tissues is a record of δ^{34}S in the diet. Mostly derived from the local geology, sulphates are taken up by plant roots and passed up the food chain. In some circumstances, plants also incorporate sulphur from local sources of SO_2 gas or sulphate-bearing water droplets, such as sea spray or acid rain (Richards et al., 2003, Peterson and Fry, 1987).

Sulphur isotopes were analysed in the *Pollentia* and Sa Mesquida fallow deer to investigate the effects of sea spray on the diet of these island herbivores.

The isotope ratio mass spectrometry took place at the NERC Isotope Geosciences Facilities, measured on a continuous flow-elemental analyser (Flash/EA) coupled to a ThermoFinnigan Delta Plus XL via a ConFlo III interface. Collagen carbon and nitrogen isotope ratios ($\delta^{13}C$, $\delta^{15}N$) are reported in per mil (‰) relative to VPDB and AIR standards respectively. $\delta^{13}C$ and $\delta^{15}N$ ratios were calibrated using an in-house reference material M1360p (powdered gelatine from British Drug Houses) with expected delta values of –20.32‰ (calibrated against CH7, IAEA) and +8.12‰ (calibrated against N-1 and N-2, IAEA) for C and N respectively. $\delta^{13}C$ and $\delta^{15}N$ analyses were undertaken in duplicate and the average standard deviation of these pairs was $\delta^{15}N = \pm 0.04‰$ and $\delta^{13}C = \pm 0.03‰$. Samples fell within the acceptable range of atomic C:N values (2.9–3.6) and percent carbon (% C) and nitrogen (% N) to sufficiently reflect *in vivo* collagen values from well preserved bones (Ambrose, 1990). $\delta^{34}S$ ratios were calibrated using an in-house reference material BROC-2 (powdered broccoli) with expected delta values of 11.67‰ (calibrated against S-1 and S-2, IAEA). $\delta^{34}S$ analyses were run in duplicate and the average standard deviation of the duplicates was ±0.20‰.

Strontium isotope analysis is a widely adopted method for assessing animal movement and local versus non-local dietary patterns (see for example Bentley, 2006, Chenery et al., 2011, Price et al., 2002). This geochemical provenancing technique is based on the principle that different geological terrains have characteristic strontium isotope ratios ($^{87}Sr/^{86}Sr$) that transfers through the food-chain becoming reflected in skeletal material. Tooth enamel is, unlike bone, resistant to diagenetic change and, because it is not remodelled through life, it preserves the signature of geographical origins, allowing migration to be assessed (e.g. Sykes et al., 2006). Six mandibles (three each from Sa Mesquida and *Pollentia*) were selected for Sr analysis.

Oxygen isotope analysis was carried out to complement the Sr analysis, with samples taken from the same specimens. The oxygen isotope composition ($\delta^{18}O_c$ values) of mammalian body tissue is directly related to the composition of ingested water. For most large mammals, the composition of ingested water reflects local meteoric water (Longinelli, 1984; Luz et al., 1984). Although this correlation can be complicated by the ingestion of leaf water by browsers (Kohn, 1996, Kohn et al., 1998), a recent study has shown that oxygen isotopes ratios in CO_3^{2-} and PO_4^{3-} ($\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ values) of fallow deer are consistent with meteoric water across Europe (Miller et al., in prep).

Strontium and oxygen isotope analysis also took place at the NERC Isotope Geosciences Facilities. The enamel surface of each tooth was abraded to a depth of >100 microns using a tungsten carbide dental burr and the residue discarded. Thin enamel slices from the length of the tooth were then cut using a flexible diamond edged rotary dental saw. Bone and dentine samples were taken by a similar approach of abrading the surface and then cutting a small slice. For strontium analysis, samples were placed in de-ionised water at 60° for about an hour and the rinsed three times to remove and soluble contamination. Then they were cleaned ultrasonically in high purity water to remove adhering particulate material, rinsed again several times, dried and weighed into pre-cleaned Teflon beakers. The samples were then mixed with ^{84}Sr tracer solution and dissolved in Teflon distilled 8 M HNO_3. Strontium was collected using Dowex resin columns (Dickin, 1995).

The Sr isotope composition and concentrations were determined by thermal ionization mass spectroscopy (TIMS) using a Thermo Triton multicollector mass spectrometer. Samples were run at c. 3V using single Re filaments loaded using TaF following the method of Birck (1986). The international standard for ^{87}Sr/^{86}Sr, NBS987, gave a value of 0.710251 ± .000005 (n=19, 2σ) during the analysis of these samples. Blank values were in the region of 100pg.

For $\delta^{18}O_C$ analysis, approximately 3 mg of clean, powdered enamel was loaded into glass vials and sealed with septa. The samples powdered came from the length of the teeth, thereby averaging variability caused by seasonal variation during tooth formation. The vials were transferred to a hot block at 90˚C on a Multiprep system (GV Instruments, Manchester, UK). The vials were evacuated and four drops of anhydrous phosphoric acid were added. The resultant CO_2 is collected cryogenically for 14 min and transferred to a GV IsoPrime dual inlet mass spectrometer.

The resultant isotope values were normalized to the PDB scale using an in-house carbonate reference material (KCM) calibrated against NBS19 certified reference material. The $\delta^{18}O_C$ values were then converted into the SMOW scale using the published conversion equation of Coplen (1988) (SMOW=1.03091 x δ^{18}O PDB + 30.91). The 1σ reproducibility of the KCM reference material for this set of analyses was calculated by analysis of variance (ANOVA), which separates the within-batch variation from the between-batch variation (Miller and Miller, 1988).

Genetics

The surface of each sample was removed via surface sanding and bone powder was obtained using a mikrodismembrator (Sartorius). 0.05 g of bone powder was then incubated overnight at 50°C with 1 mL of extraction buffer (0.5 M EDTA at pH 8.0, 0.5% SDS and 0.5 mg/mL proteinase K) in a 1.5 mL tube. DNA was extracted using a QIAquick purification kit™ according to manufacturer’s instructions.

Precautions to avoid contamination were taken during every stage of aDNA extraction and PCR set up, which took place in a separate laboratory dedicated to ancient DNA research free from contemporary DNA or PCR product. No laboratory materials or clothing were transferred from the post amplification rooms to the ancient laboratory. All work surfaces and equipment were thoroughly cleaned with 10% bleach (sodium hypochlorite) followed by 70% ethanol. Surfaces, equipment, and solutions were also routinely exposed to UV light for at least 10 minutes. All extractions and PCR setup was carried out in class II PCR hoods. Negative extraction and PCR controls (1 sample in every 5) were included to detect potential contamination in reagents and cross contamination between samples. 50% of samples were replicated by extracting twice from independent samples of the same bone followed by PCR amplification and DNA sequencing.

A 333 bp subsection from the 5’ end of the mitochondrial control region was PCR amplified using a combination of the overlapping primers 1F: 5’ TTTAAACTATTCCCTGACGCTTA 3’ and 1R: 5’ AAGCATGGGGTATATGTAATGT 3’ and 4F: 5’ACATTACATTATATACCCCATGCTT 3’ and 5R: 5’ CACCACAGTTATGTGTGAGCA 3’. PCR Reactions (25µl) contained 2 µl of DNA extract, 1X Multiplex *PCR* Kit (Qiagen) and 0.2 µM of each primer. Thermal cycling conditions were as follows: an initial denaturation of 15 minutes at 95°C followed by 45 cycles of 30 seconds at 95°C, 90 seconds at 50ºC (Fallow 1F/1R) or 59ºC (Fallow 4F/5R), 45 seconds at 72°C followed by a final extension for 30 minutes at 60°C. Negative controls (no DNA) were used for all PCR runs. Purified PCR products were sequenced at DBS Genomics, Durham University.

2. Supplementary Information – Radiocarbon and isotopes analysis data

Map Nº and Site	Sample Nº	Element	Dating	δ13C VPDB (‰)	δ15N AIR (‰)	C/N ratio	87Sr/86Sr	δ18O SMOW carbonate	δ13C carbonate	δ34S VCDT (‰)
Pollentia 3rd - 4th century	PL117	Mandible		-20.5	4.1	3.4				
	PL118	Maxilla		-21.9	5.8	3.4				
	PL119	Mandible		-20.6	5.2	3.5	0.708426	29.43	-12.73	14.4
	PL120	Mandible		-21.2	5.6	3.5	0.79112	28.60	-12.15	16.3
	PL121	Humerus		-20.6	4.7	3.2				
	PL122	Mandible		-20.5	6.5	3.4	0.709047	28.60	-12.15	
	PL123	Humerus		-20.6	7.5	3.3				14.0
	PL124	Tibia	OxA-27878 (1776,26) 142-336 AD	-20.9	5.6	3.3				16.7
	PL125	Radius		-20.7	5.0	3.3				
	PL126	Metatarsal		-21.0	5.5	3.1				
	PL127	Metatarsal		-20.5	6.2	3.4				
	PL128	Tibia		-21.4	6.0	3.4				
	PL129	Tibia		-21.2	5.7	3.4				
	PL130	Scapula		-21.2	5.7	3.5				
	PL131	Scapula		-20.4	4.5	3.3				
	PL132	Humerus		-20.8	5.1	3.6				
	PL133	Calcaneum		-20.7	5.1	3.4				
	PL134	Calcaneum		-21.3	5.3	3.3				
	PL135	Radius		-20.5	5.8	3.4				
	PL136	Metacarpal		-21.3	5.1	3.3				17.1
	PL137	Metatarsal		-20.4	4.9	3.4				15.4
	PL138	Tibia		-20.6	5.3	3.3				
	PL139	Scapula		-21.5	5.8	3.3				
	PL140	Tibia		-21.3	5.4	3.5				
	PL141	Metatarsal		-20.5	6.7	3.4				
	PL142	Scapula		-20.7	5.7	3.3				
Sa Mesquida 4th – 6th century	SM143	Mandible		-19.5	6.0	3.5				
	SM144	Mandible		-20.8	4.8	3.4	0.709097	29.17	-12.23	
	SM145	Mandible		-20.3	5.9	3.4				
	SM146	Mandible		-20.0	4.1	3.5				
	SM147	Mandible		-19.8	4.6	3.3				
	SM148	Mandible	OxA-27936 (1678,25) 260-420 AD	-20.0	4.7	3.4	0.7086	29.42	-11.58	
	SM149	Mandible		-20.3	5.8	3.4	0.709026	26.55	-12.93	16.5

	SM150	Mandible		-20.1	4.9	3.3				17.5
	SM151	Mandible		-20.1	6.4	3.3				
	SM152	Mandible		-19.9	3.9	3.3				
	SM153	Mandible		-19.8	5.4	3.4				
	SM154	Mandible		-20.2	5.6	3.4				
	SM155	Maxilla		-20.2	6.2	3.4				
	SM156	Metatarsal		-19.6	5.3	3.4				14.8
	SM157	Radiusl		-20.0	5.4	3.4				
	SM158	Mandible		-19.2	6.7	**3.3**				
	SM159	Mandible		-20.1	5.0	**3.3**				
	SM160	Tibia		-20.1	5.7	**3.3**				
	SM161	Tibia		-19.5	5.3	**3.3**				18.0
	SM162	Tibia		-20.1	5.9	**3.3**				
	SM163	Metatarsal		-19.7	4.9	**3.3**				16.6
	SM164	Radius		-19.9	4.9	3.3				
	SM165	Humerus		-20.3	5.4	3.3				
	SM166	Radius		-20.1	3.9	3.4				
	SM167	Metatarsal		-20.0	5.5	3.3				
	SM168	Tibia	OxA-27936 (1678,25) 260-420 AD	-20.6	4.9	3.3				17.1

3. Supplementary Information – Genetic samples

Name	**Origin**	**Paper reference**	**Haplotype number**
***Dama Mesopotamica* reference**			
DM3	Stuttgart Zoo	Massetti et al., 2008	2
DM4	Stuttgart Zoo	Massetti et al., 2008	1
DM5	Stuttgart Zoo	Massetti et al., 2008	1
DM6	Stuttgart Zoo	Massetti et al., 2008	1
DM7	Stuttgart Zoo	Massetti et al., 2008	1
DM8	Stuttgart Zoo	Massetti et al., 2008	1
DM9	Stuttgart Zoo	Massetti et al., 2008	3
NC024819	Unknown	Hassanin et al. 2012	1
JN632630	Unknown	Hassanin et al. 2013	1
AF291896	Iran	Randi et al., 2001	1
Mallorca			
PL117	Pollentia	This study	4
PL119	Pollentia	This study	5
PL120	Pollentia	This study	5
PL121	Pollentia	This study	5
PL 123	Pollentia	This study	6
PL125	Pollentia	This study	5
PL126	Pollentia	This study	7
PL127	Pollentia	This study	5
PL128	Pollentia	This study	5
PL135	Pollentia	This study	5
PL142	Pollentia	This study	8
PL136	Pollentia	This study	5
PL573	Pollentia	This study	5
SM146	Sa Mesquida	This study	5
SM149	Sa Mesquida	This study	5
SM151	Sa Mesquida	This study	5
SM155	Sa Mesquida	This study	5
SM158	Sa Mesquida	This study	5
SM580	Sa Mesquida	This study	5

4. Supplementary Information – Dental ageing.

Site	Spec. No	Site Code	Dp4	P4	M1	M2	M3	MWS	Age
Pollentia	**PL119**	**FBY87-LH19105-545**	f		d			E	13-20
Pollentia	PL117	FBY87-5574-853			c			E-G	13-54
Pollentia	PL120	CR82/83-3059		f				H	44-147
Pollentia	**PL122**	**CR82-869**							
Sa Mesquida		1417	a					B	< 2 mths
Sa Mesquida		501	b					B	< 2 mths
Sa Mesquida	SM158	DA10/03/3039-3005	d					C-D	4-12 mths
Sa Mesquida		256	d					C-D	4-12 mths
Sa Mesquida	SM154	SM87/5A17/1423	e	c				E	13-20
Sa Mesquida	**SM144**	**SM87/5B56/479**		f	f	e	c	G	33-54
Sa Mesquida		1426					c	G	33-54
Sa Mesquida		3015					d	G	33-54
Sa Mesquida		1153		f	g	e	d	G	33-54
Sa Mesquida	**SM143**	**SM87/5A/168**		f	f-g	e		H	44-147
Sa Mesquida	**SM147**	**SM87/5B/607**		f	g			H	44-147
Sa Mesquida	SM151	DA10/03-3023-3039		f	g	e	e	H	44-147
Sa Mesquida		3017		f				H	44-147
Sa Mesquida		1510		g				H+	44-189
Sa Mesquida	SM145	SM87/5A17/1427			h	f	f	I	61-183
Sa Mesquida	SM149	DA10/03-3023-3038		g	j	f	f	I	61-183
Sa Mesquida		3014					f	I	61-183
Sa Mesquida		3013					f	I	61-183
Sa Mesquida	SM159	SM87/5B41/30			j	g	f	I	118-189
Sa Mesquida	SM146	SM87/5A/1375		l				J	118-189
Sa Mesquida	SM148	SM87/5B56/479		g	k	h	h	J	118-189
Sa Mesquida	SM150	DA10/03-3023-3037		h	k	h	h	J	118-189
Sa Mesquida	SM152	SM87/5B56/353		j+				J	118-189
Sa Mesquida	SM153	SM87/5A6394/147				i	i	j	118-189
Sa Mesquida		576				h	i	J	118-189
Sa Mesquida		1428		g	l			J	118-189
Sa Mesquida		1430				h	g	J	118-189
Sa Mesquida		1422		h	k	g	g	J	118-189
Sa Mesquida		1419			l	g-h	g	J	118-189
Sa Mesquida		577				i	i	J	118-189
Sa Mesquida		1424				g	g	J	118-189
Sa Mesquida		1421				j	j	J	118-189
Sa Mesquida		1420				i	i	J	118-189
Sa Mesquida		3016					k	J	118-189
Sa Mesquida		148		j	l			J	118-189
Sa Mesquida		1418		g	l			J	118-189
Sa Mesquida		1425			l	h		J	118-189