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Dama Dentition: a new tooth eruption and wear method for assessing the age of fallow deer (*Dama dama*).

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Running Title: Tooth eruption and wear method for assessing fallow deer age

Keywords Fallow deer, dental ageing, tooth eruption, tooth wear, known-age populations

Abstract

Reliable ageing techniques for wild animals are notoriously challenging to develop due to the scarcity of sizeable collections of known-age specimens. Without such techniques it is difficult to reconstruct hunting patterns, which is a significant problem for the examination of assemblages from pre-farming cultures. This paper presents a new method, based on mandibular tooth eruption and wear, for assessing the age of fallow deer. The method was developed from a large collection (*n* =156) of known-age *Dama dama* specimens, has been blind tested by members of the zooarchaeological community, and represents a user-friendly system with the potential to generate large compatible datasets through which the dynamics of human-*Dama* relationships can be examined.

Introduction

A prime concern of zooarchaeology has always been to determine the age of the animals represented within archaeological assemblages: hunting strategies, management regimes and the cultural significance of juveniles versus adults cannot be ascertained without such information. Various ageing techniques have been developed for different species and skeletal elements: some classic examples are presented in Wilson et al. (1982), with more recent approaches in Ruscillo (2006). The majority are concerned with domestic animals and while these techniques have been vital for elucidating human-animal relationships over the last 14,000 years, the comparative scarcity of methods pertaining to wild fauna has left a knowledge gap about hunter-gather communities, which account for many more millennia of the human past. In order to answer fundamental questions about animal management before domestication, but also to understand the role hunting played in farming societies, it is necessary to have access to well-researched, reliable ageing techniques for wild animals.

Some techniques have been developed for the ageing of cervids. Most recently, Dudley Furniss-Roe (2008) and Pérez-Barbería et al. (2014) established dental eruption and wear methods for assessing the age of red deer (*Cervus elaphus*). This species has been the focus of crown height ageing studies (Klein et al., 1981; Steele, 2006; Steele and Weaver, 2012) which have also been employed as a method for ageing reindeer, *Rangifer tarandus* (e.g. Pike-Tay et al., 2000). Whilst these two cervid species have attracted considerable attention from zooarchaeologists, fallow deer (*Dama dama dama* and *Dama dama mesopotamica*) have been almost entirely overlooked. This is despite the fact that the two *Dama* sub-species are very common in deposits from the late Pleistocene onwards and have been important to human economies ever since.

For instance, at the Epipalaeolithic Turkish site of Öküzini, fallow deer account for over 26% of the animal bones in some of the site’s phases (Atici, 2009). They are abundant in Neolithic and Bronze Age assemblage from Turkey (Fabiš, 2003) as well as those from Crete (Harris, 2014) and Cyprus (e.g. Vigne, 2011; Daujat, 2013; Vigne et al., 2015). Fallow deer also make up substantial components of the zooarchaeological assemblages from Roman period sites on Sicily (Wilson, 1990; Sykes et al., in prep) and Mallorca (Valenzuela et al., in prep.) as well as medieval sites in Britain (Carden and Sykes, 2010; Bowen et al., in prep). Today, fallow deer populations are very abundant in many areas of Europe and understanding their demographics is of central importance to deer managers (Brown and Chapman, 1990; Moore et al., 1995).

Ageing techniques for fallow deer have been created in the past. The seminal works are those of Brown and Chapman (1990; 1991) which examined 53 fallow deer of know age from Richmond Park in England, to develop ageing systems based on tooth development, eruption and wear. These studies were followed by Moore et al.'s (1995) assessment of various dental ageing techniques – eruption, wear, measurement of crown height and cementum analysis – on another 50 animals of known age, this time from Phoenix Park in Dublin. The same Dublin population later formed the basis of Carden and Hayden's (2006) larger study (*n* = 210 individuals) of post-cranial epiphyseal fusion. Despite the existence of these useful techniques, none have been consistently adopted by zooarchaeologists. This is perhaps because they were designed for use by a different discipline (primarily zoology) and, by comparison to the relatively simple zooarchaeological methods for dental ageing (notably Grant, 1982) they are not user-friendly for rapid application in the field: Brown and Chapman (1990) involves a complicated scoring system to determine the animal's age. Another potential problem is that the existing dental ageing techniques gives no consideration to the deciduous forth premolar, which is an important source of information in zooarchaeological studies.

In an attempt to further our understanding of how human-*Dama* relationships changed through time, this paper sets out a new dental ageing system, based on a large number of animals of know age. It is our hope that this method will become adopted as standard zooarchaeological technique for ageing fallow deer, just as Payne (1973) and Grant (1982) have become the standards for the dental ageing of cattle, sheep and pigs.

Materials

Osteological collections of known-age fallow deer are rare because, on the one hand, as a 'wild' animal, specimens generally derive from hunted individuals of indefinite history. On the other hand, biologists and zoologists have traditionally considered fallow deer not wild *enough*, preferring to focus collections on more iconic species, such as the red deer. By example, the Natural History Museum in London contains very few fallow deer specimens, despite (or perhaps because) the species is one of the most populous wild animals in the British Isles.

Three known-age collections of *Dama dama* were identified for this study and, together, they offered 156 mandibles of known age (Table 1). The first is that housed in the Muséum national d'Histoire naturelle in Paris (France). Unlike Britain, in France fallow deer have retained an ‘exotic’ status, being rare in the countryside but kept in menageries, such as the Ménagerie du Jardin des plantes, from which the collection derives. A total of 49 individuals are stored in the collection but only 10 of these had exact birth and death dates recorded. Furthermore, being kept in captivity undoubtedly had an unnatural effect on the teeth of some specimens: as a ‘population’ they exhibited excessively high levels of wear and oral pathology. This, combined with the small sample size of known-aged mandibles, rendered the collection insufficient to form the basis of a new ageing method, although they do provide very useful information concerning dental development at the younger end of the age spectrum (see Table 1). The second collection was provided by Norma Chapman. This material includes two individuals from Richmond Park (RP) in England, which were tagged at birth. A further six known-aged individuals from Epping Forest (EF), England, were also available for study.

The most sizeable collection is that from Phoenix Park, Dublin, which is stored at the National Museum of Ireland (NMI), Natural History Division, Dublin (Ireland). This park population, managed by the Office of Public Works in conjunction with the National Parks and Wildlife Service, has been the focus of an ongoing tagging at birth programme, which began in 1980 and has been carried out most years since (Hayden et al., 1992; Carden and Hayden, 2006). Specifically, individually identifiable ear tags were attached to the deer at (or shortly after) birth, each with a unique combination, colour coded by year and numbered. The animals examined in this study are known to have died as a result of road traffic accidents or from natural causes over a four-year period (Carden and Hayden, 2006: 228). Necropsy was performed between one to fourteen hours after death, and the bones subsequently prepared (maceration and natural burial) and examined to determine at what age ephiphyseal fusion occurred (Carden and Hayden, 2006).

< Table 1 around here >

Methods and Results

All three collections were visited, with analysis centring on mandibles from the left-hand side, although specimens from the right were also recorded. Pathological specimens and those that demonstrated obviously abnormal wear were noted so that they could be excluded, where appropriate, from further analyses.

Assessing age-related variations in crown heights

Where the teeth were fully erupted, crown height measurements were taken for the deciduous fourth premolar (Dp4), the permanent fourth premolar (P4) and the first, second and third molars (M1, M2, M3). These crown height measurements were taken on the lingual surface, from the cementum-enamel junction to the highest point of the crown (Figure 1).

< Figure 1 around here >

The relationships between crown height and age are shown in Figure 2a-e, which present the crown height data for each individual tooth plotted against the specimen’s age, with linear regression line also displayed.

< Figure 2 around here >

The strongest correlation between age and crown height is seen for the M1 (Fig. 2c), the regression line having a R^2 value of 0.6755. By contrast, the M3 (Fig. 2e) shows surprisingly little age-related variation in crown height, with an R^2 value of just 0.0008. This is presumably because the M3 is the last tooth to erupt and sits at the back of the dental arcade, so the crown has less time to wear down and its position reduces occlusion with the maxillary M3. On the basis of these distributions, it would seem that crown heights are a poor measure for assessing age in fallow deer. There may be scope for developing techniques for the M1 further, potentially to devise a system more akin to the work of undertake for red deer (e.g. Steele, 2006; Steele and Weaver, 2012); however, based on these results, it was felt that the zooarchaeological community would be better served by method closer to the more familiar and widely adopted system of Grant (1982). Therefore, all the mandibles had their state of tooth eruption and wear recorded.

Assessment of tooth eruption

For each mandible, high-resolution photographs were taken of the occlusal surface and buccal surface (Figure 3), focusing on the Dp4, P4, M1, M2 and M3.

< Figure 3 around here >

It was possible to establish age-related tooth eruption, loss and replacement without ambiguity, since the presence/absence of particular teeth can be quantified unequivocally. More subjective was assessing the *state* of eruption, so the following codes from Ewbank et al. (1964) were adopted:

- C - perforation in crypt visible.
- V - tooth visible in crypt
- E - tooth erupting through bone
- H - tooth about half way to full occlusal height.

Table 2 shows the approximate age at which each tooth passes through the different states of eruption. These are compared with the results of Chapman and Chapman (1970), Brown and Chapman (1990) and Moore et al. (1995). As can be seen, there are some slight variations between the different studies, likely reflecting inter-population differences in diet and landscape. However, overall, there is general consistency. The important difference of this study is that, by including the Dp4 and by breaking the eruption process into different stages of eruption it is possible to gain a finer resolution age assessment than previous methods have allowed.

< Table 2 around here >

Creation of tooth wear stages (TWS)

To develop tooth-specific wear patterns that might be assigned to age, images of the individual teeth (Dp4, P4, M1, M2, and M3 – see Figure 4 for outlines and directional terminology) were captured from each mandibular photograph. These images were coded with their sample number but all references to age were removed, so not to bias the decisions about tooth-wear progression. The images were printed out in hard copy and each tooth was traced with black ink to highlight the progression of enamel-dentine patterns and facilitate the grouping of the images into Tooth Wear Stages (TWS). Figure 5 demonstrate an idealised pattern of TWS progression. More detailed examinations of the traits that characterise each TWS are provided in Tables S1-S5.

< Figures 4 and 5 around here >

Creation of mandibular wear stages (MWS)

To calculate overall mandibular wear stages (MWS) with associated age estimates, all of the mandibles in the collection were re-examined as complete specimens (as opposed to individual teeth) using the newly developed TWS system (Figure 5). At this point the specimens were reconnected to their age data, so that the TWS results could be placed into age-related MWS categories (see Table 3). For several reasons, this aspect of the study reduced the sample size from 156 to 113 individuals. Notably, the three adult individuals from the Paris collections were excluded from the MWS calculations as they demonstrated such abnormally accelerated wear associated with the population’s high level of oral pathology. For the Chapman collection, the individuals attributed to ‘older than 109 months’ were also excluded. A number of the Phoenix Park mandibles could not be used because, on reconciliation with the ageing data, the attributions appeared erroneous (e.g. suspected data entry number transposition, whereby 18 months became 81 months). Some mandibles lacked the full set of dentition due to post-mortem tooth loss and others could not be utilised because the occlusal wear on some teeth was obscured either by poor photography or inadequate cleaning.

As is always the case with dental ageing systems, the tightest resolution with the least overlap between age groups, is found at the younger end of the spectrum, up to about 20 months of age (MWS A to F). This is because, for sub-adult animals, it is possible to combine both tooth eruption and wear patterns. Once the full set of adult dentition is in place (20 months/Stage F onwards) calculations must be based on tooth wear alone. For stages F to J, mandibles are most easily separated into their respective MWS on the basis of the TWS for the M3. Whilst the state of wear for this tooth is diagnostic for placement into MWS, Table 3 shows that there is considerable overlap in the age estimates for stages G to J. Despite the lack of resolution at the upper end of the age spectrum, this system appear to represents a significant step forward in ageing techniques for fallow deer. To be a genuine step forward, however, the system needs to be used and have the capability of generating consistent results.

< Table 3 around here >

Inter-observer and repeatability testing

Issues of ease of application, repeatability and levels of inter-observer error were tested by with help from members of the Professional Zooarchaeology Group. Each member was given three known aged (but anonymised) mandibles, randomly selected from the Dublin collection to which the ageing system was applied. A week later, the same mandibles were aged again by two members of the group. The results of these two tests are shown in Tables S5 and S6.

A high level of inter-observer variation was noted in the assignment of individual tooth wear stages, which ranged from as low as 42% to 79% of the mode TWS (Table S6). Despite this variation, it is notable that 93% of assignments were to the TWS immediately higher or lower than the mode value. Results were far more consistent for the assignment of mandible wear stage: the majority of observers (79 – 96%) assigned the mandibles to the same MWS, with 100% of observations falling within one MWS score of the mode value. Importantly, the MWS assignments corresponded to the known-age of the individual. The repeatability test again highlighted some variation in the assignment of TWS scores but the MWS results were identical (Table S7), indicating that workers are able to apply the method with a high level of consistency.

Together these test results demonstrate the utility of the system for generating standardized and accurate ageing data. The system therefore has applicability for both archaeological and modern studies of human-deer relationships.

Archaeological and Deer Management Applications

The methods presented above were applied to archaeological *Dama* mandible bones collated as part of the AHRC-funded *Dama* International Project: this includes physical specimens as well as photographic records sent by researchers from across Europe. Data for 77 archaeological fallow deer mandibles were acquired from a variety of archaeological periods (Neolithic to Medieval) and geographical regions (Mediterranean to Britain). These were complemented by 104 modern specimens recovered from a 'poaching cache' on the island of Barbuda in the Caribbean, where fallow deer is the national animal (Baker et al., 2014). Despite the small samples size for the archaeological material, the results are highly interesting. As can be seen from Table 4 the Neolithic material derives exclusively from animals aged over 20 months of age (MWS F or above). Through time, there is a shift towards a higher percentage of animals aged under 20 months of age: 12% in the Bronze Age assemblages, 21% for Roman period material and 30% for the medieval period.

< Table 4 around here >

This shift would appear to chart changes in human-deer relationship, as the species moved from being a wild, hunted animal in the Neolithic, to being more closely managed in the Bronze Age and Roman periods, when fallow deer were deliberately introduced to Mediterranean islands (Masseti, 2002; Sykes, 2010). The high percentage of juvenile animals in the medieval assemblages likely reflects the state of emparked deer, which were closer to livestock than wild animals (Birrell, 1992; Bowen et al., in prep).

Against this archaeological evidence, the data for modern Barbuda are particularly interesting, since they demonstrate an exceptionally high percentage (53%) of animals under the age of 20 months. That 35% of the Barbudan animals are less than 12 months of age is, potentially, concerning, as it suggests little regard for herd sustainability.

Conclusion

Up to now, in the absence of a standardised dental ageing method for fallow deer, examinations of human-*Dama* relationships have been restricted and detailed studies concerning hunting and management strategies have not been possible. By developing a tested system based on collections of known-age fallow deer, the opportunities for examining the bio-cultural history of this species are now considerable. The ability of researchers to assign stages of mandible wear consistently opens up the possibility of generating large compatible datasets that have the potential to inform on hunting strategies and the dynamics of fallow deer taming, management and domestication. This is a significant step forward for Prehistoric assemblages from the Western Mediterranean, where fallow deer were both endemic and culturally important, but also for assemblages from medieval northern Europe, where translocated populations became particularly well established. Aside from the clear archaeological potential of this method, it also has applications in wildlife management since age assessments are key for developing deer management strategies. We hope that this paper provides the methodological foundations upon which further studies – archaeological and modern – can be built.

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Supporting Information

Detailed descriptions of the traits that characterise each TWS are provided in Tables S1-S5 and the blind testing results are provided in Tables S6-S7.

Table S1. Progression of enamel-dentine patterning for Dp4 with trait descriptions for each tooth wear stage (TWS)
Table S2. Progression of enamel-dentine patterning for P4 with trait descriptions for each tooth wear stage (TWS)
Table S3. Progression of enamel-dentine patterning for M1 with trait descriptions for each tooth wear stage (TWS)
Table S4. Progression of enamel-dentine patterning for M2 with trait descriptions for each tooth wear stage (TWS)
Table S5. Progression of enamel-dentine patterning for M3 with trait descriptions for each tooth wear stage (TWS)
Table S6. Results of inter-observer variation test undertake on three mandibles
Table S7. Results of repeatability test.

References

Atici L. 2009. Implications of age structures for Epipaleolithic hunting strategies in the Western Taurus Mountains, southwest Turkey. *Anthropozoologica* **44(1)**: 13-39

Birrell J. 1992. Deer and deer farming in medieval England. *The Agricultural History Review* **40(2)**: 112-126.

Bowen F, Baker K, Carden RF, Evans J, Higham T, Lamb A, Madgwick R, Miller H, Thomas R, Sykes N. In prep. Wild to domestic and back again: the dynamics of fallow deer management in medieval England.

Brown W, Chapman N. 1990. The dentition of fallow deer (*Dama dama*): a scoring scheme to assess age from wear of the permanent molariform teeth. *Journal of Zoology* **221(4)**: 659–682.

Brown W, Chapman N. 1991. Age assessment of fallow deer (*Dama dama*): from a scoring scheme based on radiographs of developing permanent molariform teeth. *Journal of Zoology* **224(3)**: 367–379.

Carden RF, Hayden TJ. 2006. Epiphyseal fusion in the postcranial skeleton as an indicator of age at death of European fallow deer (Dama dama dama, Linnaeus, 1758), In *Recent Advances in Ageing and Sexing Animal Bones*, Ruscillo D (ed.). Oxbow Books: Oxford, 227-236.

Chapman N, Chapman D.1970. *Fallow Deer: Their History, Distribution and Biology*. Terence Dalton: Lavenham.

Daujat J. 2013 *Ungulate invasion on a Mediterranean island: the Cypriot Mesopotamian fallow deer over the past 10,000 years*. Unpublished PhD, University of Aberdeen and Muséum national d'Histoire naturelle de Paris (France)

Dudley Furniss-Roe T. 2008. *Incremental structures and wear patterns of teeth for age assessment of Red Deer*. BAR International Series 1835, Archaeopress: Oxford.

Ewbank JM, Phillipson DW, Whitehouse RD, Higgs ES. 1964. Sheep in the Iron Age: a Method of Study. *Proceedings of the Prehistoric Society (New Series)* **30**: 423-426.

Fabiš M. 2003. Troia and fallow deer. In *Troia and the Troad: Scientific Approaches*, Wagner GA, Pernicka E and Uerpmann H-P (eds). Springer-Verlag: Berlin; 263-276.

Grant A. 1982. The use of tooth wear as a guide to the age of domestic ungulates. In *Aging and Sexing Animal Bones from Archaeological Sites*, Wilson B, Grigson C, and Payne S (eds). Archeopress: Oxford; 91-108.

Harris K. 2014. Hunting, performance and incorporation: human-deer encounter in Late Bronze Age Crete. In *Deer and People,* Baker K, CardenRF, and Madgwick, R (eds). Windgather Press: Oxford; 48-58.

Hayden TJ, Moore NP, Kelly, PF. 1992. The fallow deer of Phoenix Park: an evolving management plan. In *Management, Welfare and Conservation of Park Deer*. Proceedings of the Second Deer Park Symposium: Leicester; 27-45.

Klein RG, Wolf C, Freeman LG, Allwarden K. 1981. The use of dental crown heights for constructing age profiles of red deer and similar species in archaeological samples. *Journal of Archaeological Science* **8**: 1–31.

Masseti M. 2002. *Island of Deer: Natural History of the Fallow Deer of Rhodes and the Vertevrates of the Dodecanese (Greece),* Masseti M (ed.). Environmental Organisation: City of Rhodes.

Moore NP, Cahill JP, Kelly PF, Hayden TJ. 1995. An assessment of five methods of age determination in an enclosed population of fallow deer (*Dama dama*). *Biology and Environment: Proceedings of the Royal Irish Academy* **95B(1)**: 27-34.

Payne S. 1973. Kill-off patterns in sheep and goats: the mandibles from Aşvan Kale. *Anatolia Studies* **23**: 281-303.

Pérez-Barbería FJ, Duff EI, Brewer MJ, Guinness FE. 2014. Evaluation of methods to age Scottish red deer: the balance between accuracy and practicality. *Journal of Zoology*, **294**(3): 180-189.

Pike-Tay A, Morcomb CA, O'Farrell M. 2000. Reconsidering the quadratic crown height method of age estimation for *Rangifer* from archaeological sites. *ArchaeoZoologia* **11**: 145–174.

Ruscillo D. 2006. *Recent Advances in Ageing and Sexing Animal Bones*. Oxbow Books: Oxford.

Steele TE. 2006. Accuracy of age determinations from tooth crown heights: a test using an expanded sample of known age red deer (*Cervus elaphus*). In *Recent Advances in Ageing and Sexing Animal Bones,* Ruscillo D (ed.). Oxbow Books: Oxford; 119-128.

Steele TE, Weaver TD. 2012. Refining the Quadratic Crown Height Method of age estimation: do elk teeth wear quadratically with age? *Journal of Archaeological Science* **39**(7): 2329-2334.

Sykes NJ. 2010. Fallow deer. In *Extinctions and Invasions: A Social History of British Fauna*, O'Connor T and Sykes NJ (eds). Windgather Press: Oxford; 51-58.

Sykes N, Carden RF. 2011. Were fallow deer spotted (OE* pohha/* pocca) in Anglo-Saxon England? Reviewing the evidence for Dama dama dama in early medieval Europe. *Medieval Archaeology* **55**(1): 139-162.

Sykes N, Baker K, Bartosiewicz L, Carenti G, Hoelzel R, Johnstone C, Lamb A, Miller H, Wilkinson B. In prep. Refugia or exotica? The fallow deer of Sicily and Sardinia.

Valenzuela A, Bowen F, Carden RF, Evans J, Higham T, Lamb A, Madgwick R, Miller H, Sykes N. In prep. Domesticating the wild: the fallow deer of Roman Mallorca.

Vigne J-D. 2011. Le daim de Méopotamie (Dama dama mesopotamica). In *Shillourokambos, un établissement néolithique pré-céramique à Chypre, les fouilles du secteur 1*. In Guilaine J, Briois F, and Vigne J-D (eds). Éditions Errance, Paris, École Française d'Athènes: Athens; 971–1000.

Vigne, J-D, Daujat J, Monchot H. 2015. First introduction and early exploitation of the Persian fallow deer on Cyprus (8,000-6,000 cal. BC). *International Journal of Osteoarchaeology*. DOI 10.1002/oa.2488

Wilson B, Grigson C, Payne S. 1982. *Ageing and Sexing Animal Bones from Archaeological Sites. British Archaeological Reports* Archeopress: Oxford.

Wilson R. 1990. *Sicily under the Roman Empire*: *The Archaeology of a Roman Province, 36 BC – AD 535*. Aris and Phillips: Warminster.

	Age Group (in months)																			
Paris	**<1**	**1-6**	**7-12**	**13-18**	**19-24**	**25-36**	**37-48**	**49-60**	**61-72**	**73-84**	**85-96**	**97-108**	**109-120**	**121-132**	**133-144**	**145-156**	**157-168**	**169-180**	**181-192**	**Total**
Male	3		1										1							**5**
Female	1		1						1		1									**4**
Unknown	1																			**1**
Total	**5**		**2**						**1**		**1**		**1**							**10**
Chapman	**<1**	**1-6**	**7-12**	**13-18**	**19-24**	**25-36**	**37-48**	**49-60**	**61-72**	**73-84**	**85-96**	**97-108**	**109-120**	**121-132**	**133-144**	**145-156**	**157-168**	**169-180**	**181-192**	**Total**
Male (EF)				1			1													**2**
Female (EF)						1	1				1		1*							**4**
Male (RP)									1											**1**
Female (RP)													1*							**1**
Total				**1**		**1**	**2**		**1**		**1**		**2***							**8**
Dublin	**<1**	**1-6**	**7-12**	**13-18**	**19-24**	**25-36**	**37-48**	**49-60**	**61-72**	**73-84**	**85-96**	**97-108**	**109-120**	**121-132**	**133-144**	**145-156**	**157-168**	**169-180**	**181-192**	**Total**
Male		1	13	15	3	5	1	1	3	2	3	1	2	2	2					**54**
Female		5	9	14	5	7	5	1	2	4	2	3	4	4	2	5	3	4	5	**84**
Total		**6**	**22**	**29**	**8**	**12**	**6**	**2**	**5**	**6**	**5**	**4**	**6**	**6**	**4**	**5**	**3**	**4**	**5**	**138**
Grand Total	***5***	***6***	***24***	***30***	***8***	***13***	***8***	***2***	***7***	***6***	***7***	***4***	***9***	***6***	***4***	***5***	***3***	***4***	***5***	***156***

Table 1: Demographic composition and sample size of the fallow deer collections considered in this study: Muséum national d'Histoire naturelle (Paris, France), Norma Chapman's personal collection from Epping Forest (EF) and Richmond Park (RP), and the National Museum of Ireland (Dublin). N.B * = deer aged as >109 months.

This study (n=113)	Chapman & Chapman 1970 (n=180)	Brown & Chapman 1990 (n=53)	Moore *et al*. 1995 (n=50)
Dp4 – H at birth, lost at *c*. 20 mths			
P4 – E at c. 20 mths, in wear by 24 mths	17-21 mths	22 mths	H at 20 mths, fully erupted at 22 mths
M1 – V at birth, H at 5 mths, in wear at 7 mths	3-5 mths	5 mths	
M2 – C at 3 mths, V at 9 mths, H and in wear at 15 mths	9-13 mths	18 mths	H at 12 mths, erupted at 20 mths
M3 – C at 12-15 mths, V at 18 mths, E at 18-20 mths, H and in wear at 20-24 mths	13-21 mths	26 mths	erupting at 20 mths, erupted 28 mths

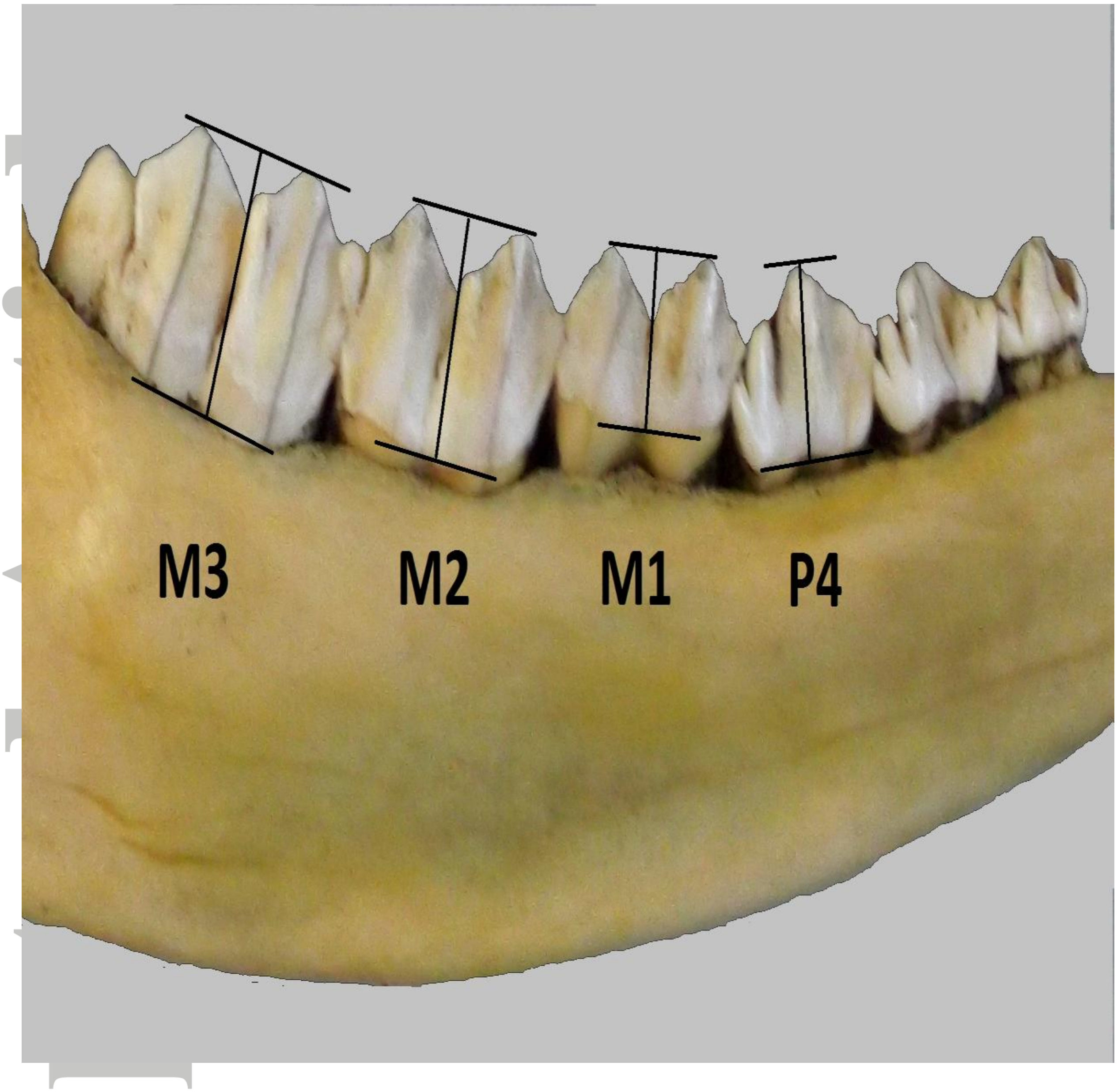
Table 2. Dental eruption sequence for this study compared with Chapman and Chapman's (1970) and Brown and Chapman's (1990) ages for 'coming into wear', and with the results of Moore et al. (1995). Age range reported in months (mths) since birth.

Mandible Wear Stage	Descriptor (Tooth Wear Stage)	Estimated Age	*n*
A	**Dp4 H**; M1 V	Birth to 7 days	5
B	**Dp4 a-b**; M1 V	Up to 2 months	2
C	**Dp4 c-d**; M1 V-H	4-5 months	2
D	Dp4 d-e; M1 a-b; **M2 C-V**	5-12 months	16
E	Dp4 e-g; M1 c-d; M2 a-c; **M3 C-H**	13-20 months	26
F	P4 a-d; M1 c-d; M2 c-d; **M3 a-b**	20-33 months	6
G	P4 d-e; M1 c-e; M2 d-e; **M3 c-d**	33-54 months	9
H	P4 e-g; M1 f-h; M2 f-g; **M3 e**	44-147 months	19
I	P4 g; M1 g; M2 g; **M3 f**	61-183 months	15
J	P4 g-l; M1 g-j; M2 g-l; **M3 g+**	118-189 months	13

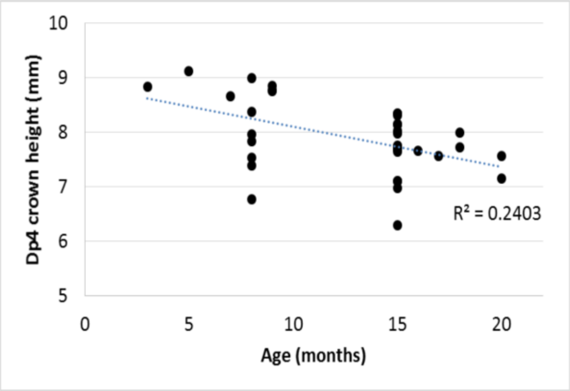
Table 3. Correlation chart for converting TWS data into overall MWS, with associated age estimations based on the known-age data from the Chapman, Paris and Dublin collections. The most diagnostic TWS for assigning MWS are highlighted in bold. Sample sizes (n) for each MWS are provided.

	Neolithic Turkey/Balkans		**Mediterranean Islands Bronze Age**		**Mediterranean Islands Roman**		**Medieval Parks UK**		**Modern Barbuda**	
MWS	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
A) Birth-7 days										
B) Up to 2 months										
C) 4-5 months					1	*4*	4	*20*	10	*9.6*
D) 5-12 months			2	*8*	1	*4*			26	*25*
E) 13-20 months			1	*4*	3	*13*	2	*10*	19	*18.3*
F) 20-33 months	1	*12.5*	1	*4*					11	*10.6*
G) 33-54 months	2	*25*	7	*28*			2	*10*	20	*19.2*
H) 44-147 months	3	*37.5*	4	*16*	8	*33*	5	*25*	9	*8.65*
I) 61-183 months	1	*12.5*	3	*12*	2	*8*	3	*15*	9	*8.65*
J) 118-189 months	3	*37.5*	7	*28*	9	*38*	4	*20*		
Total	**8**	***100***	**25**	***100***	**24**	***100***	**20**	***100***	**104**	***100***

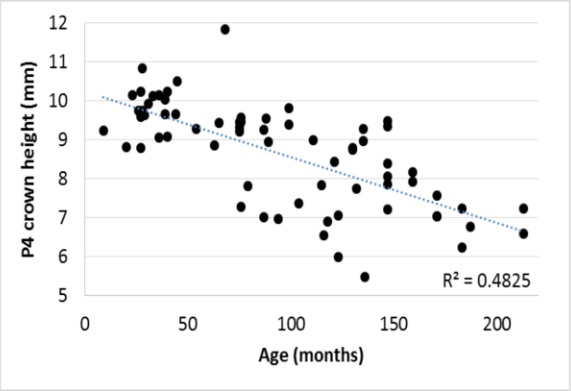
Table 4. Ageing data for archaeological *Dama* from sites of different date and geographical region.


M3
M2
M1
P4

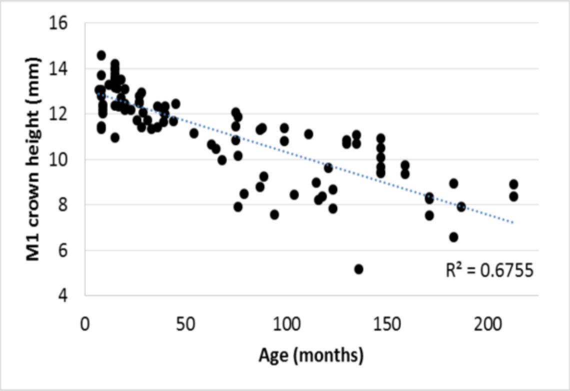
A)


Dp4 crown height (mm)
10
9
8
7
6
5
0
5
10
15
20
Age (months)
R² = 0.2403

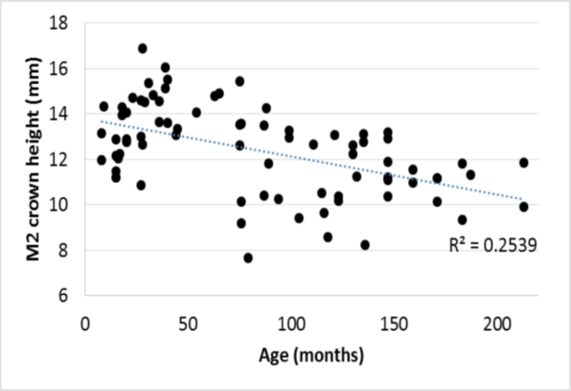
B)


P4 crown height (mm)
12
11
10
9
8
7
6
5
0
50
100
150
200
Age (months)
R² = 0.4825

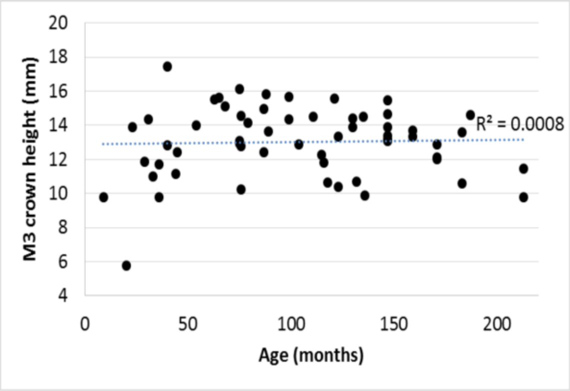
C)

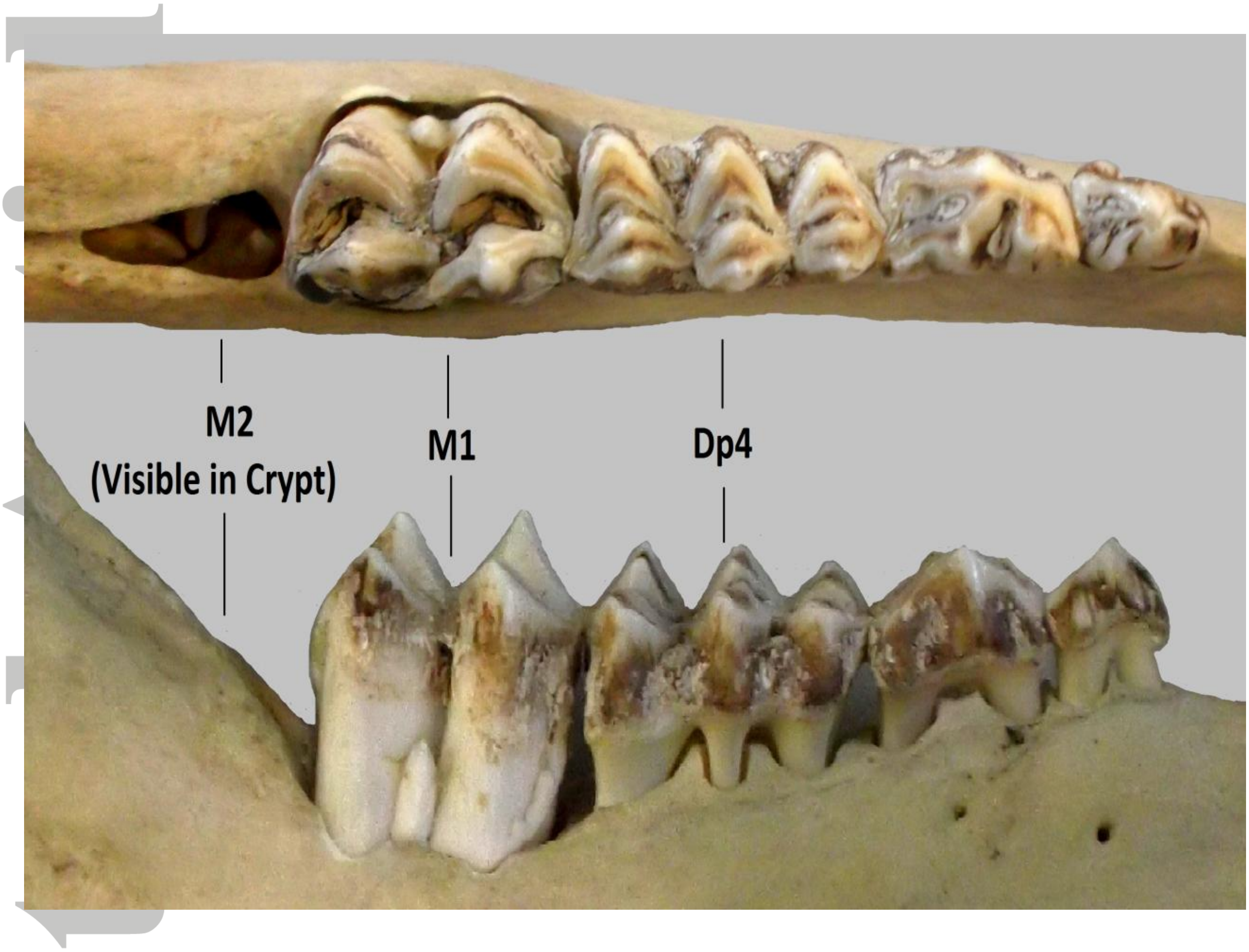

M1 crown height (mm)
16
14
12
10
8
6
4
0
50
100
150
200
Age (months)
R² = 0.6755

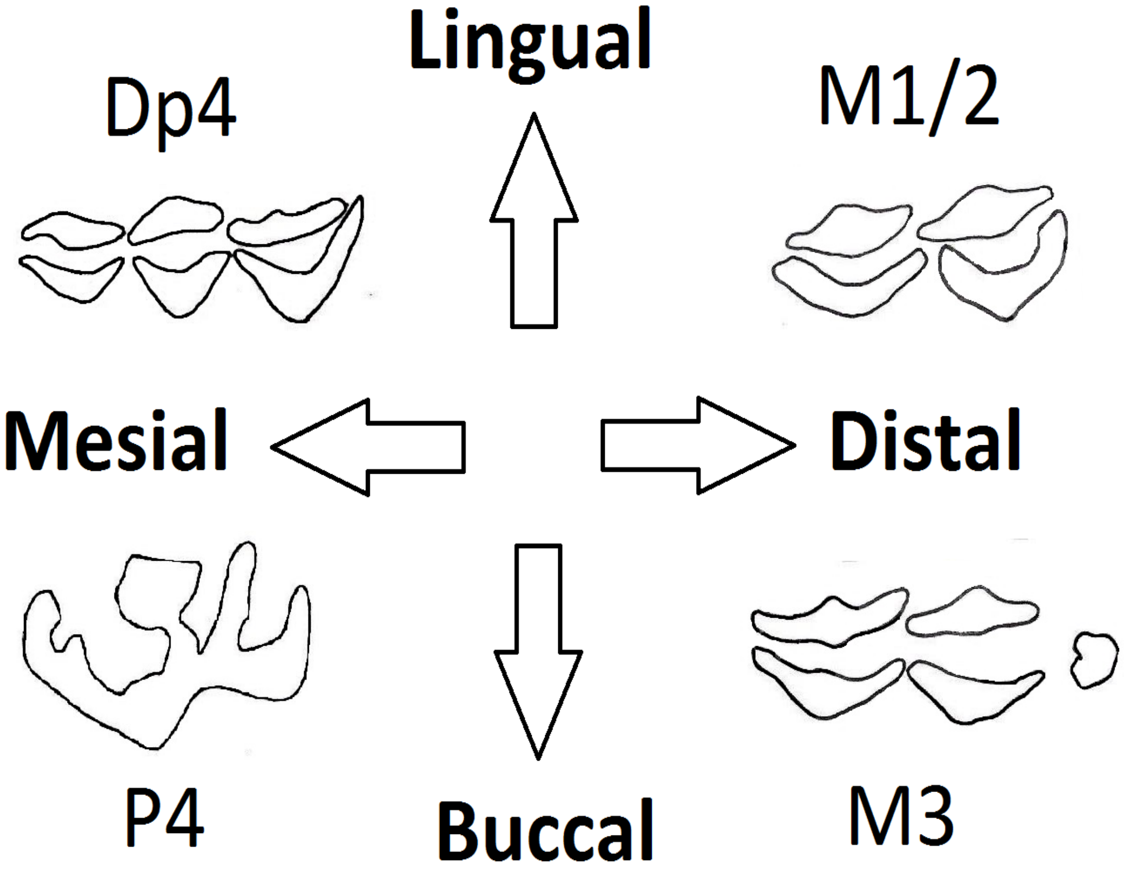
D)

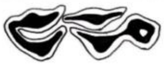
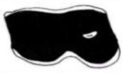

M2 crown height (mm)
18
16
14
12
10
8
6
0
50
100
150
200
Age (months)
R² = 0.2539

E)


M3 crown height (mm)
20
18
16
14
12
10
8
6
4
0
50
100
150
200
Age (months)
R² = 0.0008


M2
(Visible in Crypt)
M1
Dp4


Lingual
Dp4
M1/2
Mesial
Distal
P4
Buccal
M3

TWS	Dp4	P4	M1	M2	M3
C	Perforation in **C**rypt visible				
V	Tooth **V**isible in crypt				
E	Tooth **E**rupting through bone				
H	Tooth about **H**alf way to full occlusal height				
a					
b					
c					
d					
e					
f1					
f2					
g1					
g2					
g3					
h					
i					
j					
k					
l