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War Horses and Equine Herd Feeding Management at the End of the Third Century BC: New Insights from Pech Maho (Southern France)

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ABSTRACT

The *emporion* of Pech Maho was destroyed after a warlike event at the end of the third century BC. Shortly after that, around 200 BC, the site was resettled. This reuse is characterised above all by massive deposits of equid carcasses in various locations around the city. The conditions of these deposits are investigated in this paper. We focus on examining several biological parameters (weight, age and sex) of the equid population, as well as their feeding habits, using three different proxies: stable isotope, dental meso- and microwear. This interdisciplinarity gives us access to the overall equid diet, as well as to the diet during the last phases of their lives. This population is largely dominated by small size young adult males. Isotopic as well as morphometric analyses indicate that they were bred in various locations before being brought to Pech Maho. Dental wear analyses show that they experienced the same feeding throughout their lives and just before their death. The animals were all slaughtered within a short period of time. This study illustrates the advantages of combining proxies in order to enhance our understanding of the life and death conditions of Iron Age equids.

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Introduction

The archaeological site of Pech Maho, in Southern France (Sigean, Aude), is a fortified coastal *emporion* founded in the middle of the sixth century BC and partially abandoned at the end of the third century BC (Gailledrat and Belarte 2019). The *emporion* was in use for nearly three centuries as an important place of exchange between the Iberian-Languedocian and Mediterranean worlds (Figure 1) (Gailledrat 2014). At the end of the third century BC (*circum* 225–200 BC), the site was destroyed by a warlike event, identified thanks to traces of looting, destruction and the discovery of Hellenistic-type weaponry (Gailledrat 2014). After this event, towards 200 BC (Pech Maho IV), the site was once again briefly reused. This chronological phase is characterised by human bodies without a grave simply abandoned on the ground or summarily buried, or even dismembered body parts, evidence of collective banquets, and at the end of this sequence, a funeral pyre of a dozen individuals (Gailledrat et al. 2017). These ‘post-destruction’ levels also contained massive deposits of horse and donkey carcasses (Gailledrat and Gardeisen 2010). A minimum of one hundred-and-one horses

and thirteen donkeys have been identified in several zones of the site (Figure 2) (Boulbes and Gardeisen 2014; 2018). These equids were slaughtered, skinned, butchered and quartered. Cut marks are present on several portions of the skeleton: the long bones bear traces of emaciation indicating the removal of muscle mass, while the ribs are sliced on both edges, delimiting portions 80–100 mm long, perhaps corresponding to ‘individual portions’. The equids deposits would therefore be made up of cutting and direct consumption waste (Gailledrat and Gardeisen 2010). After dislocation and dispersal at the site, the carcasses were covered by a thin layer of sediment. The excellent preservation of the remains owes a lot to this protective sediment (Gailledrat and Gardeisen 2010).

Accumulations of horses are documented in several other Iron Age settlements (Foucras 2014; Lepetz, Boury, and Boulestin 2014; Meniel 2014; Cabrera Díez and Moreno García 2014; Albizuri et al. 2019; Celestino Pérez and Rodríguez González 2019; Bayle and Salin 2012), but the number of individuals at Pech Maho is exceptional in an archaeological context. Several hypotheses have been put forward to explain the presence of these equid deposits. In the context



Figure 1. Geographic position of the Pech Maho site, Aude, France.

of the Second Punic War, they could have been Roman army mounts or the mounts of allies who came to punish the town of Pech Maho for having given free passage to Hannibal's army (Tite-Live, XXI, V, 21–24). Yet, the accumulation of horses at Pech Maho took place after the destruction of the town, which is not consistent with the death of horses during the war event. They could also have been killed for human consumption, or animals deemed to be unfit for work or training

(Gailledrat and Gardeisen 2010). But, it would imply that this exceptional equid accumulation is unrelated with the war event that took place shortly before. None of these hypotheses is really satisfactory to explain the Pech Maho equids accumulation and its context. Moreover, the deposit modalities and their repartition inside the site are more consistent with ritual practices that took place after the destruction of the town (Gailledrat 2017).

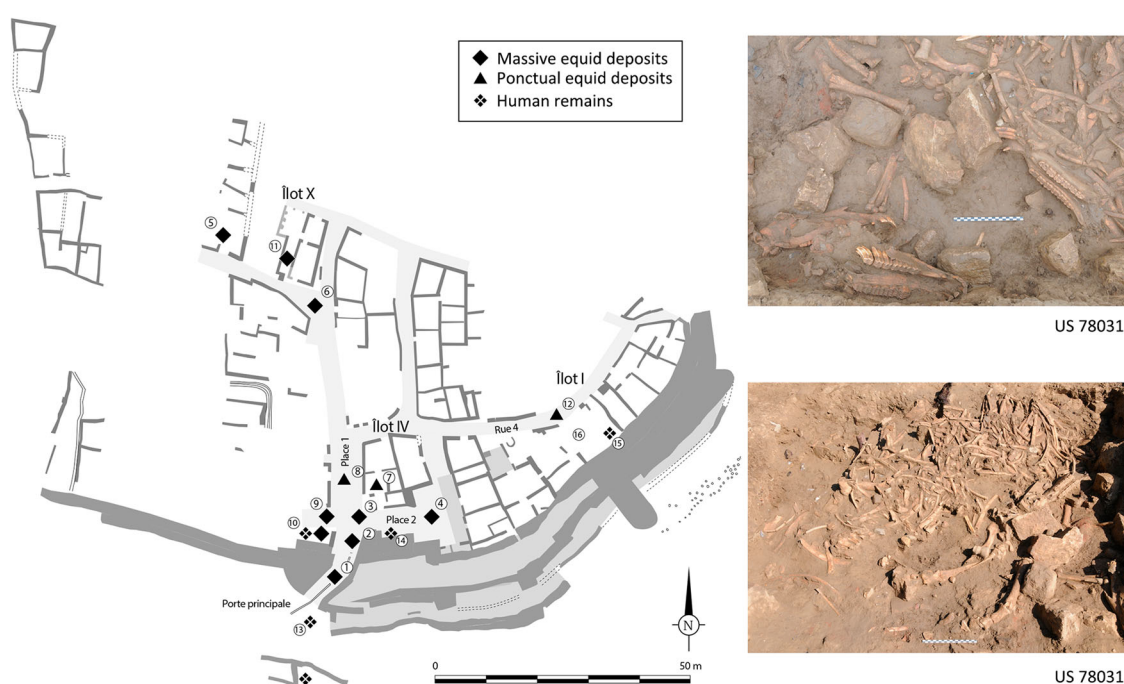


Figure 2. Plan of the Pech Maho settlement in the third century BC with finds of equid and human remains.

In this study, we aim to reconstruct the diet of the Pech Maho horses over several time scales using two different methods and to compare it with biological parameters. Analyses of carbon and nitrogen ratios of bone collagen are used to reconstruct the average diet of the last years of life (Fahy et al. 2017) and dental wear (mesowear and microwear) reflects the diet of the last phase of life (Fortelius and Solounias 2000; Solounias and Semperebon 2002). The diet of a domestic animal is directly correlated to husbandry practices. Dietary reconstruction on several time scales can detect an evolution in the treatment of horses by human populations and shed some light on the context of horse killing at Pech Maho. At the same time, it contributes to contextualising the animals in relation to some of their biological characteristics.

Pech Maho Horse Population

A huge number of equids (MNI = 114) were killed on site or near the site and cut up before being deposited in differentiated deposits. These mixed deposits recurrently comprised Equidae bones, weapons, harnessing pieces and possibly decollated wine amphorae (Gailledrat 2014). Cut mark on the bones indicate that equid meat was partly recovered and probably consumed (Gailledrat and Gardeisen 2010). Some traces of violence (traces of chopping up with machetes) were clearly identified (Gailledrat and Gardeisen 2010). The deposits were found in eight zones of the sites (37, 61, 68, 71, 72, 73, 75, 77 and 78) and their spatial distribution does not seem to be random. They were mainly deposited in heaps, in open spaces near former public buildings and fortifications, and never inside areas recognised as former houses. The deposits may have been made in a short period of time and are contemporaneous from an archaeological perspective. Remains are mostly found in association with sets of warrior and ritual objects (Gailledrat 2014). The bones are well preserved and anatomically dispersed. A lot of bones bear cut marks but cannot all be linked to food purposes (Boulbes and Gardeisen 2018). Nearly 150 bone and dental elements corresponding to at least 13 individuals can be attributed to the domestic donkey, and around 101 individuals to *Equus caballus*.

Studies have been conducted on the morphology, size and skeletal proportions of the equids from Pech Maho (Gailledrat and Gardeisen 2010; Boulbes and Gardeisen 2014; Boulbes and Gardeisen 2018). On the basis of morphological characteristics, the material was divided into the largely predominant horse remains, and those attributed to the much rarer donkey. The presence of hybrids, identified at sites as early as the La Tène Iron Age (Fages et al. 2019), has not yet been demonstrated at Pech Maho. DNA sampling of 25 previously determined horse tooth specimens recently confirmed this attribution (Lepetz et al. 2021).

The study of the skeleton differentiated several morphotypes within the horse population (Figure 3). Abnormally high coefficients of variation for numerous metric variables on postcranial bones and normality tests underline the statistical heterogeneity of the collection (Boulbes and Gardeisen 2014).

The main type corresponds to the Iron Age horse usually described in Western Europe (Johnstone 2004) and in Gaul (Foucras et al. 2019; Méniel 1998; Forest 2008). Individuals are small and slender. Average withers height is around 1.23 m and weight estimations based on distal metapodial dimensions are about 236 kg. Metacarpal shape or slenderness index is situated between 14 and 15.5, corresponding to slender and mid-slender categories on Brauner's scale (Brauner 1916) (Figure 3). Additional features are a moderately elongated and narrow muzzle, and not very advanced cursorial adaptation according to the relative lengths of limb bones.

Some individuals from zones 61, 71, 73, 78 are more robust. The Brauner's index of the shaft metacarpal varies between medium and mid-robust groups (Figure 3). The diaphysis width (SD) and midshaft cortical thickness can be as much a function of activity in life as phenotypic expression. The indices at extremities (Bp and Bd) are not more informative but also detect the general robustness of some specimens from the 78 deposits. Several other elements from zones 78 and 37 (and 102) are also distinguished by their larger size (withers height estimation about 1.37–1.43 m, Figure 3). This observation is not a unique case as other marginal horses are sometimes identified for this period (Forest 2013; Albizuri et al. 2019).

The donkey from Pech Maho is characterised by its very small size (Figure 3). Withers height is less than 1 m (0.96 m), and weight estimation is about 100 kilos. The metacarpal shape index varies from the very slender class (just under 13.5) to the slender class (between 13.5 and 14.5). Archaeological comparisons show that this small size was common during the Iron Age in the North Mediterranean Basin (Boulbes and Gardeisen 2018). In particular, the Pech Maho donkey is very similar to donkeys from Iberia, which could point to the common origin of these populations and/or exchanges in an archaeological context of continuous links with the Iberian Peninsula since the earliest phases of settlement at the site (Gailledrat et al. 2017). Moreover, genomic analysis of human skeletons suggested an Iberic origin for the human population (Fischer et al. 2022).

Methods

The study of dental remains identified 91 equid individuals: 85 horses and six donkeys. Thirty-nine of these animals are represented by whole or nearly-whole skulls.

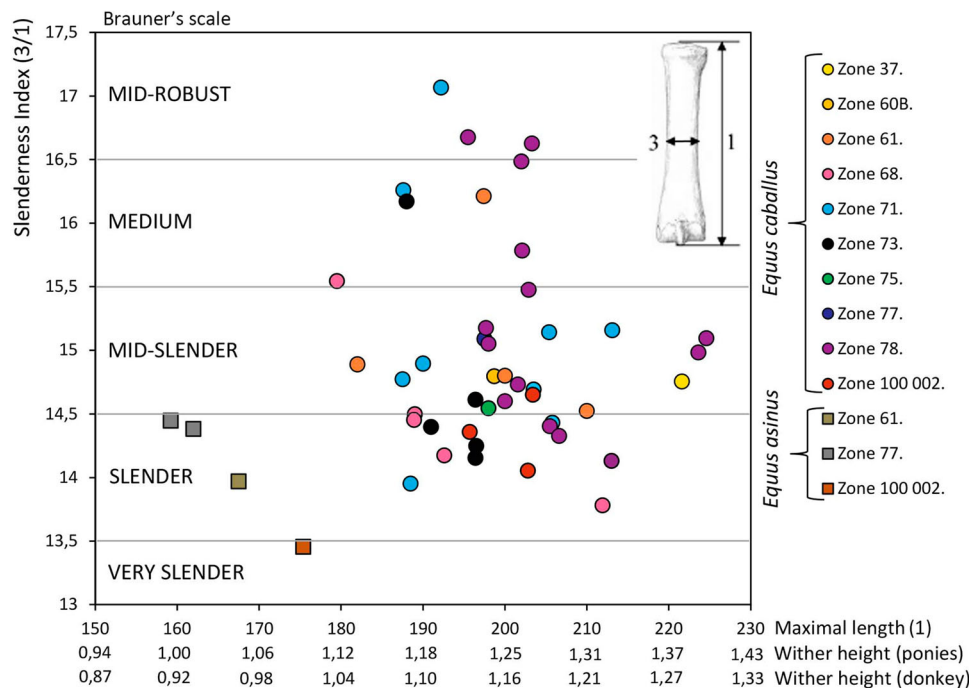


Figure 3. Bivariate plot of slenderness index (or shape index) in relation to the maximal length of the metacarpal (in millimetres) and corresponding withers height estimations (in metres). Slenderness index: breadth at the middle of the diaphysis (3)/maximal length (1)*1,000. Indices used for horse (ponies) and donkey withers height estimation come from Eisenmann's web site (Eisenmann 2009). Categories of horses adapted from Brauner (1916).

In order to better describe the equid population of Pech Maho, teeth were studied to estimate several biological parameters: weight, age and sex.

For tooth wear analysis, a tooth from every recognised individual was selected. Depending on the teeth available in the dental row, M1-2 were preferentially selected, followed by P3-4. Second premolars were always excluded from both (meso- and micro) analyses in line with the recommendations of Kaiser and Solounias 2003 and Xafis, Nagel, and Bastl 2017. In addition, teeth located in the distal portion of the jaw are more likely to indicate a more abrasive diet than the teeth in the mesial portion of the jaw (Winkler et al. 2021). In this way, each of the studied teeth directly reflects the diet of an individual and no double sampling on the same equid is possible.

For isotope analysis, every individual with available cranial bone material was sampled. One individual represented only by postcranial elements was also sampled for comparative purposes. In total, 38 specimens were sampled: 5 *Equus asinus* and 33 *Equus caballus*. Mandible was the primary sampled bone (30). When none was available maxilla (3), skull (4) or scapula (1) were sampled.

All raw data are available in App1 that can be downloaded at <https://zenodo.org/record/7540569>.

Age and Sex Determination Based on Teeth

The individual age of sampled specimens was determined following the methods of Fernandez and

Legendre (2003) and Fernandez (2009). These methods use polynomial equations whose parameters were estimated by bootstrapping from the dental height intervals of individuals of known age. They classify individuals into 3-year classes, associated with risks of error (e.g. 3–6 years, 6–9 years, 9–12 years ...). Age at death was calculated directly on the teeth used to make casts for dental wear analysis.

The sex of sampled individuals was determined, when possible, by the presence or absence of canines following Barone's (1986) observations that canines are only present in 20% of females and their morphology is atrophied compared to that of males. Paleogenomic analysis results were also used (Lepetz et al. 2021).

Weight was estimated from dental measurements using Janis' (1990) method when the first or second lower molars or the fourth lower premolars were available. When only first superior molars were available, we used Eisenmann and Sondaar (1998) equations.

Isotopes

The measurable isotopic signature of bone collagen correlates with the nature of the diet, among other things. The nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotope ratios (expressed as ‰) of bones found in archaeological excavations thus refer to the type of protein consumed (plant, animal, aquatic) and the type of environment from which the food resources

originated (marine/terrestrial, C₃ plants (wheat, barley, oats)/C₄ plants (millet)) (DeNiro and Epstein 1978; Schoeninger and Deniro 1984). It is therefore possible to reconstruct the diet and living environment of the analysed individuals from these isotope ratios and in the case of domestic animals to infer specific husbandry practices (see for examples Vaiglova et al. 2021; Knipper et al. 2017; Mion et al. 2019). Due to the constant renewal of bone during life (Dauphin 2015), this dietary information concerns the latter years of life. Mandible collagen turnover is relatively fast compared to other skeletal part therefore cover a shorter period before death (estimate to be a couple of years) than the other bones sampled with skull covering the longer period (Matsuura et al. 2014; Fahy et al. 2017).

In this study, the samples are largely composed by mandibles but eight of them correspond to the maxilla, skull or scapula (cf. *supra*). The variability of the isotopic results according to the skeletal element was tested and is available in App 4. For horses, all the maxillary and skull samples are in the variability displayed by the mandible samples. Similarly, no pattern related to the skeletal element are visible for the donkeys.

Collagen extraction followed protocols proposed by Longin 1971 and modified by Bocherens et al. 1991; see Mion et al. 2016 for details. IsoAnalytical Limited, Crewe, UK ran the IRMS-EA analyses. The elemental (%C, %N) and isotopic ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) carbon and nitrogen contents of collagen were simultaneously obtained using an isotope mass spectrometer coupled to an elemental analyser (Europa Scientific Roboprep and Europa Scientific 20–20). Samples were calibrated with the VPDB and AIR standards using the internal standard IA-R068 (soy protein, $\delta^{13}\text{C} = 25.22 \pm 0.02$ ‰, $\delta^{15}\text{N} = 0.99 \pm 0.99$ ‰, calibrated to IAEA-CH-6 and IAEA-N-1). Several internal standards were analysed in parallel with the archaeological samples to ensure reliable spectrometric analysis (IA-R038 (L-alanine), IA-R069 (tuna protein), IAEA-C7 (oxalic acid) and IA-R046 (ammonium sulphate)). Analytical precision was calculated using the calculator in the article by Szpak, Metcalfe, and Macdonald (2017) by analysing several replicates of these internal standards, as well as some archaeological samples (Appendix 2). It is 0.2 ‰ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. The indicators considered to assess the biochemical integrity of collagen were a collagen extraction yield greater than 10 mg/g (Van Klinken 1999), C/N ratio between 2.9 and 3.4 (Guiry and Szpak 2021) and the quantity of carbon and nitrogen above 13% and 4.8% respectively (Ambrose 1990). Correlation tests were also carried out in order to verify the absence of a relationship between these different indicators and the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (DeNiro 1985; Bocherens, Drucker, and Taubald 2011).

Tooth Mesowear

Mesowear analysis is a method based on the observation of wear patterns on ungulate molar cusps to infer the diet of an individual animal (Fortelius and Solounias 2000; Rivals, Mihlbachler, and Solounias 2007). The sharpness and morphology of cusp apices are correlated with relative attritive and abrasive dental wear. Thus, a diet with low abrasion (and high attrition) shows very sharp molar buccal cusps and, on the contrary, a diet with high abrasion will result in rounded and blunted cusps. There is no linear correlation between habitat parameters and mesowear scores (Kaiser et al. 2013; Schulz and Kaiser 2013) since both the vegetal composition of the diet and the presence of exogenous grit are involved in the mesowear signature (Kaiser et al. 2009). However, a high level of abrasion is more likely to be due to the consumption of siliceous grass than to the ingestion of soil or dust (Kaiser et al. 2013; Saarinen and Lister 2016). It is unclear as to which period of the animal's life tooth mesowear covers: weekly, seasonal or yearly periods. However, recent experiments suggest that it reflects the general diet over an individual's lifetime (Ackermans et al. 2020).

Broken and unworn teeth, as well as extremely worn ones, were excluded from the analysis following Fortelius and Solounias 2000; Rivals, Mihlbachler, and Solounias 2007. The paracone of the second upper molar was preferably selected, as recommended by Fortelius and Solounias (2000).

In this study, the standardised method proposed by Mihlbachler et al. (2011) and modified by Rivals, Rindel, and Belardi (2013) has already been used in other works (e.g. Rivals et al. 2017; Uzunidis, Rivals, and Brugal 2017; Uzunidis 2020). This method categorises dental wear into seven groups (numbered from 0 to 6), according to shape (0 = high and sharp; 6 = blunt with no relief). The average value of mesowear data from a single sample corresponds to the 'mesowear score' noted here 'MWS' (Mihlbachler et al. 2011).

Tooth Microwear

The microwear analysis study follows the protocol established by Solounias and Semprebon 2002 and Semprebon et al. (2004). The occlusal surface of each tooth was cleaned using acetone and then 96% alcohol. Then the surface was moulded with high-resolution silicone (vinylpolysiloxane) and casts were made using clear epoxy resin. The transparent casts were then observed with a stereomicroscope at magnifications of x35. Observations were restricted to a standard surface of 0.16 mm² (using an ocular reticule), preferably on the upper tooth paracone and the lower tooth protoconid.

Mesowear analysis is an accumulative signal which shows a general trend in the diet of an animal during its life, whereas microwear corresponds to a shorter timescale signal. Generally, it is considered to record the diet over the last days to months of an individual's life (Teaford and Oyen 1989; Hoffman, Fraser, and Clementz 2015; Merceron et al. 2016; Winkler et al. 2020).

The specimens with badly preserved enamel or taphonomic defects were excluded from the analysis (King, Andrews, and Boz 1999). Moreover, we focus on the portion of the enamel on the paracone or metacone fossettes and avoid the edges of the occlusal surface as they are more prone to alteration by taphonomic processes in horses (Uzunidis et al. 2021).

The observed micro-traces, scratches and pits in particular form on occlusal surfaces during mastication (Walker, Hoeck, and Perez 1978). The variability of the density of these traces is due to the presence of phytoliths in plants and is indicative of various diets: grazer, mixed-feeder and browser. Dust appears to impact the enamel surface less than phytoliths (Merceron et al. 2016). We observed various features following the classification of Solounias and Semprebon (2002) and Semprebon et al. (2004): pits (small and large), scratches (fine, coarse and hypercoarse), and gouges. The scratch width score (SWS) is also calculated with a score of '0' for teeth with predominantly fine scratches per tooth surface, '1' for those with mixed fine and coarse scratches on the tooth surface, and '2' for those with predominantly coarse scratches.

Statistical Analysis

Dental wear results were analysed using the software XLstat v. 2014.5.03. Isotopic results were analysed using R version 4.1.2 (R Core Team 2019) with

RStudio (RStudio Team 2018). Correlations were tested using Spearman tests. Nonparametric Wilcoxon and Kruskal–Wallis tests were used to determine differences between groups. A 0.05 probability ($p < 0.05$) is considered significant. Cluster analyses were conducted using the Ward Method 'cluster' package (Maechler et al. 2021), and visualised using the 'ggplot2' (Wickham 2016) and 'factoextra' packages (Kassambara and Mundt 2020)

Results

Biological Criteria Based on Tooth Analyses: Sex, Age and Weight

Weight could be estimated for 59 horses, age for 52 and sex for 26 animals (Figure 4). The Pech Maho horses are light: their body mass ranges from 166 kg to 334 kg with the majority of individuals ($n = 26$) weighing between 229 and 250 kg. No juveniles were identified at Pech Maho and estimated ages range from 3 to over 18 years. However, adults in the prime of life, between 6 and 9 years old, largely dominate the population ($n = 21$). Finally, both sexes are known at Pech Maho but males are much more abundant with 17 individuals compared to eight females.

Stable Isotope, C, N

State of Conservation of Collagen in Samples

Collagen extraction was successful for all the 38 prepared bone samples. For two *Equus caballus* samples, the yields were below the literature limit of 10 mg/g (Appendix 1). For the other 36 samples, C/N ratio, carbon, and nitrogen contents are in line with published thresholds. No correlation exists between isotopic values and the values of each criterion (Spearman

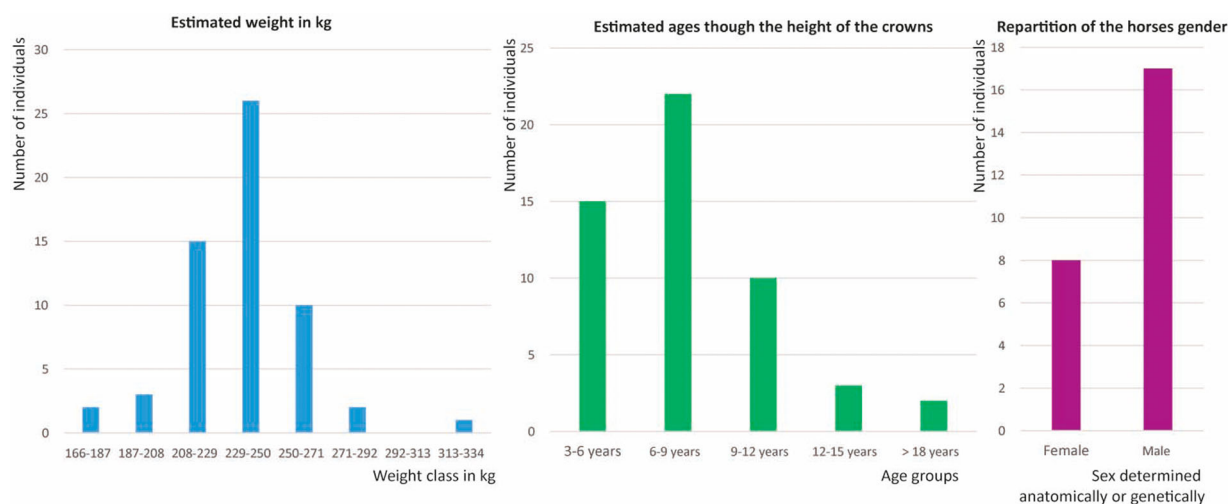


Figure 4. Histograms illustrating the demographic distribution in (from left to right): weight class (in kg), age groups (in years) and sex of the horses (*Equus caballus*) from Pech Maho according to the study of the teeth. Weight was mainly estimated through the dimensions of the lower first molars, age mainly using the crown height of the upper second molars and sex was determined through the presence of strong canines and in some case genetically (L. Orlando, Pers. Com.).

test, p -value < 0.05 & $\rho > 0.6$, Appendix 3). The isotopic information from the 36 samples with sufficient collagen can therefore be considered as well preserved.

Equid Isotopic Variability

Pech Maho equid isotopic values range from -22.6 to -18.8‰ for $\delta^{13}\text{C}$ and from 2.2 to 10.0‰ for $\delta^{15}\text{N}$ (Figure 5). Statistically, $\delta^{13}\text{C}$ values of the two taxa are different (Wilcoxon tests, $\delta^{13}\text{C}$: $W = 131$, p -value = 0.01 , $\delta^{15}\text{N}$: $W = 118$, p -value = 0.07).

The analysed *Equus asinus* specimens were found in three zones (78, 77, 73, Table 1 and Figure 6) and no statistical difference emerged between the isotopic values of those groups (Kruskal–Wallis tests, $\delta^{13}\text{C}$ $\chi^2 = 0.6$, $df = 2$, p -value = 0.7 , $\delta^{15}\text{N}$ $\chi^2 = 4$, $df = 2$, p -value = 0.2).

The analysed *Equus caballus* come from seven zones: 37, 61, 71, 73, 75, 77 and 78, but most specimens come from zone 78 (Table 1 and Figure 6). Statistically, there is no difference between the isotopic values of horses from the different zones of discovery (Kruskal–Wallis tests, $\delta^{13}\text{C}$ $\chi^2 = 9$, $df = 6$, p -value = 0.1 , $\delta^{15}\text{N}$ $\chi^2 = 10$, $df = 6$, p -value = 0.1). The *Equus caballus* specimens can be classified into two groups (groups 1 and 2) according to their isotopic values (Ward's method cluster analysis and subsequent Wilcoxon tests $\delta^{13}\text{C}$: $W = 228$, p -value = $1e8$, $\delta^{15}\text{N}$: $W = 226$, p -value = $6e8$, Figure 7). Group 1 is composed of 12 specimens with $\delta^{13}\text{C}$ values ranging from -21.0‰ to -19.9‰ and $\delta^{15}\text{N}$ values ranging from 6.3 – 9.0‰ ($\delta^{13}\text{C}$: $-20.5[-20.9/-20.3]\text{‰}$, $\delta^{15}\text{N}$: 8.0

$[7.5/8.5]\text{‰}$). Group 2 is composed of 19 specimens with $\delta^{13}\text{C}$ values ranging from -22.6‰ to -21.1‰ and $\delta^{15}\text{N}$ values ranging from 2.2 – 6.6‰ ($\delta^{13}\text{C}$: $-21.7[-22.0/-21.5]\text{‰}$, $\delta^{15}\text{N}$: $5.2[4.4/6.0]\text{‰}$).

Dental Wear Analysis

Mesowear Analysis

Mesowear analyses are still rarely applied to Holocene domestic ungulates, and among them, very few works focus on equids (Viranta and Mannermaa 2014).

Here, we were able to study the shape of the cusps of 41 horse teeth (*Equus caballus*) and five donkey teeth (*Equus asinus*) from Pech Maho (Appendix 1). The mesowear score of the Pech Maho horses from different zones is similar. Only the teeth from zones 72 and 73 fall outside the general variability, but these are very few in number (three and two teeth respectively), and cannot be statistically analysed or interpreted. The mesowear pattern observed for *Equus caballus* is dominated by round cusps and high relief with an average MW score of 2.6 (Table 2). *Equus asinus* tooth cusps are high and sharp with an average MW score of 1.6 (Table 2).

The horse samples fall within the variability of extant grazers and mixed-feeders (Figure 8). Their score is nevertheless very low and may correspond to mixed-feeders with a grazing tendency. It is not possible to accurately determine the diet of donkeys due to the paucity of donkey teeth. Nevertheless, the signal of the five available samples corresponds to that of extant mixed-feeders and browsers (Figure 8). These five individuals can be considered as mixed-feeders with a tendency to browse.

Microwear Analysis

Dental microwear revealed the very poor preservation of the Pech Maho equid teeth at a microscopic level (Appendix 1). Indeed, 25 out of the initially sampled 68 horses had to be excluded from the study (36.7%), as well as two of the six donkeys (33.3%), due to extensive taphonomic alterations. It should also be noted that conservation varies from zone to zone. In particular, teeth from zone 61 are very altered as 69.23% of them were not suitable for analysis. In zone 75, 40% of the teeth had to be discarded, 28.57% of the teeth in zone 71, 26.66% in zone 78 and 16.67% in zone 37. Teeth are thus much better preserved in the latter area. The actual dental microwear analysis of equids from Pech Maho thus concerns 43 horses and four donkeys.

In the same way as for mesowear analyses, microwear results between zones are fairly homogenous. Figure 9 compares the number of pits and scratches of the Pech Maho equids per zone. No differences were noted in the diet of this taxon, except in zone 73. Horse teeth from this zone bear significantly

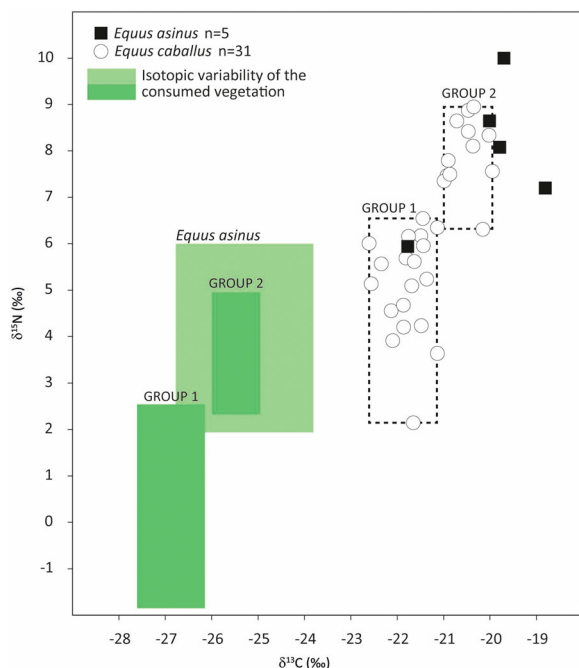


Figure 5. Stable carbon and nitrogen isotope data for Pech Maho equids. The shaded fields indicate $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the forage as estimated from the faunal collagen stable isotope data. The labels highlight the two groups modelled using Cluster Analyses (Figure 7).

Table 1. Summary of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of equids (*E. caballus* and *E. asinus*) from Pech Maho.

	n	$\delta^{13}\text{C}$		$\delta^{15}\text{N}$			
		Min	Max	Median [1 st quartile/3rd quartile]	Min	Max	Median [1 st quartile/3rd quartile]
<i>Equus asinus</i>	5	-21.8	-18.8	-19.8[-20.0/-19.7]	6.0	10.0	8.1[7.2/8.6]
Zone 73	2	-20.0	-19.8		8.1	8.6	
77	1	-19.7			10.0		
78	2	-21.8	-18.8		6.0	7.2	
<i>Equus caballus</i>	31	-21.8	-19.9	-21.4[-21.8/-20.8]	2.2	8.9	6.2[5.1/7.5]
Zone 37	1	-20.2			6.3		
61	6	-21.9	-21.4	-21.8[-21.8/-21.7]	2.2	6.2	5.2[4.3/5.9]
71	6	-22.6	-20.0	-21.4[-21.9/-20.9]	3.9	8.7	5.2[4.5/7.6]
73	3	-22.6	-21.0		5.1	7.4	
75	4	-22.3	-20.4		3.6	8.1	
77	1	-21.4			6.6		
78	10	-22.1	-19.9	-20.9[-21.1/-20.5]	4.6	9.0	7.5[6.6/8.3]
Total	36	-22.6	-18.8	-21.2[-21.8/-20.4]	2.2	10.0	6.2[5.2/7.9]

fewer scratches than equids from other groups ($p = 0.0166$). This difference does not reflect a drastically different diet, but rather a slightly reduced access to broadleaf plants. However, this result is based on a limited number of teeth (four for zone 73), which limits interpretations.

If we exclude the horses from zone 73, the horses are characterised by many pits and relatively few scratches with an overall average of 36.87 pits and 13.35 scratches (Table 2), compared to normal expectations for grazers. They fall within the variability of present-day browser (Figure 9). Moreover, the Pech Maho horses are also characterised by a high frequency of large pits and gouges (Table 2). In addition, the texture of scratches (SWS) is rather intermediate (fine and thick scratches are present). These characteristics are rather typical of mixed-feeders with mixed exogenous particles in their diet, especially sand and dust (Semprebon and Rivals 2007; Semprebon, Sise, and Coombs 2011). The donkeys show very similar

characteristics, which would tend to indicate a similar diet.

Discussion

Average Lifetime Dietary Habits of Equines (Isotopic Analyses)

If we consider that the trophic enrichment between food and horses is about 3.5 ‰ for $\delta^{15}\text{N}$ and about 5 ‰ for $\delta^{13}\text{C}$ (Ambrose and Norr 1993; Sponheimer et al. 2003; Caut, Angulo, and Courchamp 2009; Krajcarz, Krajcarz, and Bocherens 2018), $\delta^{13}\text{C}$ data from the Pech Maho equids correspond to $\delta^{13}\text{C}$ values of plants in the strict variability of C_3 plants (Figure 5;

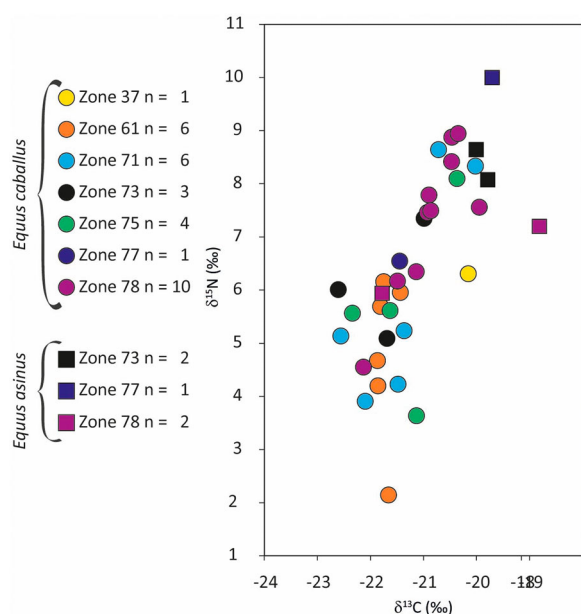


Figure 6. Stable carbon and nitrogen isotope data for Pech Maho equids according to the deposit zone where their remains were discovered.

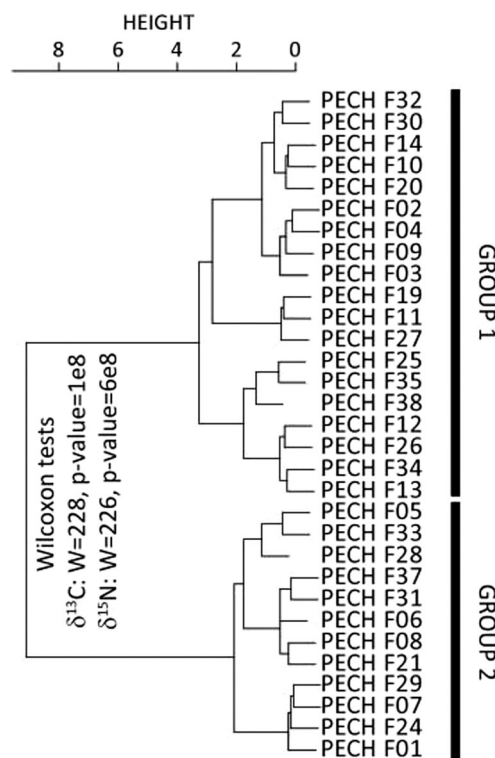


Figure 7. Cluster analysis (Ward's method) of horses, based on their isotopic signatures. Two groupings are observed for which combined isotopic values show statistically significant differences.

Table 2. Summary of dental meso- and microwear data of equids (*E. caballus* and *E. asinus*) from Pech Maho.

	N	Mesowear MWS	N	Microwear NP	NS	%LP	%G	SWS	%HC	%XS
<i>Equus caballus</i>	41	2.6 ± 0.95	43	36.58 ± 6.49	13.29 ± 3.3	27.9	69.77	0.68	11.63	0
Zone 37	5	3.2 ± 1.09	5	40.4 ± 2.27	13.8 ± 2.19	20	80	0.8	0	0
Zone 61	5	2.8 ± 1.09	5	32.8 ± 5.97	13.6 ± 3.3	75	50	0.5	0	0
Zone 71	11	2.72 ± 0.78	10	36.5 ± 4.82	13.65 ± 1.91	20	70	0.6	0	0
Zone 72	3	3.33 ± 0.57	2	31.25 ± 4.59	11 ± 4.24	50	100	0	0	0
Zone 73	2	1.5 ± 0.7	4	39.62 ± 3.68	11.12 ± 0.85	25	75	0.75	0	0
Zone 75	8	2.5 ± 0.92	6	37.83 ± 7.4	14 ± 2	50	100	0.33	0	0
Zone 77	1	2	1	47	1	15	0	1	0	0
Zone 78	6	2.83 ± 0.98	11	35.72 ± 8.38	12.54 ± 1.38	9.09	63.63	1	45.45	0
All zones minus 73	40	2.77 ± 0.89	40	36.87 ± 6.7	13.35 ± 2.09	30	70	0.67	15	0
<i>Equus asinus</i>	5	1.6 ± 0.54	4	33.25 ± 7.59	15.37 ± 2.39	25	75	0.75	0	25
Zone 73	4	1.5 ± 0.57	3	36.5 ± 4.8	14.66 ± 2.36	100	66.6	0.33	0	33.3
Zone 77	1	2	1	23.5	17.5	0	100	2	0	0

Notes: N = Number of specimens; MWS = Mesowear score; NP = Mean number of pits; NS = Mean number of scratches; %LP = Percentage of specimens with large pits; %G = Percentage of specimens with gouges; SWS = scratches width index; %HC = Percentage of specimens with hyper coarse scratches; %XS = Percentage of specimens with crossed scratches; M = Mean; SD = Standard deviation.

O'leary 1981). This is coherent with present-day observations, as C_4 plants only represent 2–6% of vegetation in the South of France, and only 50% of the documented C_4 species are endemic (Pyankov et al. 2010).

'Group 1' $\delta^{15}N$ values correspond to vegetation with values centred on 2‰, but the variability observed within the group, above a trophic level, for both $\delta^{15}N$ and $\delta^{13}C$ values, suggests that the individuals in this 'group' lived in different environments or consumed different plants. Indeed, animals with strictly identical controlled diets yield less variable isotopic values than the machine error (Sponheimer et al. 2003; West et al. 2004). For a herd of herbivores grazing on the same C_3 pasture, the observed variability between different individuals is of the order of 2‰ for $\delta^{15}N$ values and 1‰ for $\delta^{13}C$ values (Von Holstein et al. 2013; Schulting et al. 2019; Iorga et al. 2021).

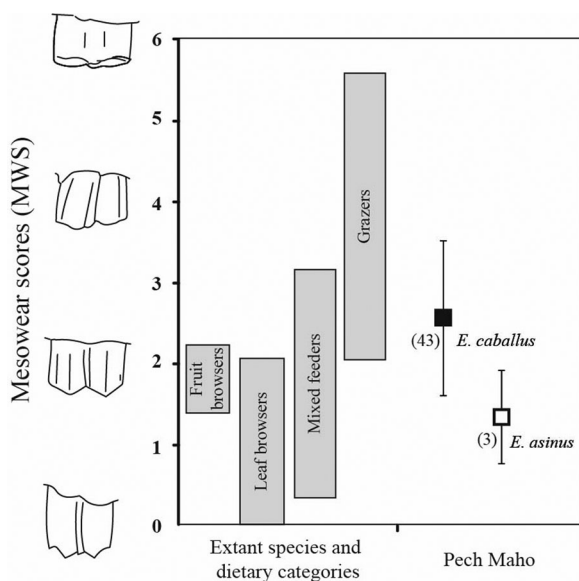


Figure 8. Mesowear score of horses (*Equus caballus*) and donkeys (*Equus asinus*) from Pech Maho per zone and in general compared to values for present-day ungulates published by Fortelius and Solounias (2000), Solounias and Semperebon (2002), Rivals et al. (2010, 2014).

The lowest $\delta^{15}N$ values observed within 'group 1' point to the consumption of leguminous plants with values of about 1‰ (Schoeninger and Deniro 1984), low tree leaves and thus more of a grazing type diet (Craine et al. 2009), or plants from humid less anthropized environments like riverbanks or lagunas (Craine et al. 2009). Higher values could be linked to areas more impacted by human practices (manuring, slash-and-burn or ploughing increase the aridity and salinity of soils, Pardo et al. 2002; Van Groenigen and Van Kessel 2002; Bogaard et al. 2007; Templer et al. 2007; Kanstrup et al. 2011; Szpak 2014). The $\delta^{13}C$ values describe slightly closed environments, such as undergrowth for the lowest values, and open, drier environments for the highest values (Heaton 1999).

'Group 1' is therefore not a homogeneous group. All the environments described by the isotopic values of this group are found in the vicinity of the Pech

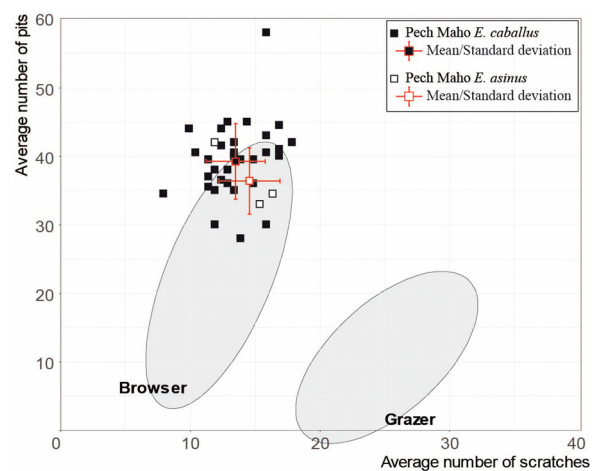


Figure 9. Bivariate plot of the mean number of pits and scratches of horses (*E. caballus*) and donkeys (*E. asinus*) from Pech Maho by zones. The error bars correspond to the standard deviation (± 1 SD). The ellipses correspond to the Gaussian confidence ellipse ($p = 0.95$) on the centroids of current grazers and browsers published by Solounias and Semperebon (2002).

Maho site. Although forest cover decreased in the late Iron Age, holm oak forests are still discernible in pollen assemblages, as are orchards, and may be compatible with the understory environments discernible in the $\delta^{13}\text{C}$ values (Berger et al. 2019; Azuara et al. 2015). Mediterranean pastures composed mainly of *Brachypodium ramosum*, accompanied by Clover, *Astragalus* or *Asphodelus*, comprise sufficiently varied leguminous plants and grasses to account for the values (Bouby and Ruas 2005). As horses are generally grazers (Schultz et al. 2020), dietary variability could also reflect different feeding practices and thus limitations in available food: branches and thus leaves, as attested in more recent historical sources, hay and wild grasses and leguminous plants, or no feeding at all (Dejmal et al. 2014). This group thus seems to be composed of individuals with different life histories, probably linked to distinct breeding practices and environments.

$\delta^{15}\text{N}$ values for specimens in group 2 correspond to vegetation with values centred on 4.5 ‰. The variability observed within this group is comparable to that of a herd sharing the same C_3 pasture (Von Holstein et al. 2013).

The $\delta^{15}\text{N}$ values of this group are high and are associated with high $\delta^{13}\text{C}$ values. Several explanations can be advanced to explain such values. The first is grazing in salt marshes, as these environments produce high carbon and nitrogen isotope values (Van Groenigen and Van Kessel 2002). Given that the values observed at Pech Maho are quite low compared to archaeological ungulate populations where life in such environments has been proposed (Müldner, Britton, and Ervynck 2014; Mion et al. 2019), seasonal grazing could be considered. The other hypothesis is grazing in a highly anthropized, largely open environment, with several present-day studies showing the impact of grazing pressure on soil and plant values and thus theoretically on the herbivores that consume them (Szpak 2014). Finally, the last hypothesis concerns a significant consumption of domestic grasses in the form of straw or seeds. No isotopic data are available for carpological remains contemporary to and nearby the Pech Maho horse assemblage. However, Early Iron Age data from Lattes and Late Iron Age data from Roquepertuse attest to comparable $\delta^{15}\text{N}$ values for barley, starch and durum wheat seeds to those of the vegetation consumed by the horses of Pech Maho group 2 (Alagich et al. 2018; Gavériaux et al. 2022). As the integration of the isotopic signal with bone collagen tends to accentuate the presence of protein-rich foods (Fernandes, Nadeau, and Grootes 2012), seed intake did not have to be exclusive to be visible. Regular consumption by all eleven animals in the group could explain such values. Ancient and medieval treatises attest to the use of seeds, particularly barley, as fodder, especially for

animals used for farming or as war cavalry (Donaghy 2012).

Interestingly, no preferential deposit zones could be linked to either of the groups differentiated by isotopic values.

Values for the donkeys in the corpus are very variable. Three donkeys with comparable values to those of horses could have been part of the same herd kept together throughout their lives, but the living environment and/or diet of the last one is different from those of the rest of the corpus. A particular geographical origin could be considered which will be investigated through upcoming strontium analysis.

Dietary Habits of Equines Around the Time of Death (Dental Wear Analyses)

Equids have adapted over time to grazing and graze primarily on abrasive plants (Schultz et al. 2020). This is the case for donkeys as well as horses (Kaiser et al. 2009) but the former may more regularly adopt mixed eating patterns and consume dicotyledons (Schulz and Kaiser 2013). In Pech Maho, the results of the dental mesowear study classify them as mixed-feeders with differences between horses and donkeys. The former are more likely to be mixed-feeders with a grazing tendency and the latter are more likely to be mixed-feeders with a browsing tendency.

In terms of dental microwear, the data available for horses and donkeys are quite similar and reflect a mixed diet, although with quite a low monocot content, as suggested by the very low number of scratches. However, this indicator may be altered if the equids consumed agricultural grasses with a lower phytolith content than those from African savannahs consumed by the individuals used to build the model (Kaiser et al. 2009; Gallego-Valle et al. 2020). The very high number of pits observed can be related to the amount of dust and sand ingested with food (Semprebon and Rivals 2007; Semprebon, Sise, and Coombs 2011).

Therefore, the diet of the Pech Maho equids does not correspond to the preferential diet of these generally mainly grass-eating animals. In the Northern hemisphere, for example, equids favour *Carex* or *Agrostis* and monocots in general (Fleurance et al. 2015). The diet described in this study is known in domestic populations with strong human intervention (stalling, artificial feeding ... e.g. Viranta and Mannermaa 2014), or in very rare Pleistocene wild populations where animal behaviour was strongly induced by a homogeneous environment in areas inhabited by a large variety of different herbivores species (e.g. Rivals et al. 2014; Uzunidis, Rivals, and Brugal 2017).

The end of the Iron Age, before the arrival of the Romans, was marked by significant population expansion (Berger et al. 2019). This increased the human impact on the plant biomes of the Aude region,

notably though agricultural development. Holm oak forests diminished sharply during this period and gave way to low sclerophyllous plants, cultivated species, particularly cereals and fruit trees (*Juglans*, *Olea*, *Castanea*, for example in Ouveillan), and pastures for domestic ungulates (perceptible through the presence of *Betula*, Poaceae and *Calluna*, for example in Ouveillan) (Sanchez Goñi 1995; Azuara et al. 2015; Berger et al. 2019). In the Mediterranean environment, the herbaceous layer is often poorly developed, except in the case of artificial grasslands dominated by xeric species of the *Thero-Brachypodieta* (Bouby and Ruas 2005) with *Brachypodium retusum*, accompanied by *Trifolium*, *Astragalus* or *Asphodelus*.

At that time, the Aude region therefore contained abundant dicotyledonous plants, with monocotyledonous plants also attested in wild and especially in domestic contexts. However, the Pech Maho site is located near a lagoon and wetland plants must have been abundant, usually dominated by grasses (Rogers 1981). In this kind of biotope, horses are known to focus on such plants and display more scratches on their teeth than the equids from Pech Maho (Uzunidis 2020). Thus, their diet is more compatible with the Aude inland biotope dominated by dicots with patches of monocots. The very high presence of pits suggests that, if this is the case, this biotope must have been very degraded (Healy and Ludwig 1965; Healy 1967).

Nevertheless, the characteristics of the diet of the Pech Maho horses could also be indicative of husbandry in a closed environment. Indeed, this hypothesis has already been put forward for several Iron Age deposits in the same geographical area. The presence of different, *a priori* incompatible snail species could indicate the presence of plot boundaries at Mas du Vigier (Nîmes, Gard, second half of the fifth / first quarter of the fourth century BC) in the form of hedges or ditches (Ratsimba et al. 2013). At the Mont Jouï site (Florensac, Hérault, last quarter of the sixth century BC), the carpological study of a plant assemblage does not correspond precisely to any known phytosociological unit and could indicate the existence of an artificial mixture intended for animal consumption (Bouby and Ruas 2005). Finally, at the El Turó de la Font de la Canya site (Barcelona, Spain, sixth century BC), the significant presence of pits in the study of dental wear leads the authors to formulate the hypothesis of parked animals (Jiménez-Manchón et al. 2019). Although the existence of a livestock penning area is therefore not attested with certainty for these periods, several indicators suggest that this practice may have been used at least occasionally. The significant presence of dust ingested by the horses at Pech Maho could reflect feeding on heavily trampled ground with little vegetation cover. Like at El Turo de la Font de Canya, the hypothesis of parked and artificially fed herds can thus be formulated.

Two hypotheses have been put forward as a result of the study of equid dental wear: (i) the equids lived in a degraded environment rich in dicots with the presence of monocots or (ii) they were parked in a pen and fed a mixture of vegetation also rich in dicots with the presence of monocots. The homogeneity of the equids' diet in the months and days before their death is remarkable. Even if their diet was strongly constrained by their breeders, these values can only be explained by a short mortality episode, on a seasonal scale. Indeed, even in a Mediterranean environment where seasonal alternations are not very marked, differences in the available plant communities are still traceable on ungulate tooth wear (Uzunidis 2020; 2021).

Influences of Biological Parameters (Age, Sex, Weight) on the Horses' Diet

Three biological criteria (age, sex and weight) were estimated from the direct study of teeth and dental rows and their influence on the long- and short-term diet of horses was observed. Indeed, breeding practices during the Iron Age may have been adapted to the biological characteristics of the living animal. This is particularly the case for sex. Indeed, the ethnological study of the present-day Sakha culture in Mongolia indicates significant differences in use according to the sex of the animal. Stallions are mainly used directly by their owners, especially as riding horses, and very few are selected for breeding. As for mares, they are exclusively assigned to breeding (Takakura 2015). This difference in use also implies differences in the treatment of horses. For example, horses for breeding are kept in pastures all year round, while horses for riding are kept in stables during the winter, in pastures near habitations during the summer and in paddocks during the autumn, where they are also fed artificially. This sex-dependent differential treatment according of horses would also be noticeable for archaeological periods. Indeed, the recurrence of certain dental pathologies in mares dating from the early Iron Age to mediaeval periods in England could indicate that they were mainly used for breeding, whereas the care given to males associated with other specific pathologies would indicate their use as mounts (Cross 2018a; 2018b). The pathologies described in male Icelandic horses of Viking age would also reflect an almost exclusive use of males for riding (Leifsson 2018). However, in other cultures or traditions, the opposite can be observed, in the mediaeval Maghreb and the Middle East, until at least the nineteenth century, horsemen preferred riding mares rather than stallions, because of their reputation for being more frugal and more resistant to climatic conditions than males (Carayon 2017; Daumas 1855; 1864). At least some cultural traditions

seem to have made no major distinction between mares and stallions for use and husbandry, as is the case for example for Cretans in Ancient Greece (Blaineau 2014).

No direct trends, clustering or correlations could be detected between the three biological criteria and the results of dental wear analyses (Figure 10). All age

classes are represented in isotopic ‘group 1’ and the presence of the three identified females in this group show that the heterogeneity of isotopic values is also visible in the biological profile of this group (Figure 11). No trends or clustering consistent with those two biological criteria could be identified in group 1. The animals composing the ‘group 2’ isotopic

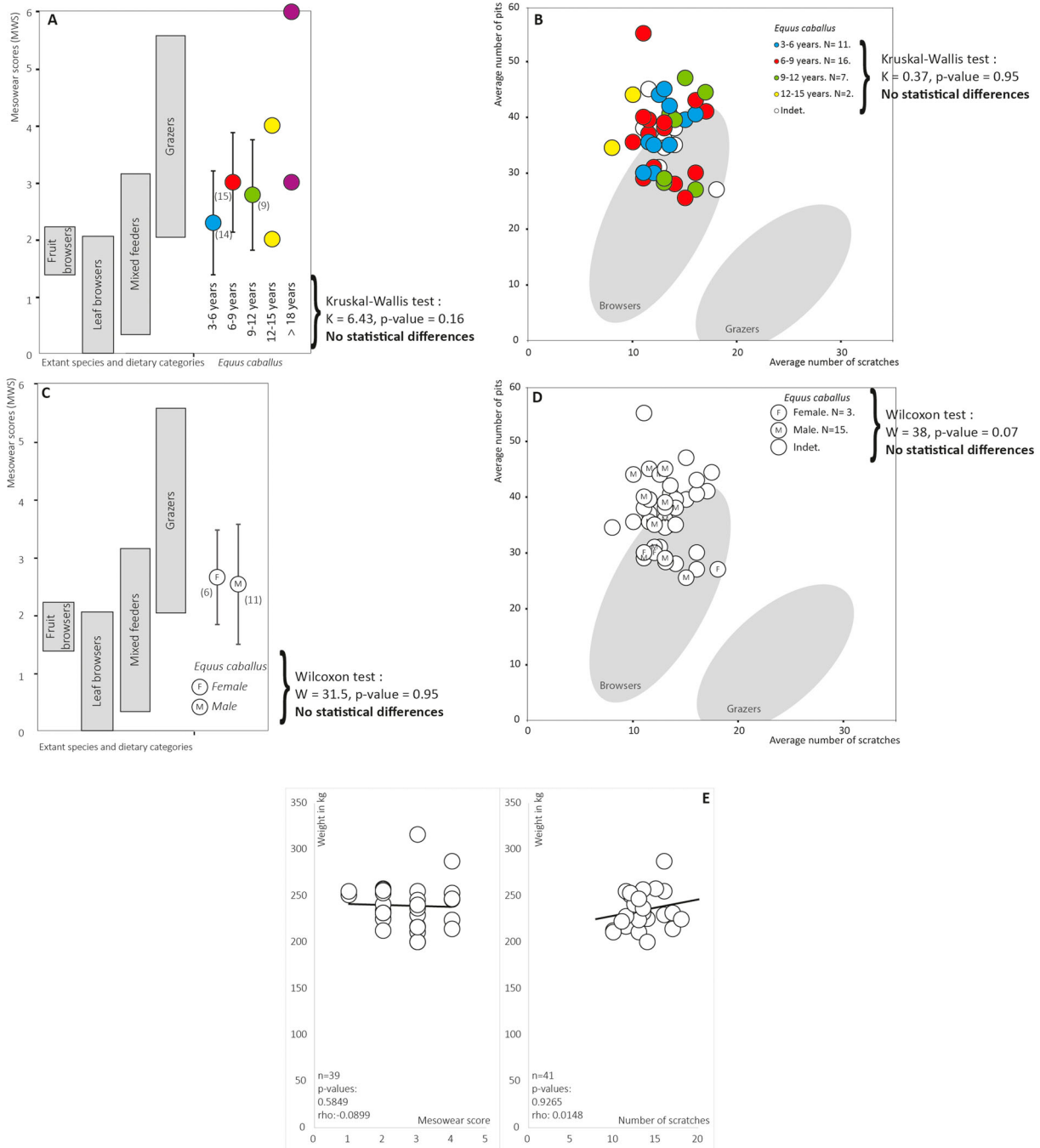


Figure 10. Representation of dental wear (meso- and microwear) of Pech Maho horses according to their age (A and B), sex (C and D) and weight (E). A and C: Mesowear score of horses (*Equus caballus*) from Pech Maho by age classes (A) and sex categories (C) compared to values of present-day ungulates published by Fortelius and Solounias (2000), Solounias and Semprebon (2002), Rivals et al. (2010, 2014). B and D: Bivariate plot of the mean number of pits and scratches of horses (*E. caballus*) from Pech Maho by age classes (B) and sex categories (D). The error bars correspond to the standard deviation (± 1 SD). The ellipses correspond to the Gaussian confidence ellipse ($p = 0.95$) on the centroids of current grazers and browsers published by Solounias and Semprebon (2002). E: Bivariate plot comparing: left, mesowear score to horse weight estimated from tooth dimensions. Right: the number of scratches compared to the weight of the horses estimated from the dimensions of the teeth. Wilcoxon and Kuskal-Wallis test results are indicated on the graphics (threshold of the $p\text{-value} = 0.05$).

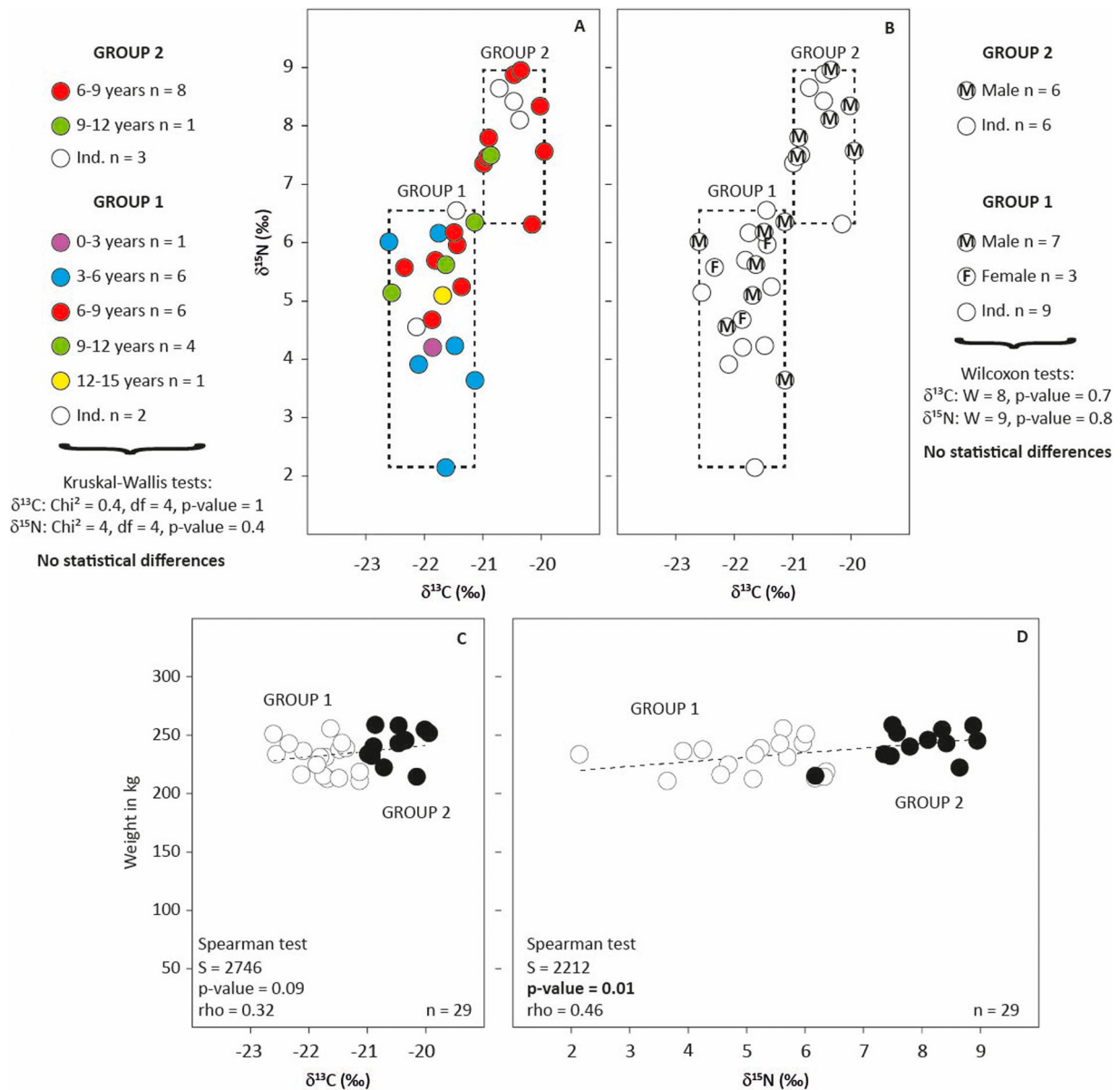


Figure 11. Representation of isotopic data ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) of Pech Maho horses according to their age (A), sex (B) and weight (C and D). Wilcoxon, Spearman and Kuskal-Wallis test results are indicated on the graphics (threshold of the p -value = 0.05)

results show a certain homogeneity in terms of sex and age: of the twelve animals, six are male and eight died between the age of 6–9 years. The slight correlation between $\delta^{15}\text{N}$ values and horse weight, mainly due to the higher weight of animals in group 2, also suggests that the diet of ‘group 2’ animals was more nutritious and allowed them to gain more weight, further reinforcing the seed consumption hypothesis.

Overall, the horse population of Pech Maho is quite homogeneous in term of age, sex or weight and shows an over-representation of one age class (6–9 years), one sex (males) and one weight class (between 229 and 250 kg). This over-representation could reflect the presence of horses used for riding or working, rather than animals kept for reproduction (Cross 2018a; 2018b). In this case, the use of horses by humans could indicate similar feeding patterns for the different biological categories, maybe more linked

to individual practices among breeders, as shown in group 1 of the isotopic results.

The homogeneity of ‘group 2’ horses in terms of biological identity, as well as isotopic values, could point to the presence of a group of males with the same diet throughout their lives, probably reflecting a specific use or origin.

What Does the Diet of Pech Maho Equines Reveal About Their Life Histories?

The combination of isotopic and dental wear analyses of Pech Maho equids provides data on the evolution of their diet over their lifetime and therefore of feeding practices. Isotopic analyses provide average information on the life span of individuals, whereas dental wear analyses focus on their last phases of their lives, which could shed light on slaughtering conditions.

Isotope analyses illustrate the existence of two groups: a heterogeneous one in terms of diet and biological parameters and another, homogeneous group. These results are not in agreement with those of mesowear analyses where a single, homogeneous group is observed. The time scale represented by dental mesowear is unclear, possibly corresponding to a weekly or monthly (Danowitz et al. 2016), seasonal (Kaiser and Schulz 2006; Marom, Garfinkel, and Bar-Oz 2018; Schulz and Kaiser 2013) or annual (Louys et al. 2012; Rivals, Mithlacher, and Solounias 2007; Ulbricht, Maul, and Schulz 2015) signal. A recent study has shown that, at least in hand-fed small ruminants, this signal corresponds to the life expectancy of an animal (Ackermans et al. 2020). At Pech Maho, the difference between isotopic and mesowear results would suggest that the two signals do not cover the same time scale. Here, dental mesowear results would concern a shorter, undefined time scale.

The differentiation of two heterogeneous and homogeneous dietary groups by isotopic analyses suggests a different treatment of equids during their lifetime, reflecting varied husbandry and feeding practices. This pattern could indicate the distinct and different origin of equids or reflect provenances from several environments. In this case, it is likely that the horses in group 2 have the same origin, while the horses in group 1 would have different origins.

Osteological analyses also highlight heterogeneity within the population of horses. Unfortunately, it is not possible to connect cranial and postcranial elements in the osteological assemblages of the deposits. Several individuals are more robust and others are taller than the general classic morphotype. Variations in the robusticity of the autopod (Hanot et al. 2020) and especially the diaphysis of metapodials can reflect in-life activity (Brooks et al. 2010; Ameen et al. 2021) and/or rapid acclimatation (Boulbes and van Asperen 2019). Such phenotypic differences are related to the use of these animals, as well as breeding techniques (housing, feeding, care, etc.), and/or environments and substrates. Larger isometric size could also correspond to an amelioration of the local morphotype as a result of husbandry strategies, castration at a young age, or a different genetic breed. It also raises the question of possible different geographic origins (horses belonging to aggressors, exchanges between other area ...).

The high homogeneity of the equids' diet at the end of their lives reflects, on the contrary, the same diet and living conditions. The concordance between mesowear and microwear results indicates that the animals underwent similar treatment over a relatively long period of time, at least several months before their death. The homogeneity of the microwear results tends to indicate a short killing period, probably over a season.

In summary, the combination of these analyses points to the following scheme to explain the presence of these equids at Pech Maho: Individuals, mostly males in the prime of their life (6–9 years), with diverse and more or less distant origins, including one group of 12 individuals that lived in the same environment all their life, were gathered together for several months. During this period, they were fed in the same way and kept in an enclosed area (e.g. paddock). Then, they were killed over a short period of time, which could have been the same day or over a season. Finally, their remains were scattered among the different deposits, regardless of their origins.

The gathering of these animals could have occurred in two different ways: either all the equids were brought together at the same time and kept enclosed for some months, maybe to participate in a major and rare human activity (battle, construction ...), and then killed once the activity was over, or the gathering took place over a long period of time and when a critical number was reached, the animals were killed, which may have been the initial intention. The over-representation of males, castrated or not, could reflect a use-horse accumulation, if the pattern is the same as for the Sakha (Takakura 2015), or for Iron Age Britain (Cross 2018a; 2018b). The over-representation of male horses is also known in graves and in ritual human activities, for example in Iron Age Britain (Cross 2018a) or mediaeval Iceland (Nistelberger et al. 2019). These two propositions are not mutually exclusive (Leifsson 2018), but given the over-representation of male horses at Pech Maho, we cannot choose one or the other hypothesis.

Conclusion

Using a combination of several food analysis tools (isotopes, dental wear) and the reconstruction of several biological characteristics (age, sex, weight), we reconstructed the feeding practices of the Pech Maho horses and the conditions of their presence at the site. Humans strongly influenced horse living habits but it was not possible to determine whether they were kept in semi-freedom in human-impacted pastures or in more constrained paddocks with artificial feeding. The human impact was even stronger shortly before their death. Our study suggests that the Pech Maho horses were from varied origins on an undetermined geographical scale. They would have been gathered together for several months before being killed over a short period of time shortly after a major war event. The reasons behind the impressive accumulation of equids at Pech Maho could not be clarified but the over-representation of male horses could indicate the selection of use-horses at the site. Further studies, and the combination of other proxies, will be needed to fully understand this accumulation.

In particular, sulphur, strontium and paleogenetic analyses may help to clarify the geographical origin of the horses at Pech Maho. Nevertheless, the approach developed here shows the relevance of combining our different analyses with complementary reading levels at different moments in the lives of these equids.

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Disclosure Statement

No potential conflict of interest was reported by the author (s).

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Data Availability Statement

All the appendix are stored online and can be downloaded at <https://zenodo.org/record/7540569>.

Appendix 1. Raw data of isotopes, dental wear and biological parameters.

Appendix 2. Calibration tables (Szapak, Metcalfe, and Macdonald 2017).

Appendix 3. Correlation test results for the conservation of isotopic results.

Appendix 4. Stable carbon and nitrogen isotope data for Pech Maho equids according to the sampled skeletal element.

Notes on contributors

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