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Morphometric evolution of the domestic triad, in western *Gallia Narbonensis* (southern France, Languedoc), between the 2nd c.BC and the 4th c.AD : Preliminary and critical use of log size index for diachronic analysis

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ABSTRACT

In bioarchaeology, the biometry of archaeozoological remains is an important component of studies on domestic species and size has been used for multiple purposes from identifying domestication, to track environmental changes or evolution of husbandry practices. The establishment of the Roman Empire has been accompanied by social, political and economic transformations that also reflect in farming practices and animal husbandry. In southern France, biometric variation has already been partially perceived during Roman times, particularly for cattle, but lack chronological accuracy and statistical validation. This paper presents a diachronic analysis of linear measurements of post-cranial bones belonging to the domestic triad (sheep, goat, cattle and suids) in western *Gallia Narbonensis* (France), between the Roman conquest and Late Antiquity, *i.e.* from 200 BCE to 400 AD. Biometric data from 64 archaeological sites, excavated and studied over more than 30 years of preventive archaeology, were analysed using a Log Size Index (LSI) approach using time as a continuous variable. The analysis of 5533 measurements first analysed per bone and variable, then separating length, breadth and depth dimensions, revealed different trends, highly influenced by the number of measurements, reflecting allometric differences but also cases of asynchronous evolution. However, these allometries within species are small when compared to interspecies differences. Overall, the size of the four taxa increased from the 2nd century BC to the 2nd century AD. Cattle and pig sizes then decreased from the 2nd century AD and only from the 4th century onwards for goats, while sheep size tends to increase during the 3rd-4th centuries. If the Roman conquest influences the size of the domestic animals, this does not affect the four species in the same way. This potentially reflects differentiated agropastoral strategies for each of the species in the western part of *Gallia Narbonensis* during the Roman period. This study, which provides a diachronic and cross-species study framework, should be seen as a first step for a more in-depth understanding of micro-regional and socioeconomic variation in domestic species morphologies.

1. INTRODUCTION

In domestic mammals, changes in bone measurements, and more generally in body sizes, have been used as marker of domestication (*e.g.* Uerpmann, 1979), environmental changes (*e.g.* Davis, 1981; Gaughan *et al.*, 2009; Savolainen *et al.*, 2013; Mccain and King, 2014; Pacifici *et al.*, 2017; Elayadeth-Meethal *et al.*, 2018) or husbandry changes (*e.g.* Albarella *et al.*, 2006a; Grau-Sologestoa, 2015; Frémondeau *et al.*, 2017; Robin and Clavel, 2018; Trentacoste *et al.*, 2018, 2021; Nieto- Espinet *et al.*, 2020).

From a broad perspective, early analyses of biometric data of domestic animal bones revealed a general trend of size decrease from the Neolithic to the end of the Iron Age throughout Europe (Matolcsi, 1970; Bokonyi, 1974; Altuna, 1980; Méniel, 1984; Vigne, 1988; Audoin- Rouzeau, 1991; Riedel, 1994; Valenzuela-Lamas and Albarella, 2017), followed by a size increase during the Roman period (Boessneck, 1971; Bokonyi, 1974; Ijzereef, 1981; Méniel, 1984; Audoin-Rouzeau, 1991; Peters, 1998). More recent analyses revealed differences between cultural regions (*e.g.* Frémondeau *et al.*, 2017; Duval and Clavel, 2018; Trentacoste *et al.*, 2018) calling for local analysis of animal size evolution through time.

In Gaul, *i.e.* a region first described by the Romans and covering present territories of France, Luxembourg, Belgium, and parts of Switzerland, Northern Italy, the Netherlands, and Germany, the size increase of domestic species, especially cattle and pigs, observed during the Roman period. This trend was considered as a direct consequence of the Roman conquest of the *Galliae Belgica, Lugdunensis and Aquitania* in 52 BCE, and then of the remodelling of their agro-pastoral economies during the first decades of the Roman Empire (Lepetz, 1996b; Méniel, 1996; Audoin-Rouzeau, 1998). Several criteria have been evoked to explain this increase in bone size: the importation of large animals from Italy (Yvinec, 1983; Krausz, 1985; Méniel, 1990, 1992, 2014; Benecke, 2001; Gaeng *et al.*, 2019), the changes in pastoral practices (*e.g.* Lepetz, 1996b) or new environmental characteristics (Lepetz and Yvinec, 1998; Lepetz and Matteredne, 2003; MacKinnon, 2010; Duval *et al.*, 2015).

In southern France, bones of cattle and caprines reached some of their smallest dimensions ever recorded during the second Iron Age *i.e.*, 5th to 2nd c. BC (Forest, 2015). However, cattle with a “very high” wither height (greater than 1.35 m) did not appear synchronously with the Roman conquest of *Gallia Narbonensis*, in 121 BCE, but well after, during the middle of the 1st c. AD (Columeau, 2002; Forest and Rodet- Belarbi, 2002). On the other hand, in the northern provinces of the Italian peninsula the appearance of large cattle occurred from the 1st c. BC (MacKinnon, 2010; Kron, 2014), *i.e.* at the same time as in northern France (Lepetz, 1996a; Cambou, 2009; Foucras, 2010; Lepetz and Zech- Matteredne, 2017; Duval and Clavel, 2018). This would imply a contemporary appearance of large cattle in several territories before, and therefore probably independently of, the expansion of the Roman Empire. Moreover, this increase in cattle size continues in Italy until Late Antiquity (MacKinnon, 2004), as in Narbonese Gaul (Columeau, 2002; Forest, 2008), Northern Gaul and Germanies (Lepetz, 1996b; Duval *et al.*, 2012; Pigiere, 2017) or in England (Maltby, 1981; Dobney, 2001; Albarella, 2007; Rizzetto *et al.*, 2017).

The fact that a similar progressive dynamic is observed on a large geographical scale does not exclude a movement of large Roman animals, which appeared as early as the 4th c. BC in southern Italy (Baker, 2000). However, it tends to favour the hypothesis that local populations evolved more slowly than would have been expected to have resulted from a massive import of large Italian cattle.

The Log Size Index (LSI) approach has helped reinvigorate interest in the size evolution of the domestic animals, and is now a standard in zooarchaeology (*e.g.* Uerpmann and Uerpmann, 1994; Davis, 1996; Meadow, 1999; Baudry, 2012; Duval *et al.*, 2015; Robin and Clavel, 2018), even if the approach has been criticized (*e.g.* Wolfhagen, 2020). LSI techniques have been developed to address sample size issues by artificially increasing

the number of measurements that can be analysed together (e.g. Weinstock, 2002; Albarella *et al.*, 2006b; Sykes *et al.*, 2011; Arbuckle *et al.*, 2014, 2016; Grau-Sologestoa *et al.*, 2021; Schmolcke and Groß, 2021). This method, originally described by Simpson (Simpson, 1941; Simpson *et al.*, 1960) and later developed by Meadow (1999), consists on a normalisation of bone measurements of interest using a reference. This reference could correspond either to the measurements of a single individual (e.g. Zeder, 2008; Duval *et al.*, 2012; Arbuckle *et al.*, 2014; Zeder and Lemoine, 2020a, 2020b), or mean measurements of several specimens (e.g. Degerbol and Fredskild, 1970; Payne and Bull, 1988; Clutton-Brock *et al.*, 1990; Uerpmann and Uerpmann, 1994; Davis, 1996, 2000; Hongo and Meadow, 2000; Stepan, 2001; Weinstock, 2002; Johnstone and Albarella, 2002; Albarella and Payne, 2005; Albarella *et al.*, 2006a; 2009; MacKinnon, 2010; Sykes *et al.*, 2011; Telldahl *et al.*, 2012; Valenzuela *et al.*, 2013; Manin *et al.*, 2016; Helmer and Gourichon, 2017; Robin and Clavel, 2018; Nieto-Espinet *et al.*, 2021).

The LSI method is based on the assumption of isometric variation between the measurements, *i.e.* all variables vary in a similar manner (Albarella, 2002; Albarella *et al.*, 2006a; Wolfhagen, 2020; Zeder and Lemoine, 2020a). However, it is known that this is not always the case as bone lengths have been shown to be more related to the wither height of the animal, whereas bone breadths and depths correlate more with corpulence (Uerpmann, 1984; Guintard, 1996; Meadow, 1999; O'Connor and O'Connor, 2008). Accordingly, in order to mitigate the effect of potential allometries on LSI values, measurements of length, breadth and sometimes depth dimensions of the bones are sometimes, but not systematically, studied separately (e.g. Duval *et al.*, 2012; Trentacoste *et al.*, 2018; Trentacoste, 2020; Nieto-Espinet *et al.*, 2020, 2021; Ameen *et al.*, 2021; Salvagno *et al.*, 2021; Wright, 2021).

In Gaul, the LSI-length of cattle and pigs starts to increase at the end of the 3rd c. BC and this size increase intensifies during the 1st c. BC for cattle (Frémondeau *et al.*, 2017; Duval and Clavel, 2018; Duval *et al.*, 2018). A similar change has been noted in northern Italy for cattle (De Grossi Mazzorin and Minniti, 2017; Valenzuela-Lamas and Albarella, 2017; Trentacoste *et al.*, 2018). In contrast, for pigs, the LSI-length tends to decrease between the 8th c. BC and the Roman period, when LSI-breadth remains constant throughout the period (Trentacoste *et al.*, 2021). Finally, although wither height analyses indicated a gain in size for sheep and goats during the Roman period in Gaul (Lepetz, 1996b), this increase appears, at the same time, very limited in Italy and more visible for sheep on the LSI-breadth than on the LSI-length (Trentacoste *et al.*, 2018, 2021). All these results question the hypothesis of a sudden increase in size of domestic animals in Gaul through the importation of Italian herds, but also that of a transmission of Roman know-how during the Roman conquests of the *Gallia Narbonensis* in 121 BCE and in the northern Gaul in 52 BCE.

While time is often divided into chrono-cultural phases (e.g. Albarella *et al.*, 2008; Colominas and Sana, 2009; Grau-Sologestoa, 2015; Colominas, 2017; Groot, 2017; Pigiere, 2017; Rizzetto *et al.*, 2017; Valenzuela-Lamas and Albarella, 2017; Duval and Clavel, 2018; Robin and Clavel, 2018), some studies have evidenced the possibility of using time as a continuous variable. In such cases, the mean time of occupation of chrono-cultural phases or sites are often used, even if the archaeological records often allow a more detailed resolution, at the scale of the stratigraphic unit (Arbuckle *et al.*, 2014, 2016; Frémondeau *et al.*, 2017; Duval *et al.*, 2018).

In our study area, a particularly large amount of archaeozoological studies has been carried out by the many specialists working in preventive archaeology and published through excavation reports which, as grey literature, are yet not widely integrated into academic research. This long-term work has resulted in a particularly large body of raw data and a detailed understanding of the archaeological occupations at the site level.

In this context, this study aims, through a critical use of the LSI for diachronic analysis, using time as a continuous variable and a larger dataset than those studied before, to provide a more detailed synthesis on metric change in the domestic triad, *i.e.* caprines (goat & sheep), cattle and suids, in western Narbonese Gaul between the 2nd century BC and the 4th century AD. For this purpose, we used LSI-values analysed first for each variable independently, then pooled by length, breadth and depth dimensions before studying the overall diachronic trends of the four species.

2. MATERIALS

This study focuses on 64 archaeological assemblages located in the south of France, in the *Gallia Narbonensis* region corresponding to the modern Languedoc (Fig. 1, SI table 1). Our study focuses on the time period ranging from 200 BCE to 400 AD and includes assemblages for which the mean of the earliest (terminus post quem, TPQ) and latest (terminus ante quem, TAQ) dates fall within the defined period. The chronological data were recorded according to existing archaeological reports (SI table 1). All the faunal remains analysed here were studied by a single specialist, Vianney Forest, who is also the only person to have carried out the biometric measurements (SI table 1).

This is to avoid any interoperator bias, also called 'personal equation' (Sumner, 1927; Jewell and Fullagar, 1966; Yablokov, 1975). All data were collected in the context of preventive archaeology over the last 30 years, first by AFAN - 'Association pour les Fouilles Archéologiques Nationales' and then INRAP - 'French Institute for Preventive Archaeological Research'.

All raw measurements are available in the excavation reports of the corresponding archaeological sites (SI table 1). Wild boars were not distinguished from domestic pigs, and aurochs seem to have disappeared from the Languedoc between the Final Bronze Age and the beginning of the Iron Age (Forest and Cheylan, 2015). The distinction of sheep and goat bones was done using published macroscopic criteria (Cornevin and Lesbre, 1891; Boessneck *et al.*, 1964; Prummel and Frisch, 1986; Helmer and Rocheteau, 1994) and personal expertise. The biometric measurements were acquired following the von den Driesch standards (von den Driesch, 1976) with new measurements (SI Fig. 1).

The analyses focus on bones of the appendicular skeleton of adult sheep, goats, suids and cattle. Only measurements with a minimum of two values were retained for the analyses. Infant and juvenile specimens were excluded. In contrast, bones which were still unfused, or incomplete for which it was not possible to establish the fusing stage, but showing apparent definitive ossification, were retained. Due to the lack of knowledge on laterality and rank, phalanges and unidentified suids metapodials were excluded from the corpus. The compilation of all biometric data includes a total of 5533 measurements (SI table 1; SI table 2).

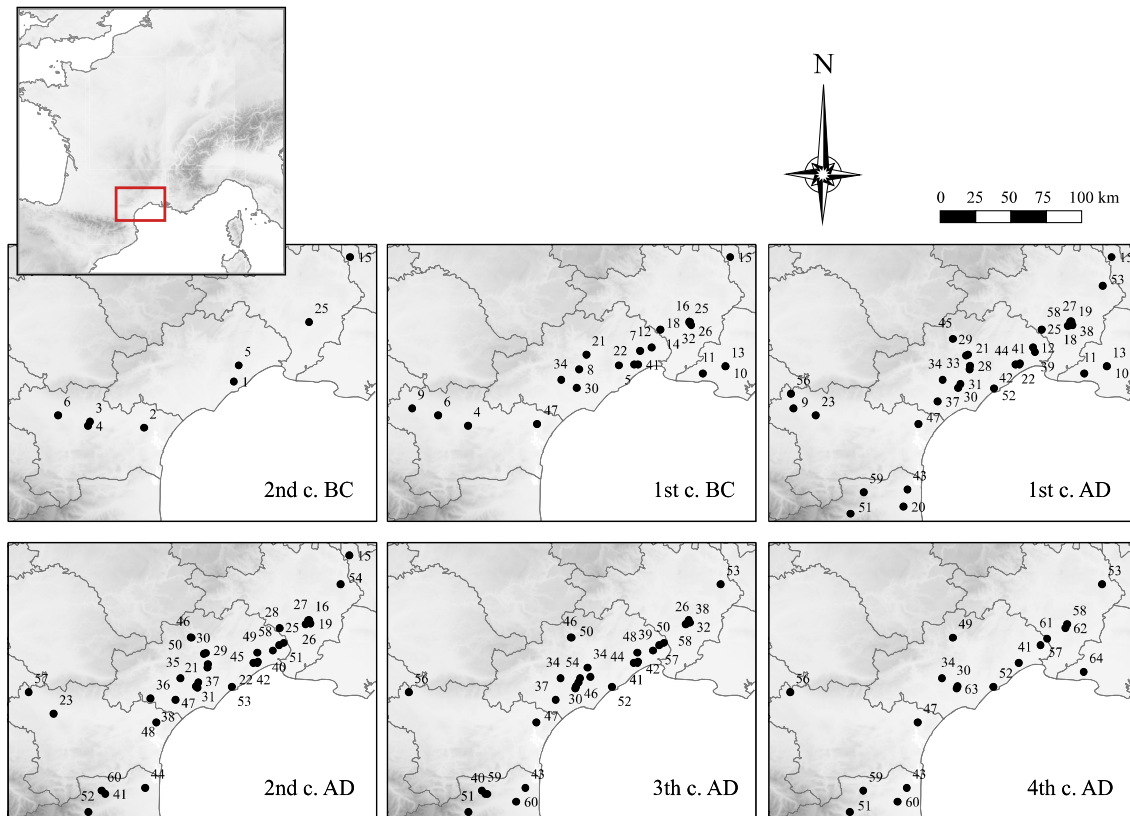


Fig. 1. Location of the archaeological assemblages studied through time, from the 2nd century BC to the 4th century AD. Information on the sites, identified by the numbers, can be found in SI Table 1. The grey lines represent the current borders of French departments.

3. METHODS

The log size index (LSI) is obtained by calculating the difference between the decimal logarithm of each measurement from the archaeological material (x) and the corresponding measurement of a reference (y) (Simpson, 1941; Meadow, 1999). The formula can be expressed as follows: $LSI = \text{Log}(x/y) = \text{Log}(x) - \text{Log}(y)$. This is actually a scaling technique for the size index (Meadow, 1981, 1999). As reference population, we used the average of each variable measured in the studied dataset (SI table 3). Thus, larger specimens than average will have positive values, while smaller specimens will have negative values. It should be noted that the size measurement expressed by LSI does not correspond to the body height classically interpreted in archaeozoology, as it is based on measurements taken in many different directions. Each measurement is dated by the mean of the possible time range of occupation, corresponding to the mean of the TPQ and TAQ of its stratigraphic unit. All analyses were performed in R (R Core Team, 2021), and LSI calculations are done with the *zoolog* package (Pozo *et al.*, 2022).

Traditionally, LSI values obtained from various variables are compared using *e.g.* t-test or Mann-Whitney test to ensure their homogeneity and detect allometries, *i.e.* when different variables provide different information (*e.g.* Albarella *et al.*, 2009; Duval *et al.*, 2012; Duval and Clavel, 2018; Trentacoste *et al.*, 2018, 2021). When LSI values are studied diachronically, with time being analysed as a continuous variable, the different variables are usually not compared to each other (*e.g.* Arbuckle *et al.*, 2014, 2016; Duval *et al.*, 2018). Here, changes in the LSI values through time were assessed by a smoothing method based on a local polynomial regression fitting (function *loess* of the R package ‘stats’ (Cleveland *et al.*, 1992)). A 90% confidence interval was added to the regression curve. Non-overlapping confidence intervals of two curves indicate significant differences.

Conversely, an increase or decrease in LSI values through time was considered significant only when the confidence intervals did not overlap. The evolution of the LSI values through time was explored between 200 AD and 400 BCE and visualised as a biplot with time represented along the x-axis, and LSI values along the y-axis.

In order to test for allometric differences between bones and between variables of each bone as already detected by previous studies (*e.g.* Zeder and Lemoine, 2020a), LSI values were first analysed separately for each variable. Then the variables were divided and analysed by dimension separating the length, breadth or depth measurements following Duval (2015) (SI table 4) and as recommended by different authors (Uerpmann and Uerpmann, 1994; Davis, 1996; Meadow, 1999; Baudry, 2012; Duval, 2015; Robin and Clavel, 2018). After these preliminary analyses, ensuring the homogeneity of the variables, all LSI values were pooled by taxa and visualised jointly.

In order to apprehend the allometric bias in LSI analysis, and thus to illustrate their potential over interpretation, we explored the variation of LSI values for archaeological specimens from the dataset, represented by multiple bones. Our dataset includes 23 skeletons from 15 sites attributed to single specimens. The range of their LSI values was calculated as the difference between the minimal and maximal of all their LSI values.

4. RESULTS

A total of 5533 measurements were analysed corresponding to 1950 measurements of cattle, 2197 of suids, 1113 of sheep and 273 of goat.

4.1. LSI per bone

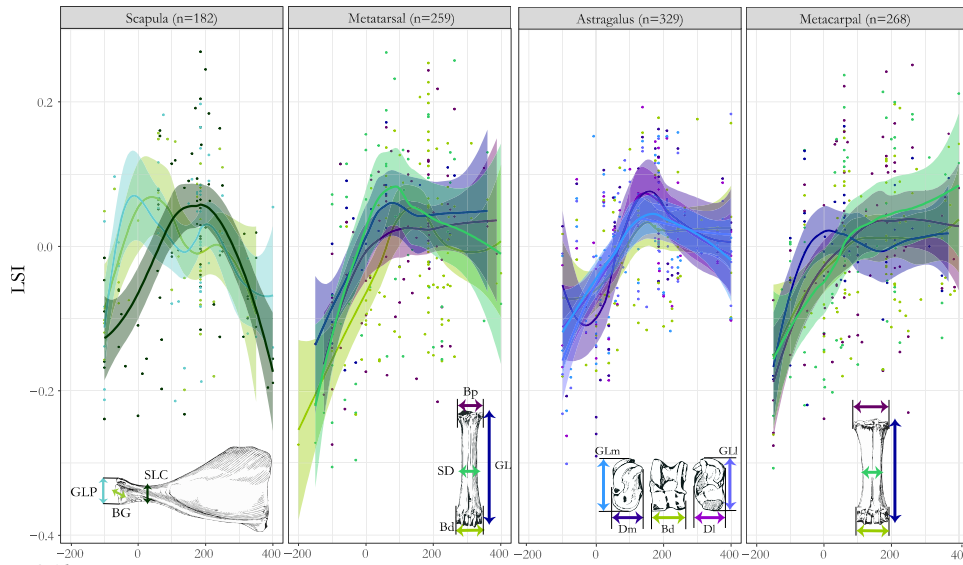
Overall, for each taxon and each bone, the LSI values of the various variables tend to overlap (Fig. 2), although some differences exist and not all bones show the same pattern over time. In general, the number of measurements is smaller at the extremes of the chronological period (SI Fig. 2) as evidenced by larger confidence intervals.

For cattle (Fig. 2A), the scapula shows a different pattern compared to the other bones, with a similar bell shape trend characterized by an increase of LSI values up to a point where the measurements decrease. The SLC reaches its maximum around 200 AD, nearly two hundred years later than the variables BG and GLP.

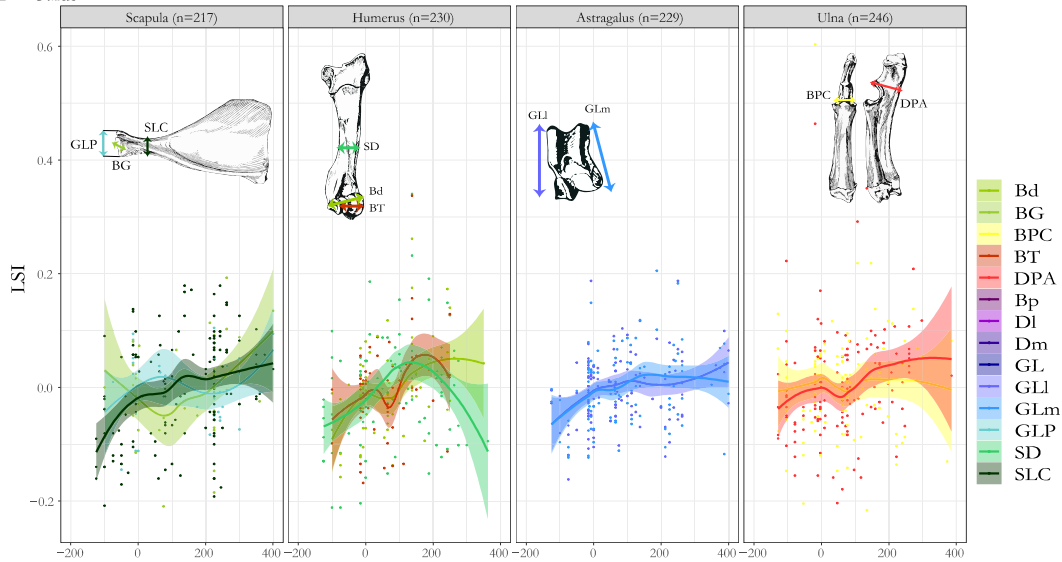
The metacarpal, the talus and the metatarsal have all their variables largely overlapping and show a main trend of increase in LSI values until a plateau. The plateau is reached at different times depending on the bone. The talus shows a maximum in LSI values around the middle of the 2nd c. AD, as in the case of metatarsal Bd. For the other variables of the metatarsal, the maximum appeared earlier, at the end of the 1st c. AD. The trend of the metacarpal is less clear with a maximum reached at the turn of our era for the GL variable, during the 2nd c. AD for the Bp and the Bd, while the SD shows a constant increase and does not reach a plateau.

For suids, bones show relatively different trends in LSI values through time. On the one hand, variables of the humerus and SLC of the scapula increase until the beginning of the 2nd c. AD, followed by a plateau. On the other hand, variables of the talus only increase during the 1st c. BC and no variation can be observed for the ulna until the 2nd c. AD. The scarcity of measurements makes interpretations of the trends at the end of the period difficult, but only SD of the humerus decreases significantly (Fig. 2B).

A – Cattle



B – Suids



C – Sheep

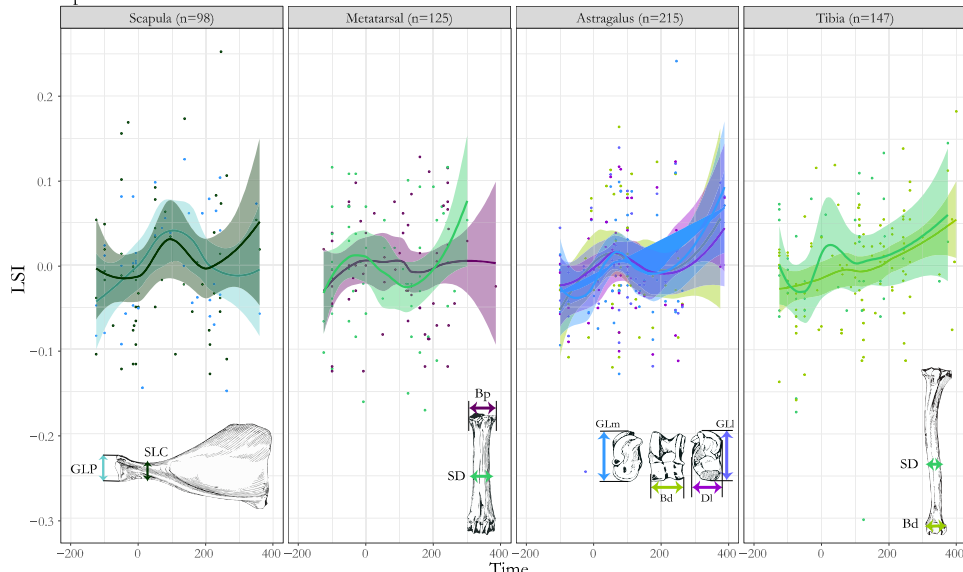


Fig. 2. Evolution through time (200 BCE to 400 AD) of the Log Size Index (LSI) values separated per bone and variables and for each taxon separately (A = Cattle, B = Suids and C = Sheep). Only the four bones with the largest number of measurements are presented (all others are shown in SI Fig. 2). Only the variables with at least 30 measurements are presented. Goats were not analysed due to the small sample size per variable. Each point corresponds to a LSI value plot in y against time in x. The sample size per bone (n =) is written in brackets. Abbreviations are those of von den Driesch (1976).

For sheep, the variables of each bone largely overlap (Fig. 2C). The talus and the tibia seem to show a similar, but insignificant, increase of LSI values through time. The scapula, represented by less measurements, and the metatarsal appear stable over time.

As a whole, this approach shows a relatively homogeneous evolution between variables of a bone for each taxon and, frequently, different patterns between the bones studied. Moreover, the trends of certain variables seem to be influenced by a limited number of measurements, which calls for great caution in the interpretations.

4.2. Breath, depth, and length

Variables were then combined according to the dimension they represent: breadth, depth or length.

For cattle, the analysis of the three dimensions revealed different patterns through time. For breadth all variables largely overlap although small but significant differences can be noted. For example, the scapula shows higher values than femur, talus and naviculocuboid during the first century BC. The scapula also shows higher than metacarpus during the first century AD, when the talus shows lower values than humerus, radius, femur and tibia. Finally, talus and metapods show higher values than radius during the third c. AD.

For depth the talus and calcaneus show opposite trends to the ulna. A difference is also observed for the length of the metapodials, reaching their maximum during the 1st c. AD, while the talus reaches it at the beginning of the 2nd c. AD.

Altogether, the three dimensions of cattle show a relatively similar pattern with a maximum around the turn of the 2nd c. AD. From there, and until the end of the 4th c. AD, LSI-breadth stagnates while LSI depth and length decrease (Fig. 3). Depth values appear smaller than breadth and length from the 1st c. BC to the 1st c. AD, and again smaller than breadth during the 4th c. AD.

For the three dimensions of suids, the variables largely overlap and show little variation through time (Fig. 3). LSI-depth increase slightly until the middle of the 2nd c. AD in two steps, with a plateau during the 1st c. AD. LSI-breadth and length reach their maximum during the 2nd c. AD. Then, LSI-depth and length seem to stagnate, while LSI-breadth decreases until the end of the 4th c. AD.

For goat, only breadth variables of the radius and metacarpal were represented by enough measurements to be visualised, though, due to their relatively small number, interpretations should be made with caution. When the variables are pooled, the three dimensions largely overlap.

For sheep, curves of the three dimensions largely overlap and show a similar evolution through time with little variation.

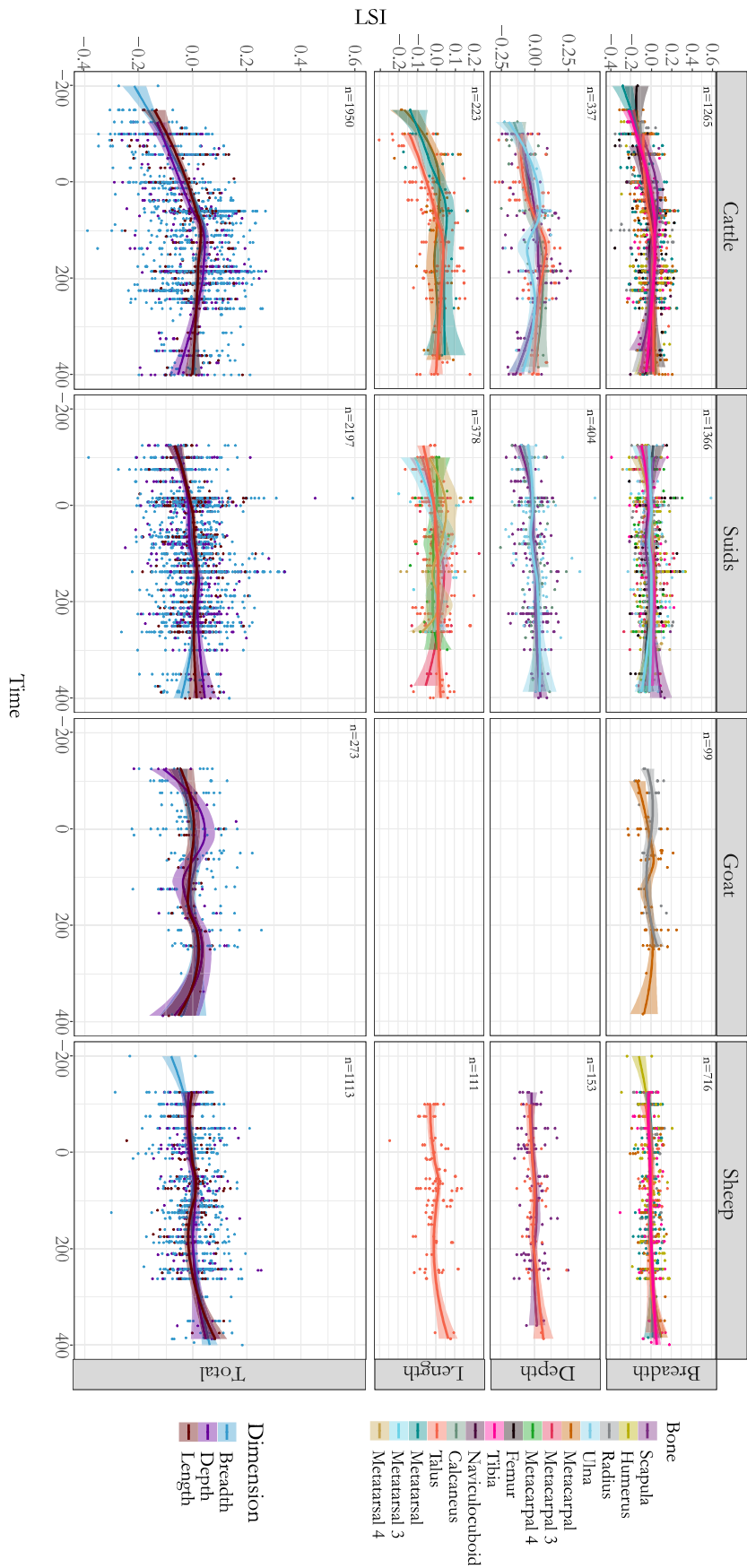


Fig. 3. Log Size Index evolution by taxa and dimension between 200 BCE and 400 AD. Dimensions of each variable were attributed following Duval (2015) (SI Table 4). Only the bones with at least 30 measurements per dimension are presented by dimension. For goat, only breadth measurements were numerous enough to be represented. For the total representation, all variables with more than two measurements were included. Each point corresponds to a LSI value plot in y against time in x. The sample sizes follow “n = “.

4.3. Overall evolution of the species through time

All LSI values were then pooled to compare changes between the four species (Fig. 4). Cattle is the species showing the greatest variation in LSI values through time. Their size is at its lowest at the beginning of the period, then reaches a maximum in the early 2nd c. AD, followed by a decrease until the beginning of the 4th c. AD. Suids size also increases until the turn of the 2nd c. AD, but in two stages, during the 1st c. BC and more briefly in the first half of the 2nd c. AD, separated by a stagnation phase throughout the 1st c. AD. Then, suids size remains stable during the 2nd c. AD before decreasing until the end of the period. Sheep and goat change in a relatively similar manner with some differences. Goat size increases from the beginning of the 1st c. BC (not enough data were available before this date) to the second half of the 1st c. AD, followed by a plateau until at least the end of the 3rd c. AD (the confidence intervals overlap over time), potentially followed by a size decrease, evidenced by only few measurements to reach a size similar to those observed at the beginning of the period. Sheep also show their minimal size at the beginning of the studied period, which increases until the middle of the 1st c. AD up to a plateau with no change in size until the beginning of the 3rd c. AD, before increasing again to reach their largest size at the end of the study period.

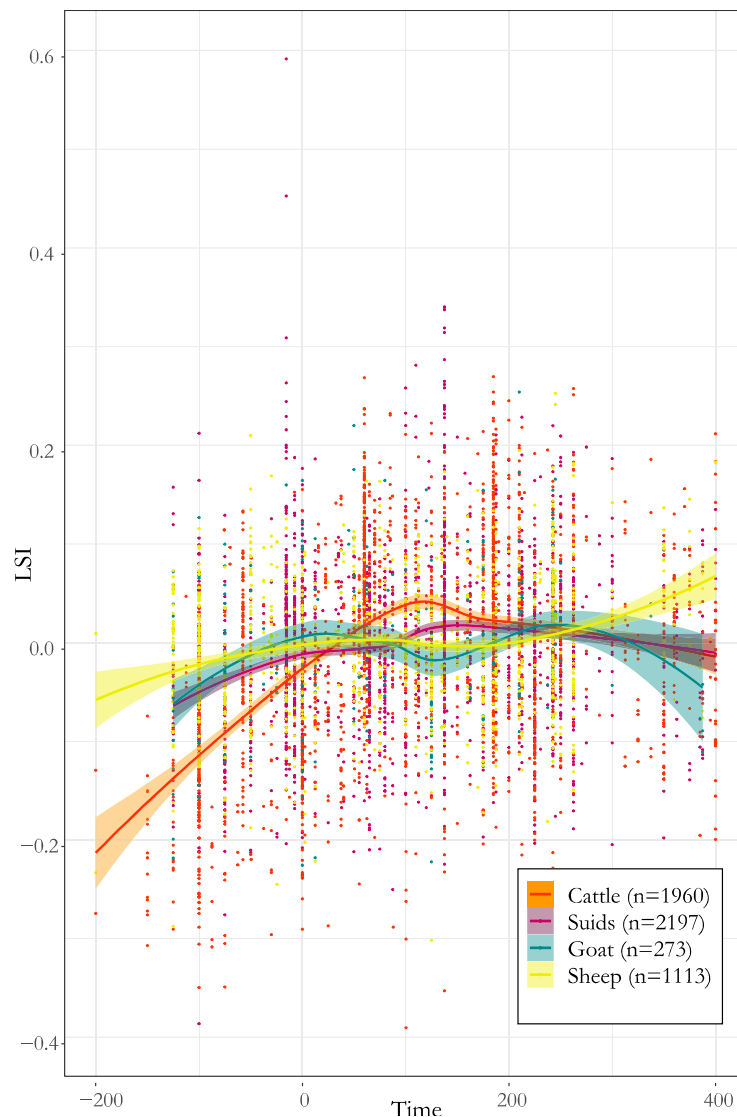


Fig. 4. Log Size index evolution for cattle, suids, goat and sheep between 200 BCE and 400 AD. All variables measured on the appendicular skeleton with more than 2 measurements were included. Each point corresponds to a LSI value plot in y against time in x. The sample size per species ($n =$) is written in brackets.

4.4. Individual variation of LSI values

LSI values were obtained from bone assemblages corresponding to 23 single individuals (Fig. 5). Intra-specimen LSI variation appears important with regards to the variation of species over time (Fig. 5A). The LSI range spread between 0.07 and 0.26 for cattle, 0.11 and 0.31 for suids, and 0.05 and 0.10 for sheep (Fig. 5B). For cattle and suids, the LSI range per specimen does not vary with the number of measurements available ($\text{corr} = 0.16756$, $t = 0.61283$, $\text{df} = 13$, $p\text{-value} = 0.5506$ for cattle, $\text{corr} = 0.46953$, $t = 0.92112$, $\text{df} = 3$, $p\text{-value} = 0.4249$ for suids) or time (mean TPQ/TAQ) ($\text{corr} = -0.40624$, $t = -1.603$, $\text{df} = 13$, $p\text{-value} = 0.133$ for cattle, $\text{corr} = -0.54839$, $t = -1.1359$, $\text{df} = 3$, $p\text{-value} = 0.3385$ for suids). Due to small number of bone assemblages for sheep ($n = 2$), correlation tests were not performed for this species.

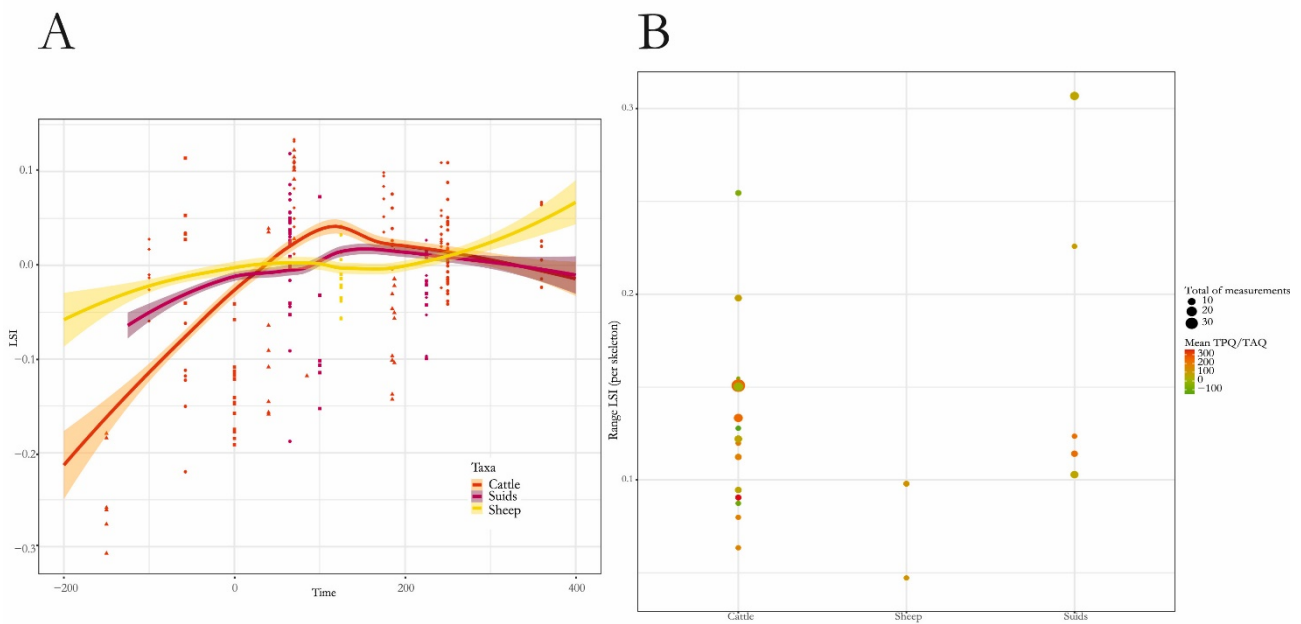


Fig. 5. Intra-specimen LSI variation. *A.* Visualization of intra-specimen Log Size Index (LSI) variation compared to the diachronic evolution of the species. Each dot represents a LSI value and are coloured by species. Values belonging to single specimens are aligned in x . The curves are those obtained in Fig. 4 (i.e. all values used for their computation are not represented). *B.* Ranges of LSI values calculated from the remains of 23 individuals separated by taxon. The size of the dots represents the number (Nb.) of available measurements and the colour reflects time. Data available in SI table 5. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

5. DISCUSSION

Overall, the results appeared highly influenced by the number of measurements per variable. In some instances, non-overlapping confidence intervals, that should be interpreted as significant differences between variables, were in fact based on too little data to reach definitive conclusions. Differences between variables or between dimensions, *i.e.* allometries, exist and should be carefully inspected before making widespread use of Log Size Index approaches when studying a specific species. However, those allometries appeared low compared to the long-term diachronic variation and the inter-species differences.

5.1. Choice of dataset and critical use of the LSI for diachronic analysis

By using measurements from a single operator, we avoided potential bias linked to inter-operator measurement error known to be potentially important for biometric data (Yezerinac *et al.*, 1992; Evin *et al.*, 2020). Surprisingly, the existence of differences between operators does not seem to be considered in current

syntheses based on LSI approaches, and may require further exploration. Besides, while in our study all the bones attributed to adults were measured, even if they were incomplete or unfused, this may vary upon operator. For example, while von den Driesch (1976) reference measurements advocate measurement of only “full grown animals”, some authors only measure fully fused elements (*e.g.* Duval and Clavel, 2018), fused elements (*e.g.* Albarella *et al.*, 2009) or a set of fusing and fused elements (*e.g.* Albarella and Payne, 2005; Albarella *et al.*, 2008). Thus, the inclusion of younger specimens by some operators may result in an increase in the number of small LSI values.

In this study, we demonstrate important variation in LSI values within single skeletons. Including skeletal groups in an analysis has the advantage of providing a large number of measurements, and highlighting potential allometries. On the other hand, it gives more weight to some specimens in the calculations. To avoid this over-representation, some authors select only one measurement per bone (Grau-Sologestoa *et al.*, 2021), one measurement per bone from any group of articulated remains (Trentacoste *et al.*, 2018, 2021; Nieto-Espinet *et al.*, 2021) or average values per dimension of a bone (Duval, 2015). How the measurement is selected remains unclear and can affect the analyses since, as we have demonstrated, allometry is not absent from LSI analyses. Here we included all available measurements and took advantage of bone assemblages belonging to single specimens to determine the intraspecimen range of LSI variation. This variation is about 0.07–0.16 in most cattle ($n = 13$), but can exceptionally exceed 0.2 ($n = 2$). In suids, it always exceeds 0.1 and even reaches 0.3 in an individual from Nimes “Place d'Assas” (60–70 AD).

Two important factors certainly contribute to the overall observed LSI variation and were not assessed in this study: sexual dimorphism and the potential presence of wild and domestic specimens in the dataset.

In this study, as in most cases when working with archaeozoological assemblages, males and females could not be differentiated, though no groups of size were detected in our analyses. Some studies focus only on elements with low sexual dimorphism (*e.g.* Albarella *et al.*, 2009; Grau-Sologestoa *et al.*, 2021), but that requires selecting measurements and therefore reducing the dataset. Conversely, variables known to be sexually dimorphic can also be used to better explore the differences between males and females (*e.g.* Grau-Sologestoa *et al.*, 2021) and potentially explore changes in sex ratio potentially linked with past husbandry practices (*e.g.* use of animals for labour or milk production).

The presence of aurochs (*Bos primigenius*), ancestor of cattle, was not considered in this study since its last detected occurrence in the region dates from between the Final Bronze Age and the beginning of the Iron Age (Forest and Cheylan, 2015). Conversely, wild boars are certainly present and are especially difficult to differentiate from domestic pigs in the archaeological record. This is particularly true in the western Mediterranean basin where the local wild boars are particularly small (Albarella *et al.*, 2009; Evin *et al.*, 2015) and where the domestic pigs arrived from the Near East during the Neolithic after genetically admixing with European wild boars all along their route of spread (Frantz *et al.*, 2019). While traditionally, small specimens are identified as domestic pigs (*e.g.* Albarella *et al.*, 2006b; Rowley-Conwy *et al.*, 2012), here we did not detect a clear group of size, but some measurements were particularly large and likely to belong to wild boar. While it is commonly accepted that the metric distinction of suids is unclear (*e.g.* Albarella *et al.*, 2006b; Evin *et al.*, 2014), geometric morphometrics can help address this problem (*e.g.* Cucchi *et al.*, 2009, 2011; Evin *et al.*, 2013, 2015). Indeed, shape seems to be a much more promising indicator of the domestic/wild status of the specimens than size, especially on dental data (Evin *et al.*, 2013, 2015) and such approaches will likely be beneficial to further biometric study in the region.

One of the original features of the study presented here is the use of time, not by grouping measurements into chrono-cultural categories, but as a continuous variable. We used the mean of possible time of occupation

(mean of the TPQ and TAQ) determined as precisely as possible for each stratigraphic unit of the sites. This approach, more precise than using the average dating of the site (e.g. Frémondeau *et al.*, 2017; Duval and Clavel, 2018) or average dating of phase (e.g. Arbuckle *et al.*, 2014, 2016) is, however, not completely satisfactory as it does not take into account the extent or uncertainty of the occupancy boundaries. In the future, it will be of prime interest to improve this aspect by, for example, applying resampling methods (e.g. bootstrap).

5.2. Diachronic evolution

Analyses computed at the scale of the variable have highlighted two main results. First, within a bone, variables do not always show identical diachronic evolution, corresponding either to different trends suggesting allometric differences, or similar trends but shifted in time, suggesting asynchronous evolution. Second, these analyses are strongly and particularly influenced by the sample size, and when the number of measurements is small, a single measurement may have a strong influence on the curve and its confidence interval and particular care must be taken during the interpretations. The analyses of the length, breadth and depth dimensions revealed relatively homogeneous trends except when the number of measurements was relatively low, such as the extremes of the chronological period, or for the goat that was the least well represented species. All measurements considered together, the comparison of the four species revealed different patterns through time. The evolution of the four species during the Roman Empire in western *Gallia Narbonensis* can now be discussed separately.

5.2.1. Cattle

Cattle are, by far, the most variable species we studied, with a regular and continuous size increase between the 2nd c. BC (starting point of our study) and early 2nd c. AD. A contemporaneous size increase has been observed in northern Italy (Trentacoste *et al.*, 2021), Catalonia (Colominas and Sana, 2009; Colominas *et al.*, 2014; Colominas and Edwards, 2017), throughout Gaul and Germania (Duval *et al.*, 2012; Frémondeau *et al.*, 2017; Duval and Clavel, 2018), Switzerland (Groot and Deschler-Erb, 2015), Netherlands (Groot, 2008; Groot *et al.*, 2016) and England (Albarella *et al.*, 2008; Rizzetto *et al.*, 2017). This increase seems to be homogeneous in both intensity and duration across Gaul, though some differences in timing have been reported, with cattle of Narbonese Gaul and Italy being already larger than those of Northern Gaul in the 2nd-1st c. BC (Frémondeau *et al.*, 2017). In Northern Italy, bovine dimensions might have increased since the Bronze Age (Trentacoste *et al.*, 2021). For southern France, the samples from the site of *Lattara*, which constitute one of the rare references in the region for the transition between Iron Age I & II, suggest an opposite dynamic from Northern Italy with a size decrease during the 5–4th c. BC (Nieto- Espinet *et al.*, 2020).

After reaching a maximum at the beginning of the 2nd c. AD, overall cattle size slightly decreased until the end of the 2nd c. AD to reach what looks like a plateau until the end of the period. This stability of LSI during Late Antiquity has been observed in Switzerland, while LSI decrease in the Netherlands (Groot and Deschler-Erb, 2015).

However, this result is mitigated by the analyses separating the bone dimensions. In fact, during the 3rd and 4th c. AD, while LSI-length and LSI-breadth remain stable from the middle of the 2nd to the end of the 4th c. AD, a decrease of LSI-depth is observed from the second half of the 2nd c. AD, a fact that was previously unknown in this region but which coincides with recent observations in Northern Italy (Trentacoste *et al.*, 2021). In comparison, in Gaul, only a fall in the length of bovine bones had been observed from the 3rd c. AD (Duval and Clavel, 2018), a result not observed here. In Catalonia (Nieto-Espinet *et al.*, 2021), only bone lengths decrease from Late Antiquity while widths remain stable until the 5th c. AD.

Cattle appeared to be the species with greatest variation between bones and between variables within a bone. For example, the variables of the scapula show a size increase followed by a decrease. For some others, like the metapods, variables show a size increase followed by what seems to be a relative stability even if the confidence intervals are particularly large. This reveals different allometries, where not all bones evolve homogeneously over time. In addition, the scapula provides another example of allometries, with asynchronous evolution of its different measurements. While the greatest length of the *processus articularis* (GLP) and breadth of the glenoid cavity (BG) reached their maximum around year 0, the *collum scapulae* (SLC) reached his maximum nearly two centuries later. A consequence of these allometry is that the trend observed by bone does not necessarily reflect the diachronic size evolution depicted by the LSI. The detection of allometry, between bones and between variables appeared however greatly influenced by the number of measurements.

In cattle, we identified differences between LSI-depth on the one hand, and LSI-length and LSI-breadth on the other hand, especially in the metapods. In northern Italy and England, only their breadths would decrease after the 4th c. AD, implying a drop in the bones robustness (Rizzetto *et al.*, 2017; Trentacoste *et al.*, 2021). This allometric trend was also identified in Languedoc, with only the length of the metapods decreasing around the 6th-7th c. AD, while the breadth decreased earlier, around the 4th-5th c. AD (Mureau, 2020).

The bovine metatarsal deserves special attention, as it has been the subject of multiple syntheses for the French area (Forest and Rodet-Belarbi, 1998, 2002; Carrère *et al.*, 2002). In the synthesis of Forest and Rodet-Belarbi (2002), the length of the metatarsal increases during Antiquity from approximately 214 (50 BC to 70 AD) to 230 mm (2nd-6th c. AD), which would represent a range of 0.031 in LSI values, a difference that could not be confirmed by our study due to the large confidence interval we observed. However, despite this uncertainty, metatarsal and metacarpal lengths differ between the beginning and the end of our studied period, confirming these preliminary finds.

5.2.2. Suids

In suids, the three bone dimensions show similar patterns, except at the end of the period where less measurements were available. Compared to cattle, the range of variation in suid size is relatively small during the period. While all dimensions increase during the 1st c. BC and then seem to remain stable for a century, the breadth and depth show a small and brief increase until the first quarter of the 2nd c. AD. Then, only the breadth shows a slight and continuous decrease for the rest of the period, while for the two other dimensions the confidence intervals are large but the size seems to increase.

This increase in pig size can be traced back to the 4th c. BC in southern France (Duval, 2015). In Northern Italy, an increase has also been identified in LSI-breadth between the Iron Age and Roman period in the North (Trentacoste *et al.*, 2021), and in LSI-length between the Republican and Imperial periods in central Italy (De Grossi Mazzorin and Minniti, 2017), while no variation in size can be noted in Catalonia (Colominas, 2017).

At the larger scale of the Gaul, limb bone lengths increased from the end of the 3rd c. BC, with regional variations in the intensity and duration of the increase (Frémondeau *et al.*, 2017). *Gallia Narbonensis* appears to be the first region to show its maximal average pig size, around 200 AD (Frémondeau *et al.*, 2017), slightly later than what we observed in our study, a difference that may be due to the geographic diversity of the studied sites or the different methodology we used. The maximal average pig size appeared smaller in *Narbonensis* than in other Gaul territories where the increase appeared more intense and spread over a longer period of time (Frémondeau *et al.*, 2017). Then, the size decrease we observed seemed to continue at least until around the 10th c. AD (Duval, 2015; Mureau, 2020).

5.2.3. Caprines

Sheep and goat cannot always be identified in the archaeological record, and in the Western Mediterranean area sheep very often outnumber goats, though some exceptions exist (Forest, 1997, 1999; Forest *et al.*, 2004). As a consequence, the number of measurements available for goats is relatively small and the obtained results should be specified with more data.

The size variation of the two species appeared limited, at least when compared to the variation in cattle. Altogether the LSI values increase for both species in the 1st c. BC, and then remain relatively stable until the end of the 2nd c. AD. Analysis by dimensions shows that only breadths increase in sheep during the 2nd-1st c. BC while in goats both breadths and depths increased during the same period. In the absence of an evolution in length, only the robustness and not the height of these two species seems to increase during the first centuries of the Roman period. Then, sheep sizes begin to increase while goat sizes seem to decrease between the 2nd and the 4th c. AD. However, the data are, again, particularly scarce for this period and should be interpreted with caution.

The trends we observe appear to be therefore congruent with a previous synthesis in Languedoc (Forest, 2008), where increases in the breadths of humerus, radius and metacarpus were recorded between the 3rd c. BC and the 2nd c. AD, whereas the distal breadth of the tibia did not change throughout the same period. In Catalonia, a size increase from the end of the 3rd c. BC has also been shown (Colominas, 2017). In addition, the site of Lattara revealed a significant increase in caprine sizes between the 5th and 4th c. BC, followed by a stability in size until the 2nd c. AD (Nieto-Espinet *et al.*, 2020). It is therefore possible that the increase we observed started at least between the first and second Iron Age.

During Late Antiquity, our results appeared incongruent with previous studies. While we observed a size increase through the period, a size decrease had previously been recorded for the period in Languedoc (Forest, 2008; Mureau, 2020). A size decrease has also been observed in breadth, but not length, measurements in Northern Italy (Trentacoste *et al.*, 2021). Conversely in Central Italy, an increase in ovine bone length between the Imperial period and Late Antiquity has been shown (De Grossi Mazzorin and Minniti, 2017). Further studies are therefore needed to confirm caprine size evolution during Late Antiquity, not only in Languedoc but also in adjacent areas where different trends have been recorded.

5.3. Lines for future research

Our analyses provide a detailed and critical description of the different variables analysed and use a diachronic statistical representation coupled with confidence intervals. We detected subtler diachronic variation allowed by a higher temporal accuracy than large chronocultural phases, and to visually inspect its statistical significance. This work confirms that LSI approaches provide valuable information when studying large-scale size variation over large time periods. It also highlights different trends between variables, bones, or between breath, length and depth dimensions among bones and, thus, underlines the importance of bone-based or variable-based analyses especially for allometry detection.

Several points should be considered for future research such as the category of the site, the climate and geography, and a larger time range.

5.3.1. Socio-cultural characteristics

While all sites were analysed together, the nature of their occupation was not homogeneous. These socio-economic differences may be reflected in animal husbandry practices and animal bones.

In northern Gaul, from the end of the 1st c. BC to the 4th c. AD, bovine remains discovered in rural contexts are on average larger than in towns (Oueslati, 2002; Duval *et al.*, 2012). Other studies of assemblages from the ancient city centres of Lodeve (Forest, 2019) and Nîmes (Forest and Massendari, 2017), also noted lower bovine measurements than those originating from rural settlements. This is also true for pigs during the final La Tène period in northern Gaul, where remains from rural sites show the largest dimensions, while from the 2nd c. AD onwards the largest values are mostly from urban centres and villae (Duval, 2015). This larger size of pigs in urban contexts has also been noted in Italy (MacKinnon, 2001) with less size variation than in rural contexts. Finally, the culture of an occupation can also influence the size of domestic animals. In Catalonia, the so-called Romanization period, between the end of the 3rd and the 1st c. BC, is characterized by a significant difference in bovine and ovine bone dimensions between settlements, with higher values among newly-created settlements than among occupations perpetuated since the Middle Iberian period (Colominas, 2017).

5.3.2. Climate and environment

Climate and environment are important parameters to consider, especially in long-term and global studies (*e.g.* Duval *et al.*, 2015; Marom *et al.*, 2019; Nieto-Espinet *et al.*, 2021). They both play an important role in determining body size (*e.g.* Davis, 1981). It therefore seems important to take into account climate fluctuations in the context of a broader biometric study, but also the different environments that can impact body mass. This would require palaeoclimatic reconstructions dedicated to the study area.

5.3.3. Geography

Regional differences have been reported in the evolution of domestic animals (Duval *et al.*, 2012; Duval, 2015; Duval and Clavel, 2018; Mureau, 2020) and more in depth analyses of size variation may also reveal micro-regional variation. For example, the evolution of herd stature seen in the lowlands of northern Italy has not been observed in the alpine regions (MacKinnon, 2004) and this has been interpreted as a characteristic of sheep breeds that are particularly constrained to this extreme environment (Mason, 1998; Hall, 2004). Other territories, although integrated into the Roman Empire, may also have experienced the same limitations to their livestock sizes, such as the west of Britain (Maltby, 1981; Hammon, 2005) or Santarem in central Portugal (Davis, 2006).

5.3.4. Time

Our study focused on the Roman period in Narbonese Gaul, between the 2nd c. BC and the 4th c. AD. A complementary study of bone dimensions of these species must be carried out between the 5th and 1st c. BC in order to discover the origin of their increase, and their link with a possible Roman influence. Although most of our observations agree with the conclusions of previous studies, the increase in ovine dimensions during Late Antiquity is an original discovery. It deserves to be further investigated with a larger sample of remains from the 2nd-6th c. AD to confirm its significance as well as its durability through Medieval Times.

6. CONCLUSION

Whatever the species considered, the increase in bone size at the beginning of the Roman Empire is a long dynamic, inscribed over tens or even hundreds of animal generations. Its beginning could be clearly prior to the 2nd c. BC and therefore calls for a continuation of this work on the Bronze Age and Iron Age periods (Valenzuela-Lamas and Albarella, 2017; Nieto-Espinet *et al.*, 2020; Trentacoste *et al.*, 2021). In any case, the duration of this size increase is at least two centuries for pig, goat and sheep, and over three centuries for cattle. From the 2nd c. AD onwards, each taxon follows a distinct morphological evolution. Cattle and goats tend to fall in size until the end of the sequence, while pigs remain at the same height (LSI-lengths), but more slender

(decrease in LSI-breadths). Sheep are the only taxon whose bone size continues to increase, following a stagnation during the 1st and 2nd c. AD.

The four species present different diachronic size changes that may result from different agropastoral or environmental conditions. It has been proposed that these changes in domestic animals were linked to the end of the Roman Empire (e.g. Leguilloux and Lepetz, 1996; Duval, 2015; Rizzetto *et al.*, 2017). However, because size evolved over a long duration, over centuries, it seems challenging, or even impossible, to link these changes to specific events. To which extent a transition of the pastoral model can be a sufficient explanation for the changes observed remain unknown (Audoin-Rouzeau, 1994; Forest and Rodet-Belarbi, 2002; Duval and Clavel, 2018; Mureau, 2020), but it seems unlikely that both the Roman conquest and its fall could have had a sudden and major impact on domestic species. The causes of the observed trends therefore remain to be investigated and are certainly multimodal. Only micro-regional studies, comparing multiple socio-economic contexts, a careful exploration of environmental conditions through time, and taking into account the time as accurately as possible will allow the tracking and understanding of distinct morphological trajectories. The concrete contribution that continuous diachronic analysis is able to offer to osteometric syntheses is undeniable and offers much promise. This time-restricted study will be extended within the framework of the DEMETER project (ERC #852573) that aims to understand how and why domestic species change over the eight last millennia in the north western occidental Mediterranean basin.

AUTHOR CONTRIBUTIONS

Marine JEANJEAN: Conceptualization; Methodology; Software; Formal analysis; Writing - Original Draft; Writing - Review & Editing; Visualization. Cyprien MUREAU: Conceptualization; Methodology; Software; Formal analysis; Writing - Original Draft; Writing - Review & Editing; Visualization. Vianney FOREST: Data acquisition and curation. Allowen EVIN: Conceptualization; Methodology; Resources; Writing - Review & Editing; Supervision; Funding acquisition.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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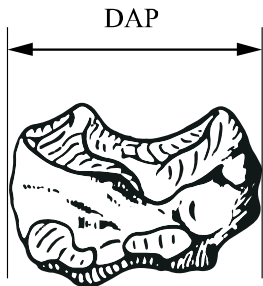


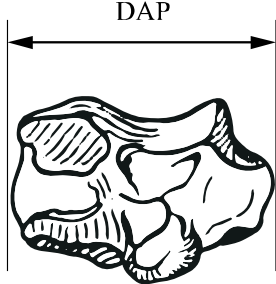

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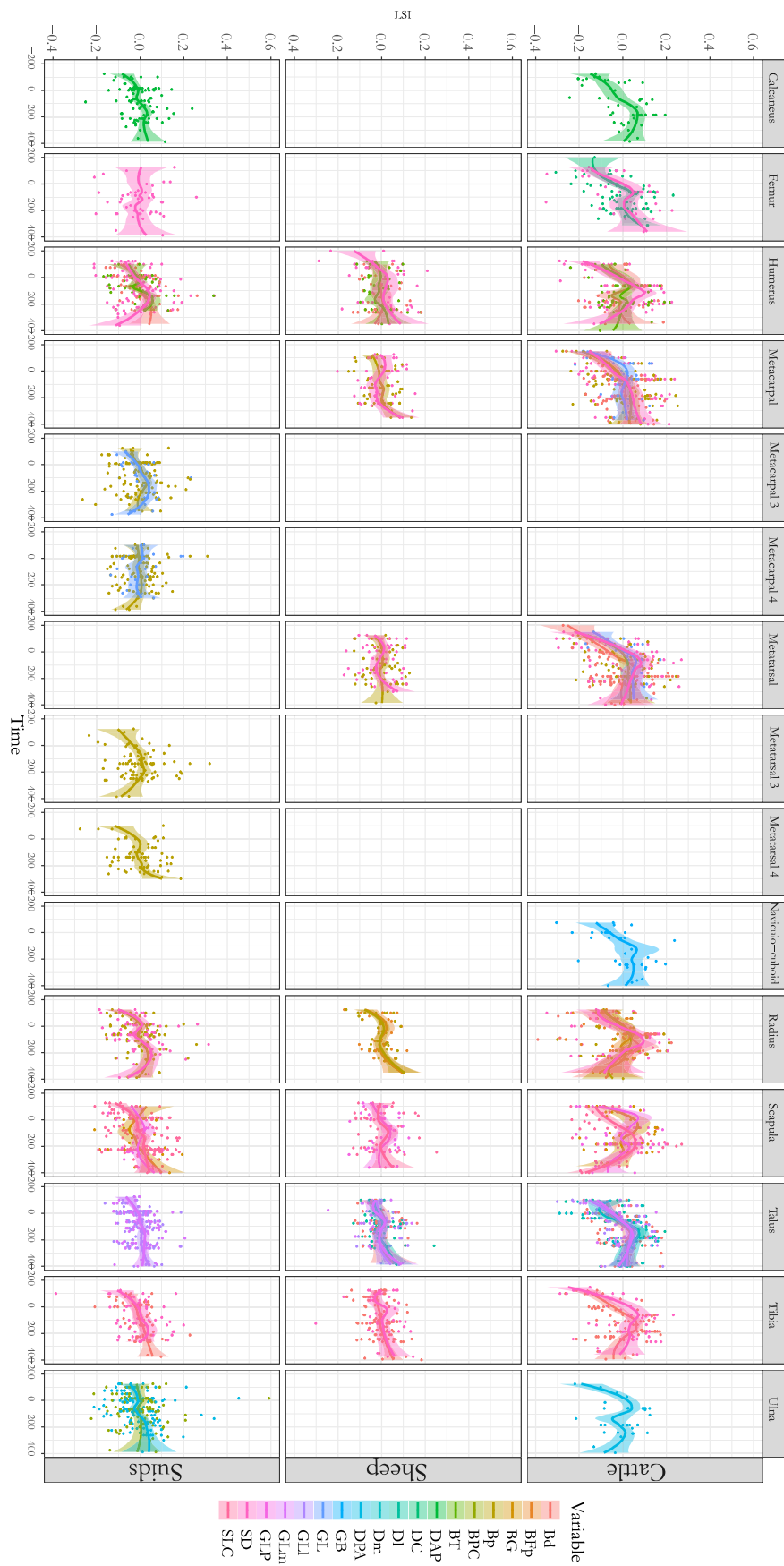
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SUPPLEMENTARY INFORMATION

<p>Pyramidal</p> 	<p>Medial cuneiform</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="767 367 922 454">  </div> <div data-bbox="1145 367 1236 495">  </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div data-bbox="716 533 911 607"> <p><i>Sus scrofa</i>, proximal view</p> </div> <div data-bbox="1091 533 1286 607"> <p><i>Ovis aries</i>, proximal view</p> </div> </div>	
<p>Scaphoid</p> 	<p>Cuboid</p>  <p><i>Sus scrofa</i>, medial view</p>	<p>Naviculocuboid</p>  <p><i>Ovis aries</i>, proximal view</p>
<p>Semilunar</p>  <p><i>Bos taurus</i>, external view</p>	<p>Calcaneus</p>  <p><i>Sus scrofa</i>, medial view</p>	

<SI figure 1>: Description of the unpublished measurements used in this study



<SI figure 2 >: Log Size index evolution by taxa (A= Cattle, B= Suids and C= Sheep/Goat), bones and variables between 200BC et 400 AD. Only appendicular skeleton measurements where there is than 30 measurements per variables are presented. Goat Log Size Index evolution is not available because of a lack of data. Each point corresponds to a measurement dated by the mean of TPQ/TAQ of its stratigraphic unit.

ID	City	Site name	Reference	T.P.Q.	T.A.Q.	Cattle	Pig	Goat	Sheep
1	Balaruc-le-Vieux	18 bis, rue de la République	Forest 2020a	-200	-100	13	0	0	0
2	Montredon-des-Corbières	Sainte-Croix	Forest 2003c	-150	-100	12	28	11	44
3	Trèbes	Beragnes	Forest 2014	-150	-100	4	1	0	2
4	Carcassonne	La Cavayère	Forest 2008a	-150	-50	130	79	9	91
5	Courmonterral	Les Joncasses	Forest 2018a	-225	200	7	2	4	8
6	Alzone	Borde Neuve	Unpublished	-125	-50	8	1	0	0
7	Castelnau-le-Lez	Mas de Caylus	Forest 2020b	-200	-50	17	72	18	38
8	Fontès	Fontcouverte	Forest unpublished	-100	-50	0	1	0	0
9	Villeneuve-la-Comptal	En David	Forest 1999	-100	1	7	1	0	2
10	Arles	La Tour du Valat	Forest 2004a	-40	25	14	4	0	27
11	Saintes-Maries-de-la-Mer	Ile de Mornès	Forest 2004c	-50	1	3	3	1	7
12	Castries	Mas de Roux	Fabre & Forest 2016	-60	75	2	13	0	0
13	Arles	La Capelière	Forest 2019f	-125	60	110	3	0	0
14	Villevieille	Impasse de la Cure	Forest 2018b and Forest 2020c	-50	100	4	4	1	10
15	Mondragon	Les Brassières Nord	Vermeulen et al. 1997	-150	-15	0	2	5	2
16	Nîmes	Les Arènes	Forest 2010a	-25	200	10	46	0	12
17	Nîmes	Carsalade	Forest 2003d	20	30	11	0	0	0
18	Nîmes	Avenue Jean-Jaurès, 59	Unpublished	70	100	1	0	0	0
19	Nîmes	Mas des Abeilles II.6	Forest 2009	-25	150	4	0	0	0
20	Perpignan	Le Petit Clos	Forest 1999/2000	50	70	207	3	0	0
21	Clermont-L'Herault	Peyre Plantade	Forest 2003a	-100	400	74	79	36	33
22	Lattes	Fromigüe	Forest 2017a	-50	300	60	12	0	0
23	Bram	Le Village	Forest 1998	0	250	75	108	2	37
24	Nîmes	Place d'Assas	Forest 2006b	60	70	14	120	0	8
25	Nîmes	Parking Jean Jaurès	Forest 2017c	-150	300	222	714	41	131
26	Nîmes	Mas de Vignoles IX	Forest 2012a	-100	-50	1	0	0	0
27	Nîmes	12, rue Leopold Morice	Forest 2017b	10	175	13	10	0	4
28	Aspiran	Soumaltre	Forest & Rodet-Belarbi 2002	1	200	22	6	0	22
29	Clermont-L'Herault	La Madeleine II	Forest 2006a	-100	150	7	13	0	7
30	Valros	Vigne de Bioaux	Forest 2010c	100	150	4	0	0	0
31	Tourbes	Mont Ferrier	Forest 2011c	10	225	6	6	6	9
32	Nîmes	24, rue Emile Jamais	Forest 2016	-200	300	5	44	0	0
33	Paulhan	Vareilles	Forest 2002a	-30	220	387	37	29	122
34	Magalas	Les Terrasses de Montfo	Forest 2015b	-100	400	16	56	15	89
35	Quarante	Soulomiac	Forest 1996/1997	100	200	0	1	0	3
36	Valros	Rec de Ligno	Forest 2010b	-25	200	12	18	22	36
37	Béziers	Le Gasquinoï	Buffat et al. 2009	50	225	1	3	0	6
38	Nîmes	Mas de Vignoles XIV	Forest 2012b	50	275	34	21	0	37
39	Mudaison	Les Aubettes	Bardot-Cambot et al. 2016	-25	425	46	1	4	5
40	Caramany	Pla de l'Aïgo II	Fabre et al. 1999	0	400	1	2	0	0
41	Lattes	Castelle-Pahon-Pinède	Fabre & Forest 2017	1	200	12	0	0	0
42	Lattes	Port Ariane	Forest 2004b	75	275	17	0	0	0
43	Claira	Sant Jaume de Crest	Forest 2011a	0	350	24	12	9	22
44	Lattes	Castelle-GR	Bardot-Cambot et al. 2017	10	175	12	2	0	0
45	Lodève	Place du Cdt Morand	Forest 2015a	0	300	5	17	11	45
46	Valros	Le Renaussas	Forest 2011d	100	275	1	0	1	9
47	Narbonne	Clos de la Lombarde	Forest 2001	-75	425	19	419	16	76
48	Castelnau-le-Lez	Parc Eureka	Forest 2019a	75	300	9	10	0	0
49	Lodève	Musée Fleury	Forest 2019b	-25	350	11	43	0	0
50	Lunel	Mas de Fourques II Ouest	Forest 2019c	150	300	0	19	0	0
51	Prades	Rue de la Basse	Forest 2015c	50	400	8	7	0	10
52	Sète	rue des Mesanges	Forest 2019e	1	600	22	21	0	0
53	Saint-Victor-la-Coste	Les Aumignanes	Forest 2008b	50	400	28	24	3	11
54	Pézenas	L'Auribelle-basse	Forest 2002b	220	265	74	52	24	80
55	Montagnac	Lieussac	Forest 1995	230	260	7	6	4	21
56	Soupeux	Fontvieille	Guillaume et al. 2007	50	500	9	4	0	2

57	Lunel-Viel	Le quartier central	Forest 2007	0	420	42	26	1	42
58	Nîmes	Mas Vigier	Forest 2011b	-100	500	5	0	0	0
59	Ansignan	Le Mas	Unpublished	50	700	6	6	0	0
60	Perpignan	Parc Ducup	Forest 2019d	-100	400	10	5	0	0
61	Villetelle	Ambrussum	Forest 1996	300	400	17	3	0	2
62	Milhaut	Careiron et Pesquier	Forest 2003b	100	150	4	0	0	0
63	Montblanc	Les Cresses Basses	Unpublished	150	500	21	5	0	0
64	Saintes-Maries-de-la-Mer	Le Carrelet	Forest 2004c	1	500	23	2	0	1

<SI Table 1> Information on the archaeological sites studied. Site names and their city of origin. Terminus post quem (T.P.Q.) and terminus ante quem (T.A.Q.) of the studied stratigraphic units and number of biometric measurements per species. The number (n) refer to those on the maps of figure 1.

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