



# Construction of chrono-stratigraphic samples (CSS) as a support for taxa quantification in zooarchaeology: an example of the use of this new unit of analysis in the Languedoc region (southern France) from Late Antiquity to the High Middle Ages (3–12th c. AD)

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## Abstract

The quantification of taxa is a major exercise in zooarchaeology. Specialists have multiplied the methods of counting animal remains, but the choice of the stratigraphic unit for these analyses (stratigraphic unit, sector of an archaeological site, occupation phase of a settlement...) constitutes an equally important, but less debated problem.

In this study, we have constructed a new analysis unit that allows us to adapt the quantification of species on an archaeological site according to the volume of animal bones found there. Each chrono-stratigraphic sample (CSS) contains a sufficient number of remains for statistical analysis and preserves as much information as possible about the activities that generated the animal remains composing it.

This method was then applied to a dataset of approximately 70,000 animal remains from 34 archaeological sites located in Languedoc (southern France). Their cluster analysis allowed to identify six main patterns of animal remains samples according to their taxa frequencies. Three are linked to the food sphere and the other three include remains of non-consumed species. The analysis of CSS spatial distribution on a few archaeological sites allowed to identify a recurrent sectorization of wastes according to the taxa that compose them. Finally, a diachronic analysis of the frequencies of caprines, cattle, and suids has been performed for the whole region, with the CSS and the occupancy stages as analysis units. The former allows us to identify many more trends, but above all, much finer than the latter.

**Keywords** Roman period · Middle Ages · Cluster analysis · Zooarchaeology · Meat diet · Waste management

## Introduction

The transition between Late Antiquity and the Early Middle Ages was a turning point in the economic, administrative and even religious history of the rural populations of Western Europe (Burns and Eadie 2001; Christie 2004; Delaplace 2015; Harper 2017). The emergence of an episcopal network, distinct from that of Roman cities, particularly favored competition between the different places of power and a fragmentation of spaces (Theuvs et al. 2001; Schneider 2003). Roman towns were not only centers of consumption but also

structured the rural landscape through their valuation and redistribution of agricultural products (Leveau 1985; Wilson 2002; Scheidel et al. 2007; Trément 2013). The contraction of the urban areas, from the fourth to the sixth centuries, therefore modified the organization of rural settlements and favored the development of new exchanges networks (Ripart and Lauwers 2007; Kasprzyk and Monteil 2017; Carneiro et al. 2020). Settlements took over new lands that had been abandoned during the High Empire, or even never occupied, following the example of the hill sites that constituted new centers of power from the fifth century onwards, on the margins of the territories administered by the urban centers (Schneider 2004, 2010; Steuer and Bierbrauer 2008; Gandel and Billoin 2011; Vigil-Escalera Guirado 2015; Chabert and Martinez 2017; Chavarría et al. 2019).

These changes in the structure of the human settlement during the early Middle Ages is reflected in the

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zoarchaeological data. This period is characterized by general trends including: global decrease in the bone dimensions of the main domestic species (e.g., Audoin-Rouzeau 1991; Yvinec 1997; Forest and Rodet-Belarbi 2002; Forest 2008; Duval 2015; Grau-Sologestoa 2015; Rizzetto et al. 2017; Duval and Clavel 2018; Salvadori 2019; Mureau 2020; Trentacoste et al. 2021), changes in taxa frequencies (e.g. Akeret et al. 2019; Clavel and Yvinec 2010; Forest 2009; Lepetz and Zech-Matterne 2018; Mureau 2020; Pigière and Goffette 2019; Salvadori 2019) and in mortality patterns (Yvinec 1988; Forest 2008; Colominas et al. 2019).

The development of regional syntheses across Western Europe led to the identification of regional trends in the abundance of the Number of Identified Specimens (NISP), corresponding to the number of remains that have been identified, reflecting meat diet trajectories and divergent pastoral systems. Among the main livestock species, suids, and then bovines became dominant in the assemblages of northern France, Switzerland and the Netherlands during early Middle Ages (e.g., Clavel and Yvinec 2010; Putelat 2015; Lepetz and Morand 2017; Lepetz and Zech-Matterne 2018; Pigière and Goffette 2019), while the relative proportions of caprines increase around the Mediterranean coast, in the Rhône valley and England (Argant 2017; Rizzetto et al. 2017; Colominas et al. 2019; Salvadori 2019). Moreover, horse meat consumption progressed in northern Gaul, England and the western Iberian Peninsula (Yvinec 1988, 1996; Lepetz 1996a; Lepetz and Hanot 2012; Putelat 2015; Argant 2017; Akeret et al. 2019; Estaca-Gómez et al. 2019) whereas this practice, not attested in Mediterranean France, northern Iberia and Italy (Forest 1997; Salvadori 2006; Grau-Sologestoa 2016), is diminishing or even disappearing in Netherlands (Groot and Deschler-Erb 2015; Pigière 2017).

In the province of *Narbonnensis prima* (eastern half of the current Occitanie region), urbanized during the Roman period and whose administrative boundaries remained quite stable until the tenth century, the territorial hold of urban centers decreased and new settlement dynamics emerged (Loseby 1992; Raynaud 2003; Schneider 2007, 2010). Multiple surveys in the territories of the cities of Béziers (Mauné 1998a), Lodève (Garmy and Schneider 1998) or Nîmes (Raynaud 2001) all tend to estimate that between half and two thirds of the settlements of the first century AD were abandoned before the fourth century AD, but most of those remaining were then transformed with reconstructions and monumentalizations (Pellecuer and Pomarèdes 2001; Buffat 2011; Chavarría et al. 2019). At the same time, numerous small farms developed at the turn of the sixth century (Schneider 2005), and settlement increased, particularly in coastal areas that had been little occupied until then, e.g.,

Camargue, the Vidourle delta and the lagoons of Saint-Blaise (Raynaud 2001; Van Ossel and Raynaud 2012).

Early zooarchaeological studies carried out in Southern France used the archaeological settlement as the scale of analysis, i.e., all the animal remains discovered on a site during a phase of its occupation (e.g., Leguilloux and Lepetz 1996a, b; Forest 2000; Columeau 2001, 2002; Faure-Boucharlat 2001; Forest and Olive 2006). This implicitly assumes a homogeneity in zooarchaeological composition across a single settlement, despite its potential archaeological diversity of occupations and structures. However, NISP has been found to be influenced by the degree of agglomeration of human settlements (e.g., Lepetz 1996b; Clavel 2001; Cambou 2009; Forest 2009; Jouanin and Yvinec 2019), whether the habitat was perched (Putelat 2015; Goudemez 2018), or the type of structure (Méniel 1996; Horard-Herbin 2000; Lepetz 2009) from which the bones come. These few examples prove that the composition of zooarchaeological samples can vary between sites in a same territory, but also within each archaeological settlement.

Conversely, the Stratigraphic Unit (abb. SU), often contain too few remains to be analyzable during an zooarchaeological study. This is especially the case for rural sites, where the waste density is often lower due to a slower filling of detrital structures and their reuse for agricultural activities (Ballet et al. 2003; Havlíček et al. 2017; Lepetz and Zech-Matterne 2018; Jouanin and Yvinec 2019). Between these two classical scales of analysis, i.e., the settlement being often too large and SU too precise, another level of analysis can be proposed reconciling at the same time the preservation of the finest stratigraphic information, essential at a site scale, and the construction of quantitatively analysable study units in large regional synthesis.

In his early studies in southern France, Vianney Forest proposed to isolate samples yielding more than 50 caprines, suids, and cattle remains, composing a domestic triad (NISPt), to compare their respective frequencies (Forest 1997; Faure-Boucharlat 2001). This numerical threshold represents a compromise between the large number of faunal remains per SU that can be found in for example, agglomeration, and smaller assemblages like in rural settlements. In the course of its research, these samples belong to one SU, or groups of SU when their stratigraphic relationships were close, and were called in French “ensembles chrono-stratigraphiques” (Forest 2008) or “lots chrono-stratigraphiques” (Forest 2009).

Since then, the diachronic syntheses, and especially all the zooarchaeological study reports, he carried out in the Languedoc region have progressively opted for this method of quantification focusing on faunal samples with a NISPt exceeding 50. It generally consists in a biplot analysis of the evolution the frequencies of these three taxa through time, with a mean *terminus post quem* (TPQ) and *terminus*

*ante quem* (TAQ) of each sample as the abscissa, and in which each sample, symbolized by a point, is frequently qualitatively classified according to its geographical location or the category of establishment from which the faunal remains come (Forest 2008, 2009, 2015, 2018; Guy et al. 2010; Forest and Rodet-Belarbi 2011). In contrast, the transition between Late Antiquity and the early Middle Ages in Narbonnese Gaul had not been the subject of any zooarchaeological synthesis until now, except on certain micro-regions, e.g., middle Hérault valley (Ginouvez et al. 2017), the Camargue (Forest 2019) and the Roussillon (Ros et al. 2020). Furthermore, in these synthetic studies, the samples were only classified by geographical area or type of settlement, thus limiting the power of intra-site investigations that this unit of work allows.

Through a PhD thesis, this method of taxa abundance study has been renewed naming the unit of analysis “Chrono-Stratigraphic Sample” (CSS) and formalizing their design rules (Mureau 2020). The present study constitutes an application of this this new chrono-stratigraphic unit applied to a sample of faunal remains from 34 archaeological sites, in order to explore changes in taxa abundance and distribution of animal remains within settlements between late Antiquity and High Middle Ages (3–12th c. AD) in the Languedoc region. To do this, first the variation of taxa NISP in CSS has been explored and compared over chronology, geographical regions and categories of the settlements. The classification of the CSS into clusters was then used to reveal variation in taxa frequencies within a selection of well documented archaeological sites. Finally, the diachronic evolution of caprines, cattle and suids frequencies in CSS has been analyzed and contrasted with a similar analysis considering instead settlement occupancy stages, in order to test the respective benefits of both methods.

## Materials

The study is based on total of 73256 identified animal remains found at 34 archaeological sites (SI Table 1) and dated between the 3th and 12th centuries AD. The sites are localized in Languedoc plain and its hinterland, from Narbonne *Narbo* to Nîmes *Nemausus*, in the east of the current Occitanie region (France). This region corresponds to the area of influence of the *Volcae Arecomici* (Barrauol 2002; Thollard 2009), integrated to the Narbonnese Province after its roman conquest in 121 BC. After the Diocletian reform in the 4th c. AD, the study region corresponds to the eastern half of the province of Narbonnese Gaul I, before its integration in the Visigothic Kingdom as Septimania at the end of the Antiquity. Even if Septimania frontiers were quite stable during the Early Middle Ages, the province came under Umayyad control in 721 and then became part of Frankish

territory following the conquest of Narbonne by Pepin the Short in 759.

Considering the successive changes in administrative and political boundaries as well as the multiple socio-economic evolutions that affected the populations of Languedoc during the Middle Ages, a partition of the territory based on anthropological criteria was a problem. We have therefore preferred a division of the study area into six small regions (Fig. 1), following the landscape units defined by the Languedoc-Roussillon regional Direction of Environment, Land Management and Housing (<http://paysages.languedoc-roussillon.developpement-durable.gouv.fr>): Nîmes plain (5 sites), Lunel-Mauguio plain (8 sites), Etangs plain (5 sites), Middle Hérault valley (6 sites), Biterrois (4 sites), Narbonne plain (3 sites). These territorial units are defined according to topographical and environmental criteria that persist throughout the chronological sequence and whose impact on agro-pastoral practices over time deserves to be analyzed. The hill sites of La Malène 'Piboulèdes' and Argelliers 'Roc de Pampelune', and the urban site of Lodève 'Musée Fleury' were kept separated due to their geographical isolation.

## Methods

### CSS design

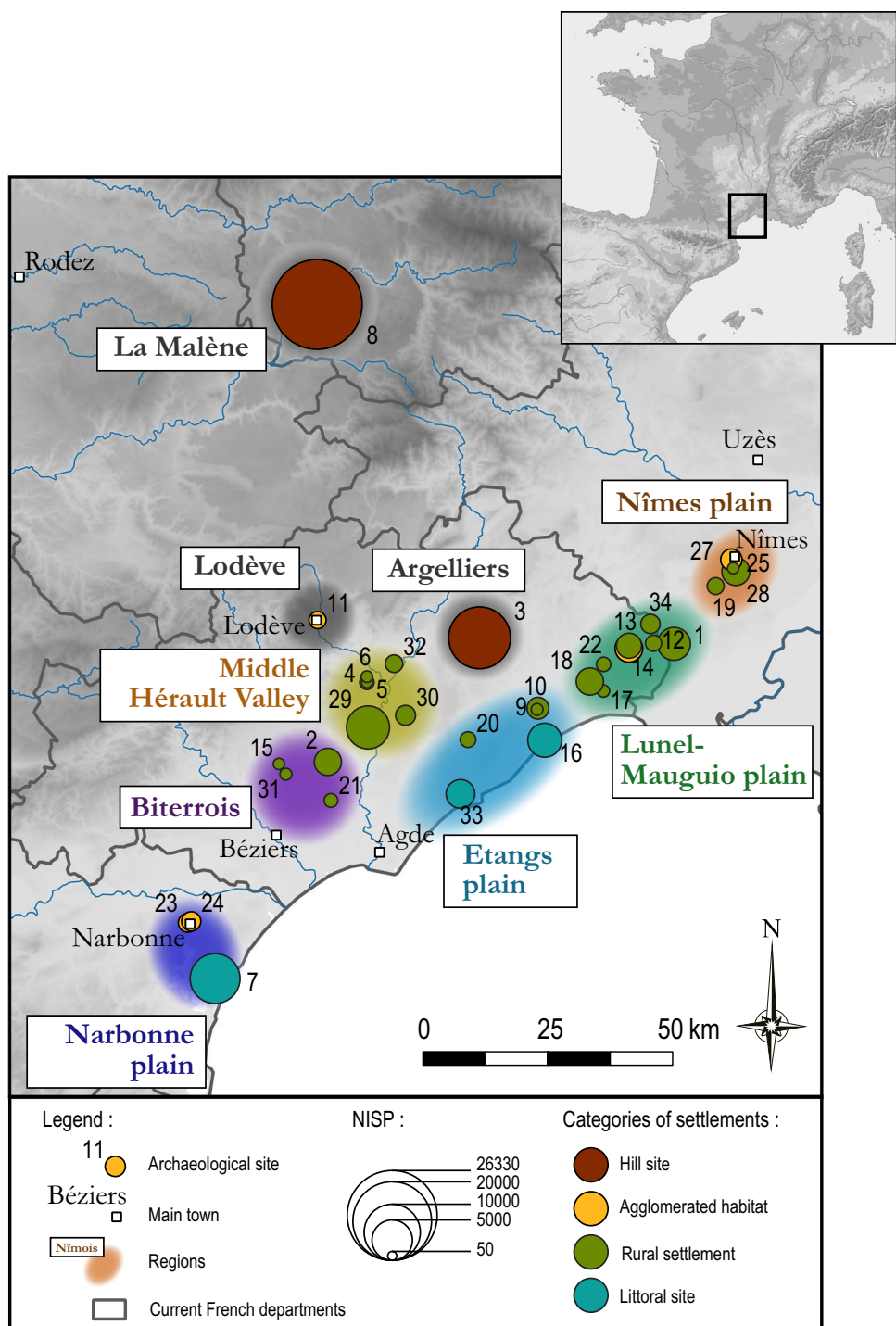
A “chrono-stratigraphic sample” (CSS) corresponds to a SU with NISP<sub>t</sub> > 50, or a group of SU with NISP<sub>t</sub> < 50 agglomerated according to a series of strict criteria: contemporaneity, stratigraphic or spatial proximity, and similar categories of the structures of origin (SI appendix). This minimum threshold of 50 remains had been defined in Languedoc according to the average volume of zooarchaeological material collected in rural contexts (Forest 2008, 2009) and agrees with that opted by (Kunst et al. 2016) in their analysis of taxa abundance in Bronze Age settlements from Turkey. Since the CSS depends on the precise archaeological site contexts their delineation was performed manually using a detailed examination of the excavation reports.

Each CSS is characterized by a TPQ, a TAQ, a time range expressed in centuries, a geographical region (Fig. 1) and the nature of the human occupation that generated those remains (SI Table 1). The latter was attributed to one of five categories observed in the corpus (Table 1). Finally, the number of taxa considered in the analysis of CSS depends on the quality of the determinations and their respective numbers in the samples (*cf. infra*).

### Taxa quantification

Methods for quantifying taxa remains vary between specialists, making the comparisons difficult. We decided to

**Fig. 1** Location of the archaeological assemblages studied, classified by NISP and category of settlement. Information on the sites, identified by the numbers, can be found on SI Table 1



**Table 1** Description of the categories of settlements from which CSS are derived. Abb: abbreviation

Category	Abb	Description
Rural Settlement	RS	Detached houses with productive facilities
Silo field	SF	Areas poor or devoid of built structures, littered with storage pits
Agglomeration	A	Settlement with a complex plot (domestic/public buildings, streets, etc.)
Hill Site	HS	Occupation perched on a topographic prominence with fortifications
Peripheral Areas	PA	Poorly structured surfaces (ditches, isolated pits, etc.) located at the margins of identified habitats



focus only on the NISP (Number of Identified Specimens Per Taxon), a basic data item that is systematically recorded (Frère et al. 2017) and whose counting method has been standardised between the different zooarchaeologists who performed the inventories of faunal remains studied here.

This study aims to propose a comparative analysis of the frequencies of each taxon. However, such an analysis is not possible for species whose overall number of remains is too low, or whose presence is limited to a few contexts. First of all, only taxa with a minimum number of remains through the studied corpus, here fixed to 100 remains, were thus included in the analyses (SI table 2).

While most domestic species yielded this minimum number of remains, difficult distinctions between some of them or with wild taxa led to many taxa grouping. The taxa identification was performed to the smallest taxonomical rank permitted by macroscopic osteological observation: “caprines” thus include both sheep (*Ovis aries*) and goats (*Capra hircus*), pigs (*Sus domesticus*), and wild boars (*S. scrofa*) are identified as “suids,” dogs (*Canis familiaris*), wolves (*C. lupus*), and foxes (*Vulpes vulpes*) as “canines,” wildcats (*Felis silvestris*) and domestic cats (*F. catus*) as “felines,” while the “equids” correspond to horses *Equus caballus*, donkeys *E. asinus* and their hybrids. Among the “bovines” only cattle (*Bos taurus*) is represented, the presence of aurochs (*B. primigenius*) being excluded, given the disappearance of this species in the region during the Bronze Age (Forest and Cheylan 2015).

Previous zooarchaeological syntheses on the Languedoc region have demonstrated the very low proportion of wild animal remains (Rodet-Belarbi and Forest 2010). As a consequence, wild species were grouped according to their respective status given by the human populations, following (Mureau 2020). Only rabbits (*Oryctolagus cuniculus*) were kept separated, because their remains were commonly found throughout the archaeological sites, and even abundant in some places (Forest 2000), but also because some authors mention that this species which is considered wild was bred in Southern France from the Roman period (Gardeisen and Valenzuela-Lamas 2004; Gardeisen 2012). Moreover, the concentrations of rabbits should be tracked in order to test whether there are cases where this animal burrowed into the archaeological levels before dying. The various bird species other than the domestic chicken (*Gallus domesticus*) were grouped as “other birds,” a potential small game. The red deer (*Cervus elaphus*), hare (*Lepus europaeus*), roe deer (*Capreolus capreolus*) and some very few morphologically identified remains of wild boars were grouped as the mammalian “big game” species known in France during historical periods (Beck et al. 2006; Lepetz and Clavel 2010; Lepetz and Morand 2017), while the reptiles, anurans, mustelids and small mammals were considered as “other” species, including numerous potential pests or intruders.

The NISP proportion of each taxon within the domestic triad (NISPt) is a method of quantification particularly used in French studies (e.g., Clavel 2001; Forest 1994; 2000; Lepetz 1996b; Oueslati 2002) by virtue of the importance of these three taxa in the vast majority of the assemblages studied and in the meat diet. It is calculated as the NISP of the taxon divided by the NISPt, i.e., cumulative sum of caprines, suids and cattle NISP (Kunst et al. 2016; Jouanin and Yvinec 2019).

## Correspondence analysis and hierarchical clustering

The analysis of remains numbers of such various taxa groups has been accomplished through a Correspondence Analysis (CA) and a Hierarchical Clustering (HC), corrected by k means, with the R package FactomineR (Lê et al. 2008; Husson et al. 2010). Note that, by default, the HC is corrected by k-means when built with the FactomineR package.

Prior to this CA and in order to test whether comparative analysis of each taxonomic group can be conducted, boxplots of the frequencies of each taxon within the different samples were performed. Outliers were only analyzed in the CA as supplementary rows to avoid their strong influence on the results (Bendixen 2003; Langovaya et al. 2013). In addition, any taxonomic group with more than 5 outliers has also been integrated as a supplementary variable, since it constitutes a case of very heterogeneous distribution of the remains that can influence the CA too.

The CA permits to identify correlated concentrations of taxa remains. In this analysis, the individuals are the CSS and the variables are the numbers of remains of each taxon or taxon group. The introduction of additional qualitative variables (i.e., century ranges, regions, occupation categories) also allows to test possible significant differences according to these three parameters, which were tested performing MANOVA on the coordinates of the SSCs for the first five axes of the CA. The CSS were then classified into clusters according to their abundance of taxa, using a hierarchical ascending classification.

Finally, CSS from a selection of five archaeological sites, and classified according to their cluster group, were localized on their settlement maps, in order to access their spatial distribution at this scale resolution. The selected sites were Aimargues “Missignac,” Paulhan “Ermitage Bas,” Mauguio “Lallemand,” Gruissan “Saint-Martin,” and Argelliers “Roc de Pampelune,” which provided a large enough number of CSS to perform a spatial analysis (SI Table 1). As the three first sites were occupied for a long period of time, the spatial projection of the CSS was performed for each occupation phase.

## Diachronic analysis

The diachronic analyses of species relative frequencies in NISPt only focused on the three taxa composing the domestic triad. Analyses were performed at the CSS and the occupation stages scales (SI table 3), the second being realized in most of the recent zooarchaeological syntheses (e.g., Colominas et al. 2017; Lepetz and Zech-Matterne 2018; Akeret et al. 2019; Jouanin and Yvinec 2019; Nieto-Espinet et al. 2021; Trentacoste et al. 2021).

The evolution of NISPt frequencies over time has been assessed with a smoothing method based on a local polynomial regression fit (loess function from the R “stats” package (Cleveland et al. 2017)). A 90% confidence interval has been added to the regression curve. Confidence intervals of two non-overlapping curves indicate significant differences. In addition, an increase or decrease in taxon frequencies over time is only considered significant when the confidence intervals do not overlap. The evolution of NISPt diachronic frequencies is visualised as a biplot where time is represented on the x-axis and frequencies of each of the three taxa (in %) on the y-axis.

These analyses have been first performed with the entire dataset, then by occupation categories and regions. In order to ensure the stability of the local polynomial regression, only the categories represented by more than 25 samples (i.e., CSS or occupancy stages) were retained for those analyses. Because too few occupation stages were available to explore the geographic variation at the scale of the six small regions (Fig. 1), the samples from Narbonne plain, Biterrois, Middle Hérault Valley and Etangs plain were combined in a “western Languedoc” category, and those from Nîmes Plain and Lunel-Mauguio plain were grouped in “eastern Languedoc.” These less precise geographical entities correspond more or less, for the western Languedoc, to the territories of the cities of Béziers and Narbonne, and to the territories of Nîmes for the eastern Languedoc.

## Results

### Taxa abundance in CSS, preliminary descriptions

A total of 339 CSS were recorded for which the NISPt frequencies of 15 taxa groups (species, or group of species) were computed (SI table 2).

Caprines are present in all the 339 CSS with an average of 55% of the remains of the domestic triad (Fig. 2). Cattle are present in 337 CSS, suids in 338, and they constitute 20 and 25% of the NISPt respectively. Chicken is present in 266 CSS (78%), but at low frequencies (~8% NISPt). Each of the other taxa groups deliver less than 2% of NISPt, but

equids and other birds stand out with a presence in almost half of the CSS.

Due to the absence of anuran, deer, rodent, fish or antler remains in more than three quarters of the CSS, a very large number of CSS with remains of these species appear to be outliers. Once grouped into taxa groups, “other birds” and “big game” species, although they individually deliver less than 100 remains, or correspond to the variables with abundant outliers, are respectively represented with 533 and 215 remains, in 162 (48%) and 101 (30%) CSS. Seven CSS show particularly high NIPS3 frequencies of equids ( $n=1$ ), rabbits ( $n=2$ ), birds ( $n=2$ ), canines ( $n=1$ ), and big game ( $n=1$ ) can therefore be considered as outliers.

### Correspondence analysis

Because outliers are known to dominate the interpretation of one or more of CA axes (Bendixen 2003; Langovaya et al. 2013), only nine groups of species were analysed: caprines, cattle, suids, chicken, horses, canines, rabbits, birds and big game. Additional taxa, represented by too few remains (felines) or present in too few CSS (“fishes,” “deer antler,” “other taxa”) were only included as supplementary variables, as well as seven outlier CSS (*cf. supra*) considered as supplementary individuals.

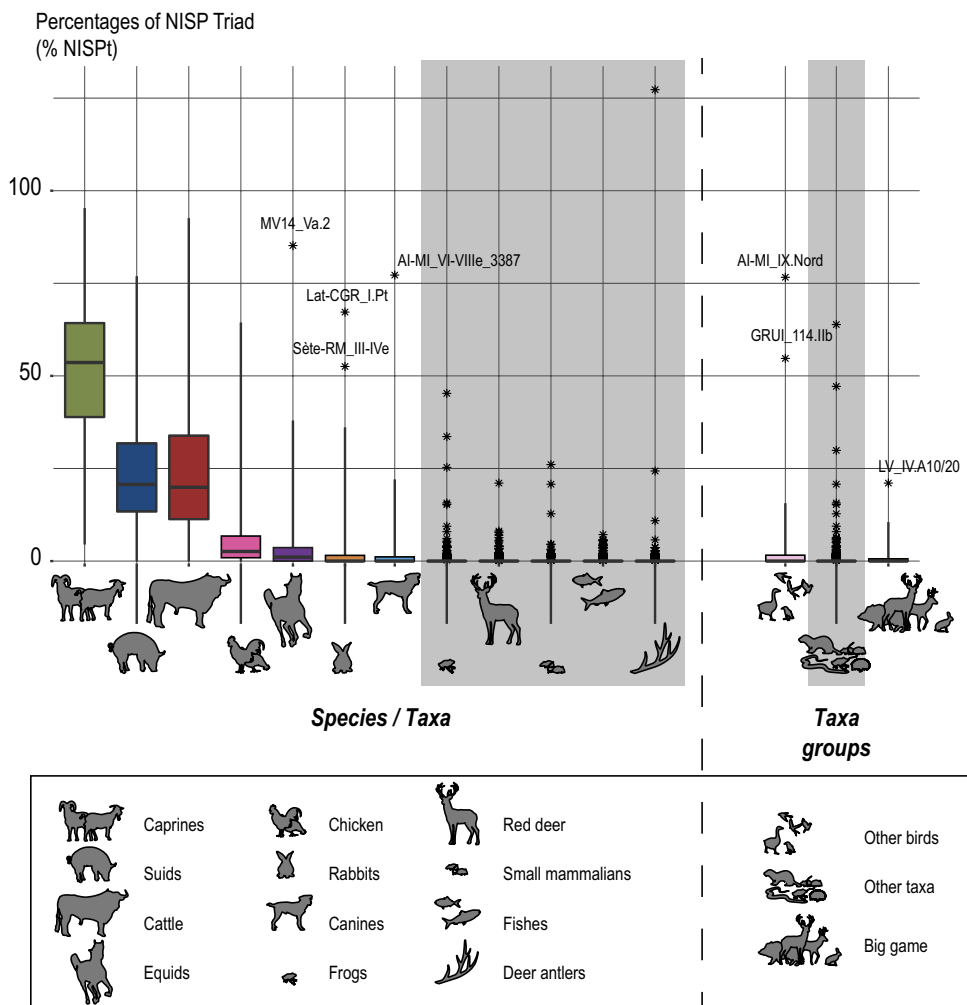
As a consequence, a CA was performed on a contingency table comprising a total of 332 CSS (rows) and the nine remaining taxa groups (columns) (SI table 4). A Chi-square test attests to a significant dependence between CSS rows and column categories (X-squared = 34707,  $df=2648$ ,  $p\text{-value} < 2.2e-16$ ).

First, we note that about 55.7% of the variation is explained by the first two dimensions (Fig. 3a).

The first axis (37.7% of explained variance) is strongly positively correlated with the frequencies of equids, cattle and canines, but negatively correlated with chicken. The second axis (17.9%) correlates positively with chicken and equids and negatively with rabbits. However, equids and rabbits have small contributions to this axis (8.0 and 6.1% respectively), contrary to chicken, which alone contributes to 47% of the component (Fig. 4a). The second taxon contributing the most to this axis are caprines (29.2%), which are negatively correlated.

The third axis (14.9%) is highly influenced by rabbits (75.4% of the contribution) and “big game” species (6.1%), positively correlated to the axis (Fig. 3b). The fourth axis (8.4%) is largely influenced by equids and birds (31.5 and 39.5% respectively), to which it is positively correlated. Cattle contribute less to this axis (20.6%) and are negatively correlated with it. The fourth axis is also the one for which canines contribute the most (5%), with positively correlated frequencies as for equids and birds. Finally, the fifth axis

**Fig. 2** Relative frequencies (in %, by NISP of the triad) in CSS. Boxplots of the main taxa represented by more than 100 remains. In grey, taxa for which the large number of outliers contradicts their integration in the CA as variables



(7.6%) is positively correlated with birds and negatively correlated with equids (Fig. 4a).

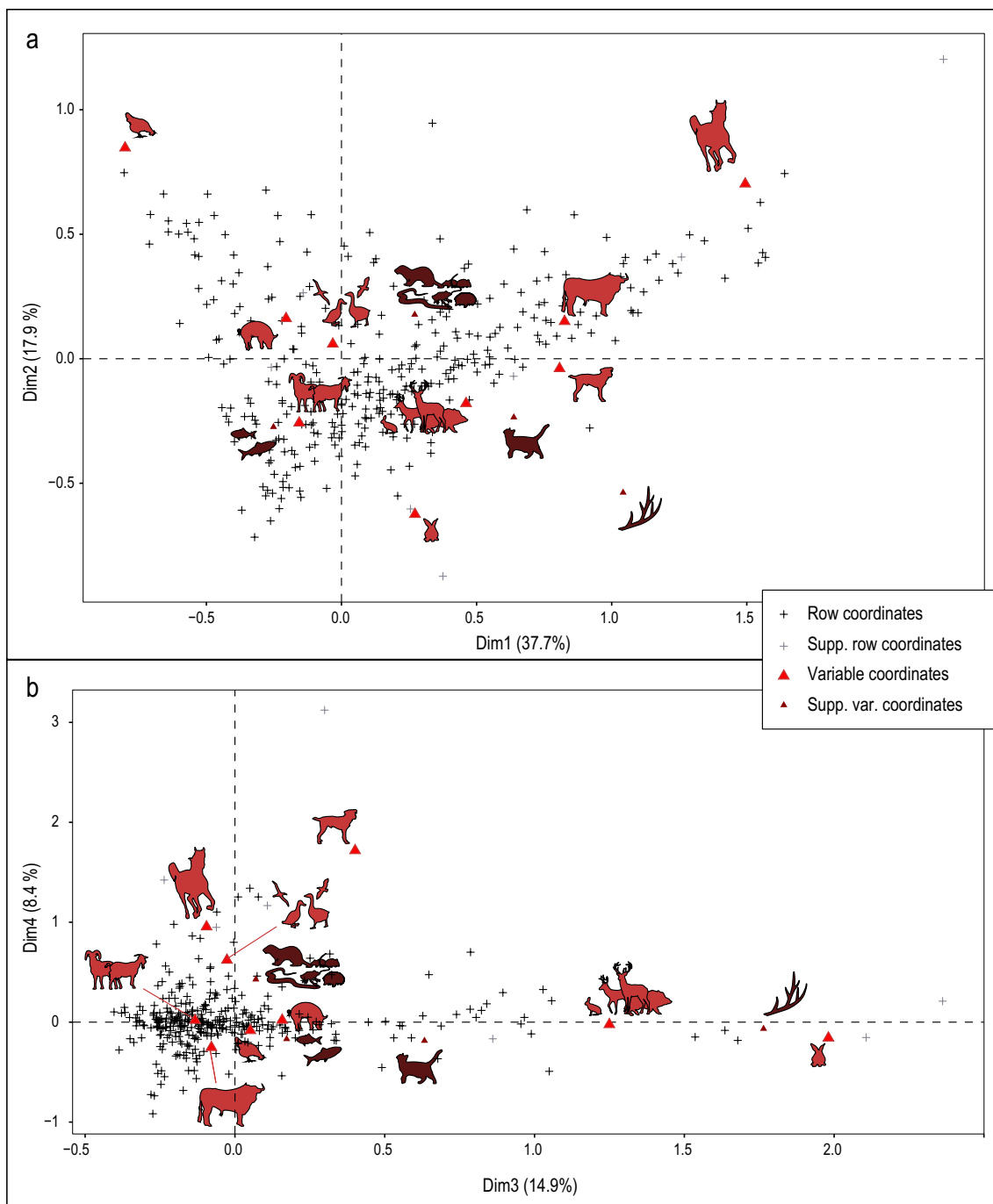
MANOVA proved significant differences (all  $p$  values  $< 2.6e-16$ ) between the proportions of species of the different chronological sequences, regions, but also categories of settlements (Fig. 4b). Through the correlations between their mean profiles and the CA axes, the three qualitative categories can be associated with some groups of species frequencies (Fig. 4a).

For example, the strong positive correlation of the third century CSS with the third axis indicates a higher proportion of rabbits in the samples from this period. Over the centuries, the coordinates of the mean profiles decrease on this third axis and thus indicate a decrease in the proportion of rabbit remains in the samples ( $p$  values in SI table 2). Conversely, the mean coordinates increase between the 7th and 10th centuries on the first axis of the CA, suggesting an increase in the proportion of cattle and equids remains at the expense of chicken.

The analysis by region reveals high frequencies of cattle and horses remains through high coordinates on the first

axis in Biterrois and Nîmes plain (Fig. 4a, SI table 2), whereas these species are less represented on the hill site of La Malène “Piboulèdes.” By their negative coordinates on the second axis, the sites of the region of the Etangs and Narbonne stand out with the hill site of Argelliers “Roc de Pampelune,” where important frequencies of caprine remains were discovered.

Finally, the taxa frequencies seem particularly correlated to certain categories of settlements (all  $p$  value  $< 2,2e-16$ ). Samples found at hilly sites correlate only negatively with the first axis, and thus would be the places where the most suids and chicken bones are found. However, the mean coordinates of rural settlements are positive on the first axis and negative on the second axis, suggesting that the proportions of caprines and cattle are high there. The average coordinates of the peripheral areas and silage areas, positive on the first two axes, indicate a strong joint representation of cattle and horses. Finally, the agglomerations have on average very high coordinates on the third axis, related to a high representation of rabbits.



**Fig. 3** Correspondence analysis. A: symmetric plot defined by the two first factors with species (columns, red triangles) and CSS (row, black crosses). B: symmetric plot defined by the third and fourth factors with species (columns, red triangles) and CSS (row, black crosses)

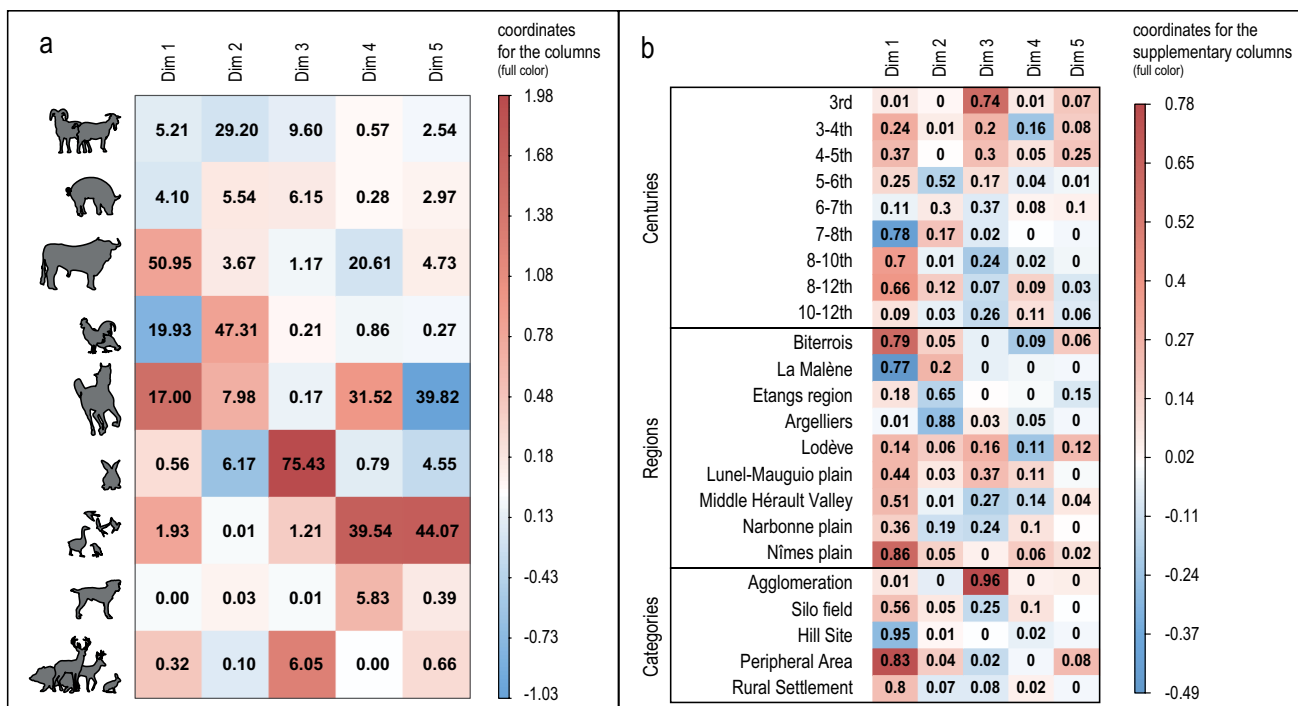
**Hierarchical clustering and cluster distribution in archaeological sites**

A HC has been performed to classify the CSS according to their coordinates in the CA. Six clusters were selected, with a within-cluster inertia reaching a plateau around 0.02 (SI Fig. 1), and projected on two biplots with respectively 1–2

and 3–4 axis of the previous CA (Fig. 5). A description of each cluster can be proposed based on their most significant correlations with species frequencies and the number of CSS they include.

The first cluster, richer in chicken (on average, 184% more than mean frequencies in the whole dataset) and suids remains (+40%), agglomerates 49 CSS with negative





**Fig. 4** Coordinates and representation of variables on the axis. A: Contribution (text) and coordinates (color) of taxa groups (rows) for the five first axis (columns). B: Coordinates (full colour) and cos2

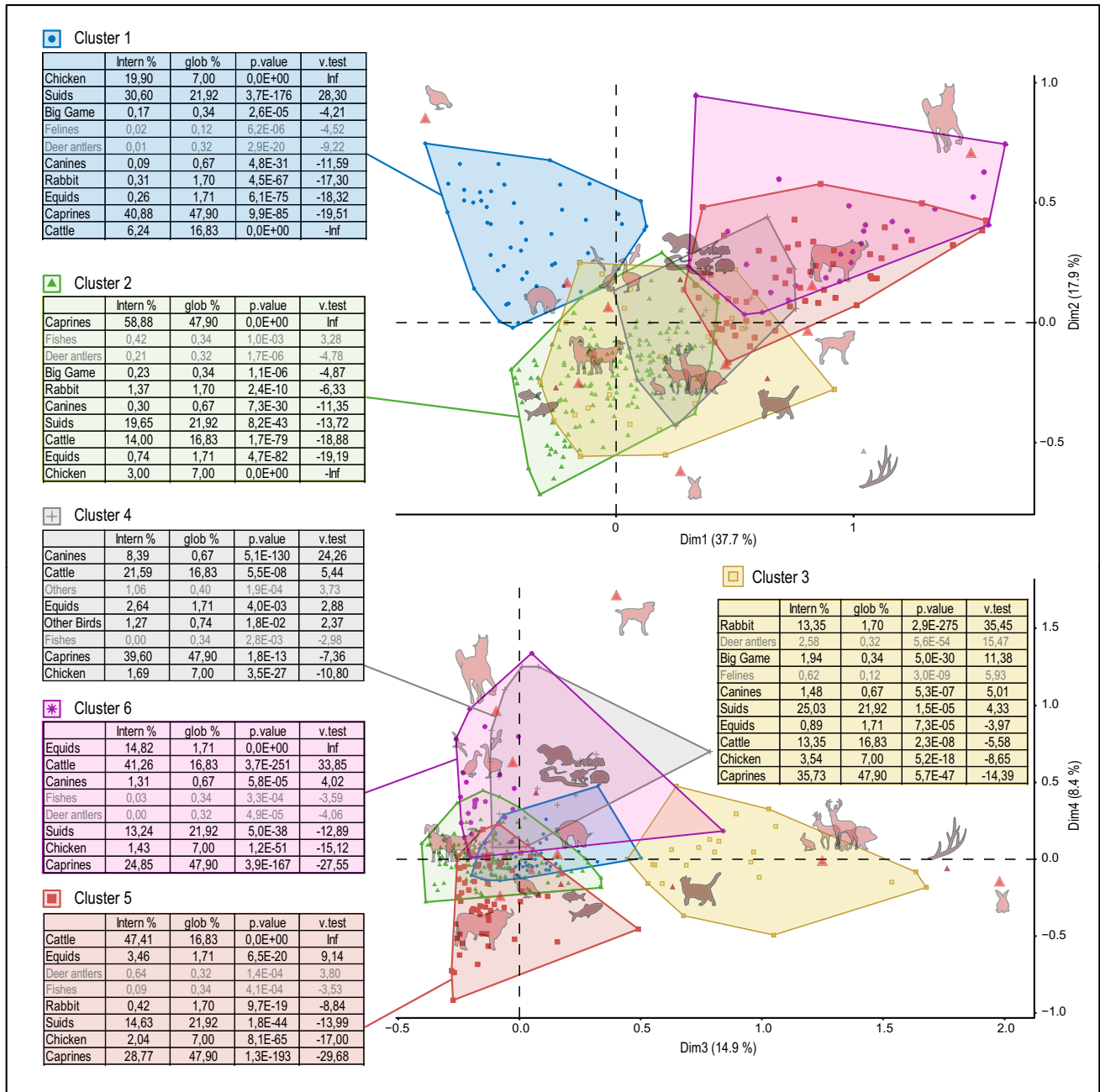
values (text) of mean individual of qualitative categories, i.e., centuries of occupation, regions of origin and categories of settlements (rows), for the four main dimensions (columns)

coordinates on the first axis and positive on the second. The second cluster contains 159 of the 332 CSS, with high frequencies of caprine remains (+23%). The third cluster, with 23 CSS, is characterised by concentrations of rabbit (13.4% of NISPt compared to 1.7% on average) and big game remains (1.9% vs 0.3% on average). The 15 CSS from the cluster 4 have a slight over-representation of cattle (+28%), but especially of canines (+1152%). This cluster is not perceptible on any of the first four axes, but explains a significant part of the inertia of the fifth axis through positive coordinates (Fig. 4a). Finally, clusters 5 and 6 are marked by high frequencies of cattle and horses. Both their coordinates are positive on the first two axes, but the fourth axis allows them to be easily distinguished. The 60 CSS of the cluster 5 are then those with the most negative coordinates, whereas most of the 26 CSS of cluster 6, rich in equids remains (+766%), have positive coordinates as do CSS from cluster 4, rich in canine remains. Indeed, the over-representation of canines is characteristic of cluster 6 (+95%), whereas it is not significant among the CSS of cluster 5, in which cattle remains abound (+181%).

A sample of CSS were projected onto the map of the five archaeological sites that yielded the greatest number of faunal remains and then classified according to the cluster with which they are associated. Through these examples, clusters of the CSS change according to their spatialization

and functional nature. At Paulhan “Ermitage” (40 CSS), throughout the occupations of the site, the CSS from the successive habitat areas belong to cluster 2, rich in caprines remains (Fig. 6a). Therefore, the CSS from the areas peripheral to these living places belong to cluster 5, with a high proportion of cattle. At Mauguio “Lallemand” (17 CSS), the CSS partitioning is less clear during the first phase of occupation than from the tenth century onwards (Fig. 6b), with the exclusion of CSS rich in equids and canine remains (cluster 6) at the margins of the habitat and the silage area, where bovine remains are more abundant (cluster 5). The same structuring takes place in Aimargues “Missignac” (29 CSS): CSS of clusters 2, 5, and 6 are found together in the first habitat to the west, then the establishment of a village to the east of the excavated area is accompanied by a major rejection of bovine and equids remains outside the houses, where suids and chicken are much more abundant (Fig. 6c).

At Gruissan “Saint-Martin” (18 CSS) and Argelliers “Roc de Pampelune” (46 CSS), the CSS associated to cluster 2 outnumber those from other clusters. At the first site (Fig. 6d), where cluster 2 CSS particularly abound, rich in caprines, deposits of bovine remains can be seen at the margins of the building, but also among the abandoned levels of its southern rooms. On the second site (Fig. 6e), almost all of the CSS belong to cluster 2, but a few CSS stand out because of the high proportion of rabbits (cluster 3), particularly in



**Fig. 5** Correspondence analysis. Visualization of individual clusters (convex hull of clusters) and variables (red triangles) on symmetric plot defined by factors 1–2 (top) and 1–3 (bottom). For each cluster is associated a table of quantitative variables that describe the most their

assigned CSS ('intern %': mean frequencies of taxa group in the cluster; 'glob %': on average, frequencies of the taxa group in the whole dataset)

the western sector of the site, as well as in a corner tower to the southeast.

**Diachronic evolution of NISP**

The variation in the relative frequency of the domestic triad (%NISPt) has been explored through time, between the 4th and 11th centuries using two approaches: first

using the 339 CSS (Fig. 7, left), then using the more traditional occupancy stage as an analysis unit (Fig. 7, right). With time as a continuous variable, each analyzed unit has then been classified in settlement categories (Fig. 7b) and geographic regions (Fig. 7c). Due to a much smaller sample size ( $n = 77$ ), the settlement categories analysis based on occupancy stages was restricted to the rural sites (Fig. 7b).

The two approaches reveal only partially congruent trends, with the approach based on CSS showing smoother curves and smaller confidence intervals.

Both methods show the most important change between the fourth and sixth centuries (Fig. 7a): the proportion of caprine remains increases sharply and they constitute the majority of samples from the beginning of the fifth century, at the expense of suids and cattle. The curves for these last two taxa also decrease in the analysis by occupation stages, but this trend is not significant. In contrast, confidence intervals of the trends obtained with the CSS are much restricted and the frequencies of these two taxa were higher than those of caprines during the fourth century. If the analysis by occupation stages does not reveal any changes between the seventh and eleventh centuries, trends can be noted thanks to the CSS analysis. Caprine frequencies decrease during the seventh century and reach their minimum at the turn of the tenth century, while cattle reach their maximum. Conversely, the proportion of caprines increases again around the year 1000 and cattle return to low frequencies, close to those of suids. Suids, on the other hand, show no change and seem to represent only about 20% of the faunal material throughout the period.

The significant increase in the frequencies of caprine animals mentioned above, between the fourth and the sixth centuries, can both be noted in rural and agglomerated settlement, thanks to CSS analysis (Fig. 7b). Indeed, a small increase in caprine frequencies can be noted in rural settlements with the approach by occupancy stages, but no significant trend can be observed for cattle and suids by this method. The analysis by CSS provides other numerous results. The slight drop in the proportions of suids and cattle during the fifth century is only significant for rural settlements, while no trend can be noted for agglomerations. In the fourth to the fifth centuries, the proportion of bovine remains is lower in agglomerations than in the rural sites, while porcine remains are proportionally much more numerous in agglomerations. An identical difference can be noted in the sixth century, but between rural sites and high settlements. Finally, the local regressions for rural sites and silage areas largely overlap and follow the same pattern as the general curves (Fig. 7a).

By combining samples classified by occupancy stages into two spatial groups, it is not possible to identify any significant differences between “western” and “eastern” Languedoc in caprines and bovine frequencies (Fig. 7c). We note only a decrease in suids frequencies in eastern Languedoc during the 3-5th centuries, and not in the west. The analysis by CSS is much more precise, with an over-representation of caprines in the Narbonne plain compared to the Nîmes and Lunel-Mauguio plains over the entire period, with the exception of the sixth to the eighth centuries. Conversely, cattle abound in the Nîmes plain, especially

around the chronological limits. The middle Hérault valley fits between the two groups of regions with a wide range of confidence that hardly allows us to pronounce on the trends that occur in this geographical area. Regional differences are less noticeable for suids frequencies, except for an increase in the Lunel-Mauguio plain that does not occur in the other regions.

## Discussion

This study provides an application of the chrono-stratigraphic sample (CSS) definition allowing both regional zooarchaeological syntheses and fine analyses of animal remains distribution within archaeological sites. This work also offers a new framework of analysis in which small samples can be included. The delimitation of CSS, defined on the basis of their archaeological characteristics, makes it possible to identify the diversity of activities around animal resources on the settlements and to test the influence of various qualitative criteria in the composition of the assemblages. Thus, the analysis of these qualitative categories helped to identify a significant chronological evolution in NISP quantifications which is not common to all the archaeological sites of the Languedoc region, but varies through region and categories of settlements.

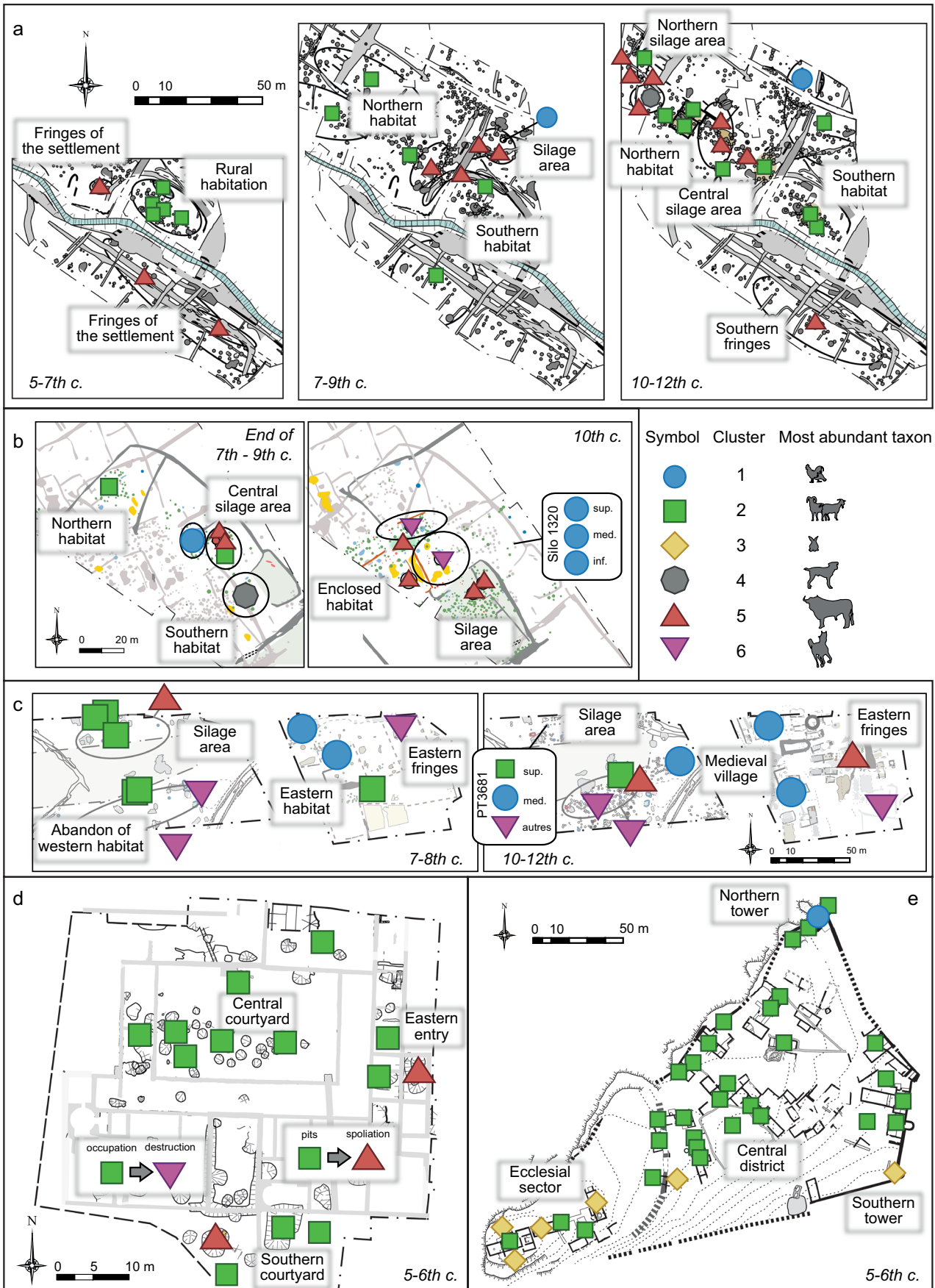
### Identification of taxa groups and their chrono-spatial variations

#### Taxa classification and nature of remains

The HC of the CSS has permitted to distinguish 6 major groups of taxa frequencies through the assemblages (Fig. 5). An estimate of the status of each species in human management of animal resources is a primary step in interpreting the nature of the animal over-representations attached to each cluster.

The CA allows to distinguish CSS strongly related to meat feeding and those containing more remains associated with non-consumed species. Indeed, caprines, suids and chicken are over-represented in CSS clusters 1 and 2. The three species represent, on average, more than 80% of the NISPt and their association with the food sphere has been attested many times in southern Gaul (Forest 1994, 1997, 2008, 2009; Leguilloux and Lepetz 1996a, b; Faure-Bouchard 2001; Columbeau 2002; Foucras 2010; Forest and Rodet-Belarbi 2011), as well as cattle. However, the CA noted that frequencies of the latter taxon remains are particularly high in a set of CSS among which caprines and suids are under-represented (clusters 5).

In this fifth group of CSS are also more represented the equids, whose status is less clear. Their consumption





**Fig. 6** Spatial distribution of CSS classified according to their cluster assignments on the successive occupancy stages of Paulhan “Ermitage” (a), Manguio “Lallemand” (b) and Aimargues-Missignac (c), as well as on the Late Antique sites of Gruissan “Saint-Martin” (d) and Argelliers “Roc de Pampelune” (e)

was rejected during the High Empire (Lepetz 1996b). Hippophagy is attested during Late Antiquity in the northwestern provinces of the Roman Empire (Yvinec 1988; Lepetz 1996b; Lepetz and Hanot 2012; Putelat 2015; Akeret et al. 2019), but this practice is not supported by any zooarchaeological source in Languedoc. The hypothesis of canine consumption, although their proportions increase during the early Middle Ages, is also ruled out in France (Yvinec 1988; Milliet 1995). Indeed, for both species, the fragmentation of their bones does not follow that of other consumed species, their age at death is generally around a mature to senile stage, and the traces of cutting are exceptional and mostly related to the removal of soft materials (leather, tendons, ligaments) (Forest 1997; Mureau 2020).

In our study, the correlation between the frequencies of equids and canines suggests that carcasses remains of these non-consumed species are concentrated in the same structures. Based on this result, the nature of the samples associated with clusters 4 and 6 of the HC seems to be that of dumps, structures collecting both animal remains from the food sphere and those of carcasses partially squared or decomposed. The good representation of bovine remains in these same samples suggests that these dumpsites could have been privileged destinations for the disposal of waste related to the cutting of this species. Conversely, the overrepresentation of equids in the richest assemblages in cattle remains (cluster 5), supports this hypothesis of a functional proximity between the processing of bovine carcasses and those of uneaten animals.

The last cluster (cluster 3) has as its main characteristic the high proportion of wild species remains. The relationship of big game with meat diet is commonly attested during historical times in France (Lepetz 2009; Putelat 2015) and the rabbit, whose introduction in northern France does not occur before the tenth century (Callou 2003) can be added to this list in Languedoc (Gardeisen 2008; Rodet-Belarbi and Forest 2010; Forest 2012). The possibility of rabbit breeding, considered during the Roman Period (Gardeisen and Valenzuela-Lamas 2004; Gardeisen 2012), seems unlikely during the studied period, given its frequencies which are quite distinct from those of other domestic species. Our results rather agree, for the transition between Antiquity and the Middle Ages, with a recent synthesis carried out on thirteen cases of concentrations of rabbits during the Roman period (Forest 2017). The latter had also favored the hypothesis of cases of food discards rich in wild animals, but also proposed that of accidental falls or abandonment of the

remains of animals considered to be vermin. Through the CA, correlation between the frequencies of all wild mammal species suggests that all were acquired by the same process, i.e., active hunting. The cluster 3 CSS would therefore constitute food releases linked to the food sphere, but presenting the singularity of a major acquisition of hunted species.

### CSS analysis benefits in the research about diachronic evolutions of species frequencies

Significant oscillations between the proportions of caprines and cattle remains have been defined through the diachronic analysis of NISPt from the fourth to the eleventh centuries (Fig. 7a). The use of CSS as a unit of analysis has not invalidated the results of an analysis at settlements scale, the more “classical” approach, but it allowed to detect more significant variations in taxa frequencies and thus to perform more precise geographical or chronological analyses. The use of a CSS method should therefore not deliver contradictory results, but rather more refined results, with the other regional syntheses for the same dataset. On this basis, it seems valid to compare our results with those acquired in geographical areas of the rest of Western Europe, even if their divergent counting methods impose some caution in the interpretation of possible convergences or differences.

The only one major trend in the evolution of NISPt was identified through both by CSS and occupancy stages methods, which was the most pronounced, the decrease in the frequencies of cattle in favor of caprines. According to previous syntheses, this trend would begin at the turn of the third century AD, which constitutes the highest point in the representation of cattle during Antiquity (Forest 2008). An increase in sheep/goat frequencies has also been noted during Late Antiquity in Provence (Columeau 2002), Roussillon (Ros et al. 2020), Catalonia (Colominas et al. 2019) and Italy (Salvadori 2019). Further north, the increase in caprine frequencies would be somewhat later and would begin in Switzerland (Akeret et al. 2019) and in England (Rizzetto et al. 2017) in the fifth century, and even in the seventh century in the Rhône valley (Faure-Boucharlat 2001; Argant 2017). On the contrary, the proportions of suids would have sharply increased in the northern half of France from the Merovingian period onwards, before giving way to predominant cattle remains in assemblages (Clavel and Yvinec 2010; Lepetz and Zech-Matterne 2018).

With the CSS as unit scale of analysis, the diachronic analysis of NISPt frequencies also reveals other significant changes through time. In particular, a decrease in the frequencies of suids can be observed. This trend is a much older dynamic in Languedoc: the proportion of suids remains reached a maximum during the late-Republican period, at a level close to that of caprines (Forest 2000, 2009), before decreasing in favor of cattle during the High Empire. The





**Fig. 7** NISPt evolutions between 300 et 1100 AD described by CSS (left) and occupancy stages (right) analyses. a: mean curves for caprines (green), suids (blue) and cattle (red). b: NISP frequencies of the three main taxa for each category of settlement. c: NISP frequencies of the three main taxa for each geographical region

latest CSS indicate a new increase in caprines frequencies after a phase of stagnation, or even decrease in favor of cattle, between the seventh and ninth centuries. Such a pause in the increase of caprines frequencies has also been noted in Italy between the second half of the eighth century and the tenth to the twelfth centuries (Salvadori 2019), or in the Iberian Peninsula during the Middle Ages, i.e., between the tenth and twelfth centuries (Grau-Sologestoa 2017). This second increase of caprines percentages in Languedoc at the end of the High Middle Ages would continue until the fourteenth century according to zooarchaeological syntheses about the medieval period (Forest 2009; Forest and Rodet-Belarbi 2011; Ginouvez et al. 2017) and has been associated with the rise of a sheep farming dedicated to wool production, for which the cities of Montpellier and Narbonne would constitute outlets for the consumption of the carcasses of culled animals (Forest 1998a). Such a production model has been proposed in northern Gaul since Early Roman period (Lepetz 1996b; Cambou 2009).

Thank to CSS analyses once again, an over-representation of suids in agglomerations can be noted in our dataset until the fifth century. Then, the absence of assemblages uncovered on urban sites does not allow us to know if this trend continues. In contrast, the CSS from hill sites differ from rural settlements in having the same high frequency of suids remains and a low proportion of cattle ones (Fig. 7b). Depending on authors, in the urban centers during the High-Empire in Languedoc, higher proportions of bovine (Gardeisen 2003; Renaud 2012) or suids remains were counted (Forest 2009). On the other hand, the remains of caprines would be in the majority in rural settlements (*ibid.*). These different results for urban contexts can be explained with the example of the city of Toulouse *Tolosa*, where concentrations of bovine remains were found in public areas, whereas frequencies of caprines and, to a lesser extent, suids, are more correlated with the domestic sphere (Rodet-Belarbi 2002). Differences in the NISPt ratio between urban and rural settlements are also noticeable in northern France (Lepetz 1996b; Clavel 2001; Cambou 2009; Jouanin and Yvinec 2019), but not in Provence, where sheep and goats deliver the majority of remains in each category of settlement (Leguilloux 1989; Leguilloux and Lepetz 1996a, b; Columeau 2001).

The analysis by CSS is also the only one to provide some details on the micro-regional evolution of the frequencies of the three domestic taxa (Fig. 7c). The trends are mostly

similar from one territory to another, but we note the strong representation of cattle in the Nîmes plain throughout the period. Such results need to be reinforced by new discoveries, this region gathering only five archaeological sites and only three rural ones. Two of these rural sites are gallo-roman villae, occupied since the High Empire: Milhaud “Careiron et Pesquier” and Nîmes “Saint-André-de-Codols.” During the Antiquity, the frequencies of bovine remains are generally high in this category of agricultural exploitation (Forest 2009). During Late Antiquity, the perpetuation of large agricultural estates precisely constituted in the eastern Languedoc an alternative to the multiplication of small pioneer farms scattered across the other regions of the languedocian plain (Raynaud 2001, 2003; Schneider 2007; Buffat 2011). These small farms on the lagoon plains seem to have delivered much more sheep/goats remains, explaining the increase of caprines frequencies through the Late Antiquity at the scale of the whole Languedoc region. In contrast, the maintenance of cattle farming in these large gallo-roman villae could explain the over-representation of cattle, at the expense of caprines, in the Nîmes region until the fifth century. However, this hypothesis is not enough to understand the maintenance of high cattle frequencies throughout the early Middle Ages and their growth at the end of the first millennium. Similar, but not systematic over-representations of cattle have been noted in the neighboring region of Camargue, a humid territory located in the Rhone delta and favorable to the breeding of these large ruminants (Forest 2019). Such a suspected bovine specialization of Camargue farms could have extended to the Nîmes plain, or could have met the latter's meat demand (Gardeisen 1993; Forest and Rodet-Belarbi 2011).

Finally, the two other taxa groups associated with food are chicken and big game. Since they were not included in our diachronic analyses, changes in their proportions could only be captured through the CA. The decrease in the coordinates of the chronologic mean profile on the first axis of the CA between the third and seventh centuries nevertheless suggests an increase in the proportion of chicken within the samples (Fig. 4b), which was also noted in Provence during Late Antiquity (Leguilloux and Lepetz 1996a, b). In the other provinces of Gaul, this proportion remained stable (Faure-Boucharlat 2001; Jouanin and Yvinec 2019). Conversely, the decrease in big game frequencies throughout the chronological sequence contrasts with the observations made in northern France, where the proportion of big game increases from late Antiquity onwards, and in particular that of the red deer (Lepetz and Clavel 2010). The proportion of cervids remains also increased in Italy, but from the 8th-10th centuries especially on castral sites (Salvadori 2010).

## About the limitations of the CSS method and the quantification of taxa in the restitution of pastoral systems

### Impact of taphonomy on species distribution

Following the abandonment of an animal remains, many mechanical actions (animal chewing, trampling, transport between dumps, mobilization in embankments...), meteorological or sedimentary are able to alter the bony substance. Estimating the impact of possible physico-chemical factors in the division of the assemblage into clusters is important, because the over-representation of certain species could be linked to the better conservation of their remains.

In our study, CSS with an abundance of chicken remains are distinguished on the first axis of the CA from those rich in bovine and equid bones. This result could indicate that the Chi-square distance of the CSS is primarily impacted by taphonomy rather than chronological, socio-economic and cultural factors. Indeed, the bones of cattle and equids, which are large mammals, are of greater structural density and size than those of chicken, whose remains may therefore be more partially collected in stratigraphic levels that are more subject to post-abandonment actions (Payne 1975; Lyman 2014).

However, there is some evidences to suggest that these losses have little impact on the taxa distribution in the CSS. Indeed, rabbits and other birds, whose dimensions are close to chicken, never adopt similar coordinates on the first five axes of the CA. The frequencies of rabbits are even positively correlated with the first axis, as are the largest mammalian taxa (cattle, equids, and even big game species).

Finally, the other axes of the CA confirmed and complemented the trends identified from the first axis. However, equids, whose bones have a greater size and structural density than those of small species, have the same coordinates as chicken on the second axis, other birds on the fourth and rabbits on the fifth. Differential destruction of animal remains according to the nature of the remains of each species therefore seems negligible in this study.

### Interpretative limitations of animal remains counting methods

The CSS method certainly helps to analyze the distribution of taxa within zooarchaeological assemblages in much greater detail. However, the limitations of quantifying animal remains preclude any attempt to interpret the actual composition of the herds raised during this period, or the hunting roster (Forest 2000).

Indeed, the different ways of counting animal remains cannot be directly converted into numbers of heads in a herd or volumes of meat actually consumed. Some authors prefer

to weigh the mass of the bone remains, whose correlation with the masses of meat carried by the preserved bone segment would be more direct (Payne 1972; Vigne 1991; Chaix and Méniel 2001). By this way, but also by more complex calculations of correlations from the NISP, regional syntheses permitted to note that beef constitutes the main source of meat in roman and medieval societies (e.g., Deschler-Erb 2017; Forest 1997). The greatest ratio of sheep and goats in the NISP throughout historical times in southern France explains why the region has been called a 'sheep-dominated country' (Audoin-Rouzeau 1997). However, zooarchaeological studies have shown that the mass of bovine meat was the most important in most assemblages until the end of the Middle Ages in Languedoc and Roussillon (Forest 1997). In reality, the consumption of sheep meat only became predominant in the late Middle Ages in Languedoc (Forest and Rodet-Belarbi 2011).

The diachronic analysis of NISP frequencies, even if carried out at the scale of the CSS, should therefore only be considered as an exploration of the relative evolutions of remains attributed to each species. Thus, it only purpose trends in the relative interest of the human societies for these species, rather than a restitution of the composition of the original livestock and game. Similarly, each cluster constructed through the CA of the NISP of each taxon does not allow us to estimate their weight in human exploitation, but to isolate samples whose composition suggests that they are the product of relatively similar activities, which the zooarchaeologist attempts to describe.

### Implications of socio-economic factors on meat diet

The diachronic follow-up of average species frequencies is an extreme simplification of the interpretation concerning the degree of interest of human societies towards this taxon. The advanced analysis with a classification of the CSS by occupation categories, and more importantly the CA coupling all the qualitative variables, allowed to detect significant variations between human groups for same period.

For example, the very high proportions of suids and chicken remains on high sites seem to confirm the presence of an elite. Indeed, the latter has been attested through multiple clues brought to light on this category of archaeological sites in the Jura (Gandel and Billoin 2011), in Auvergne (Chabert and Martinez 2017) and in southern France (Schneider 2005, 2007; Constant et al. 2015) and must have relayed the power of urban centers to the borders of administered territories. Moreover, previous syntheses in northern France have noted a higher ratio of suids, chicken and big game on sites occupied by aristocratic populations in the early Middle Ages (Faure-Boucharlat 2001; Clavel and Yvinec 2010; Putelat 2015). This trend had not previously been seen in southern France (Forest and Rodet-Belarbi 2011) and

it only occurs in the Iberian Peninsula from late medieval periods (Grau-Sologestoa 2017).

At the Argelliers ‘Roc de Pampelune’ village, the concentration of cluster 3 CSS, rich in the remains of big game and rabbit, could precisely be linked to the spatial proximity of these food rejects to the church around which the western quarter of the site is organized (Fig. 6). Such a partition has so far only been found in Languedoc among the surface collects of another medieval hill site, the ‘castrum of Ventajou’ at Félines-Minervois (Loppe et al. 2005), occupied much later (11th–14th c.). Among the contemporary assemblages of the “Roc de Pampelune” characterized by such a spatial distribution, the closest we know is located in the northern Auvergne on the Merovingian fortress of Molles “La Couronne” (Mureau and Martinez 2020).

It is more difficult to comment on the over-representation of suids and big game in agglomerations, as faunal remains from urban contexts are rare from Late Antiquity onwards in Gaul (Cambou 2009; Jouanin and Yvinec 2019). This difference between agglomerations and rural settlements has previously been perceived among the roman Languedoc assemblages, but these syntheses have rather noted a convergence between the NISPt frequencies of these two categories of settlements during the Late Antiquity (Forest 2008; Van Ossel and Raynaud 2012), also noted in Northern Italy (Salvadori 2006). In Switzerland, the abundance of suids remains would rather characterize the rich rural settlements, while towns would include significantly higher quantities of bovine remains (Deschler-Erb 2017). Although our results do not allow us to follow any trend during the early Middle Ages, due to the lack of urban assemblages, it seems that cattle frequencies remain higher in the rural sphere and suids are more represented in agglomerations until the fifth century.

Other factors may, however, play a role in the valuation of animal flesh. In addition to taxa variations, P. Méniel proposes to add the criteria of the age at death of the consumed animals and the frequencies of the different anatomical parts (Méniel 2001). These three parameters have allowed the identification of a social hierarchy of meats in Roman (Cambou 2009; Lachiche 2012) and medieval contexts (Clavel 2001; Faure-Boucharlat 2001; Borvon 2012; Putelat 2015). In Languedoc, faunal remains from eight medieval *castra* in the southern Massif Central, occupied between the 10th and 16th centuries, reflected two dietary patterns. The first was rich in pig meat and the other relied heavily on the flesh of young lambs/goats (Durand et al. 1997). The former is easily detectable through a CA of taxa frequencies and its CSS would own to our “cluster 1” type of taxa composition. However, the latter can only be identified through a study of mortality ages. Otherwise, its samples would certainly be merged in the “cluster 2,” with CSS rich in caprines remains and found on a majority of rural settlements.

## Spatial distribution within sites and waste management

The correlation observed between the spatial distribution of CSS and their taxon frequencies at the scale of a few archaeological tends to show a recurrent and sectorized animal waste management, rather than a direct release at each activity area.

First, the localization of CSS associated with clusters 4, 5, and 6 suggests that uneaten equines and canines were discarded with bovine remains at the periphery of living spaces. The identification of this recurring trend is unprecedented at the scale of rural sites in France, but it is much better known because it is more spectacular in urban contexts at historical periods. Indeed, a practice of evacuating the carcasses of uneaten animals at the gates of cities is zooarchaeologically well documented during Roman times in France (e.g., Lepetz et al. 2013), Switzerland (Lachiche 2012; Deschler-Erb 2017) and its medieval manifestations, particularly recorded from concentrations of equids remains, are numerous from the fifth century (e.g., Clavel 2001; Clavel and Robin 2013; Barme and Clavel 2015; Rodet-belarbi 2017). In Languedoc, an abundant deposit of waste from the secondary phases of animal carcass cutting in a section of the Agau canal, dated to the thirteenth to fourteenth centuries, showed very similar characteristics to the assemblages from the city of Montpellier, located further upstream. The author thus considered that the urban populations of Montpellier or those of a suburb economically linked to it had thrown the waste of their most cumbersome activities into the Lez, a tributary of the river diversion channel that is the Agau (Forest 2004).

In the case of our study, the positive correlation of the so-called “peripheral” spaces and the silage areas, both far from the habitats, with the first axis of the CA is evidence of the concentrations of equids, canines and felines remains that take place there (Fig. 4b). In the study of some thirty rural settlements in the north of the Iberian Peninsula, Grau-Sologestoa (2019) identified these deposits as “concentrated dumps,” opposed to spontaneous or specialized deposits which constitute simple depository events around a limited panel of species. Analysis by CSS allows the distribution of these different deposits to be studied at the scale of the archaeological sites. The dumps are spatially distant from the habitats at Paulhan “Ermitage” and Aimargues “Mis-signac,” throughout their seven centuries of occupation (Fig. 6). These are CSS of cluster 5, contrary to Mauguio “Lallemand” where these peripheral dumps belong to cluster 6, richer in equid and canine remains. Finally, at Gruissan “Saint-Martin,” the CSS of clusters 5 and 6 relate to phases of abandonment of the site. They suggest a retraction of the habitat towards the central and northern courtyards, where excavated housing has been found, while the rooms of the former building were transformed into giant dumps.



One last taxon could be associated with equids and canines in this list of non-consumed species. Indeed, in cluster 4 of the HC, the strong representation of birds other than chicken alongside these non-consumed species could indicate that a proportion of them were killed without any intention of eating them. Certain concentrations of passerines, in particular corvids, have for example been associated in northern France with the elimination of crop pests (Yvinec 1993; Clavel 2001). A more detailed analysis of the distribution of each species would make it possible in the future to better determine their respective status.

### Lines for future research

This study constitutes a new step in the understanding of changes that affected the various meat diets and pastoral systems of Mediterranean Languedoc between Antiquity and the Middle Ages. Its extension to the Provençal territory would make it possible to follow more broadly the trajectories of the Mediterranean France through the historical times. Moreover, the increase in the ratio of caprines is still difficult to determine and could have originated between the end of the second century and the second half of the third century AD (Forest 2008). The temporal scope analyzed in this paper is therefore too limited to follow this dynamic and invites us to continue this work on the scale of the whole Roman period.

An additional clarification would also deliver precious precisions in the characterization of the taxa diversity. Indeed, pigs and wild boars have not always been distinguished among the suids and the understanding of the ratio between sheep and goats among the caprines remains incomplete. Indeed, the latter is about one goat for every four sheep, as in Roman samples from Languedoc (Forest 2008) or late-antique samples from the neighboring region of Roussillon (Ros et al. 2020). In northern France, the distinction is rarely mentioned in most zooarchaeological studies (e.g., Jouanin and Yvinec 2019), but ancient synthesis for Northern France estimates the frequencies of goats around 5% of caprines bones (Lepetz 1996b). It is important to investigate more to know if over-representation of goats in Languedoc is characteristic of all settlements, or whether it is more prevalent in certain territories. However, we note an increased representation of goats on the two coastal sites of Sète “Rue des Mésanges” (Pomarèdes et al. 2020) and Gruissan “Saint-Martin” (Mureau 2020), which are located in rocky environments that could be more favorable to their breeding. This hypothesis had also been proposed to explain the over-representation of goat remains at Saint-Julien-les-Martigues on the Estaque limestone massif in Provence (Columeau 2001).

The variations in NISP observed on the scale of a single site also raise questions about the methods of waste

abandonment within a human group. Although dumping pits specifically dedicated to the burial of waste were built in the urban sphere from the Middle Ages onwards (Catalo 2003), most of the structures from the transition between Antiquity and the Middle Ages were functional structures (silos, ditches, wells, cellars, etc.) whose conversion into dumps may have taken place fortuitously when they were abandoned. This event in the life of a settlement may motivate some inhabitants to opportunistically collect waste accumulated in temporary bins or on ground levels and centralize it there. Therefore, the nature, location, and size of the structure converted into a dumping ground may influence the composition of animal waste. These parameters should therefore be considered in further studies in order to clarify the actions undertaken by ancient populations during their waste management.

Finally, the remains of a single animal can be found among various types of waste. The processing of the carcass involves multiple stages (skinning, butchering, boning, trimming, cooking, consumption) and each of them produces wastes that may be abandoned in different structures (Lignereux and Peters 1996; Lepetz 2007). The identification of each of these stages cannot be accomplished on the only species scale and requires an analysis of the anatomical distribution of the bones for each domestic taxon. Indeed, a classification of each bone according to their skeletal order could permit us to identify concentrations of assemblages linked to specialized activities, in particular in cities and hill sites where carcass cutting tended to be more standardized from the first century BC onwards (Lepetz 1996b; Mauné et al. 1997; Cambou 2009; Foucras 2010; Renaud 2012). Some previous studies have proposed to classify these anatomical parts according to utility criteria such as the modified general utility index (MGUI) (Binford 1980). A multi-factorial analysis coupled with qualitative categories would be, in our opinion, a more objective solution to attempt a classification of the past consumed meats.

### Conclusion

During Late Antiquity, the proportion of caprines in the archaeozoological assemblages of Languedoc begins to increase. It suggests their growing importance in regional breeding at the expense of pigs and cattle. The Carolingian period, during the ninth and tenth centuries, nevertheless constitutes a period in which cattle are better represented.

In this paper, these trends were captured by a quantification method using the CSS as a unit of analysis. Each sample studied thus makes it possible to study with great archaeological precision the diversity of species frequencies within any single site and to discover the diversity of dietary patterns. This method also allowed us to note



a variation in taxa frequencies according to the nature of the areas. An extension of these studies to other contexts is therefore desirable in order to better understand the waste management methods used by the populations of southern France as well as their possible evolution between Antiquity and the Middle Ages.

A typology of archaeozoological assemblages based on taxa criteria has also been performed thanks to the CA analysis of these CSS. It will allow to provide keys for the identification of the nature of animal remains that will be discovered in the future. The over-representation of pigs and chickens characterizes in particular the agglomerations and hill sites, whereas the areas in the periphery of houses are gathering places for equids, canines and cattle bones. This approach, through the number of samples it can process, has finally made it possible to detect and statistically validate micro-regional trends. Among them, the Nîmes plain seems to be a territory of specialization in cattle breeding, while the sites of the Narbonnese plain have yielded a much higher proportion of caprines during Late Antiquity and from the ninth century onwards.

The CSS construction is therefore a very effective tool for quantifying species. It can support studies within sites, but also helps regional syntheses to perceive chronological, micro-territorial or even socio-economic trends. In the future, it will be used on a larger temporal and geographical scale to test its effectiveness and relevance on a large panel of archaeozoological assemblages uncovered in various excavation conditions.

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**Data Availability** All data inventoried and analyzed during this study are included in this published article (and its supplementary information files). In particular, detailed information about CSS taxa abundance is provided in SI Table 2 and their construction methods are detailed in SI appendix. Finally, species frequencies considered in the diachronic analyses by occupancy stage are in SI Table 3.

## Declarations

**Competing interests** The authors declare no competing interests.

**Conflict of interest** The authors declare no competing interests.

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