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The diversity evolution of sheep morphology in French zooarchaeological remains from the 9th to the 19th century: Analysis of pastoral strategy

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ABSTRACT

Although the economic importance of sheep husbandry in the Middle Ages, especially during the development of the major cloth industries, and the speculation of animals for wool, is recognized, until now the evolution of sheep forms on the French mainland have not been the subject of major investigations. The purpose of our study, therefore, was to assess the morphological diversity of sheep across eleven centuries, and attempt to reconstruct the zootechnical practices used in husbandry and their effectiveness from the zooarchaeological remains. In addition, a database was created, with the help of numerous specialists, grouping 16,353 measured bones corresponding to 59,801 distributed measurements from the 9th to the 19th centuries in France.

Our purpose was to describe the shape of animals bred for wool (through size or dimensions) across a wide territory using bone remains and the help of common methods and tool, such as shoulder height, the slenderness index, and the log size index. The work carried out within the framework of this study should be reproducible for any type of zooarchaeological study.

The results reveal an evolution in sheep diversity and morphologies according to three stages, from the end of the Late Middle Ages to the industrial era. The first phase corresponds to fairly homogeneous sheep herds from the 9th–10th and the 12th–13th centuries, with a low diversity of forms: small and stunted. We then witness an important development in morphological variety from the 13th–14th centuries, in all dimensions, from the smallest to the largest. Many of the various forms emerged without impacting sheep dimensions in depth; overall, the herds remained composed of smaller individuals. Finally, from the 12th–13th and the 18th–19th centuries, there is a loss of diversity in sheep forms to the benefit of herds primarily consisting of larger dimensioned individuals. This zootechnical evolution can be compared to the effect of merinisation operating at the end of the modern period.

1. Introduction

Considered central to the medieval French economy, sheep farming was particularly important for the production of wool. The importance of this and associated products to agriculture in the Middle Ages has been demonstrated through both archaeological data and historical sources: wool, meat, milk, and manure to aid soil fertilization. (Aubron et al., 2011; Audoin-Rouzeau, 1997a; Clavel, 2001; Clavel and Yvinec, 2010; Forest, 1997; Fossier, 1997; Frère and Yvinec, 2009; Lepetz and Yvinec, 1998; Moriceau, 1999). In addition, some researchers have observed a global increase of sheep bones within french archaeological sites, from the Early Middle Age to the modern period (Audoin-Rouzeau, 1997b; Clavel, 2001; Clavel and Yvinec, 2010). However, evidence of the improvement or transformation of animals in order to optimize their production is seldom found in archaeological remains (Audoin-Rouzeau, 1991) and only mentioned late in the historical sources (Denis, 1993). This study is a first step of a global research about sheep morphology during medieval and modern period in France. Following analyses will focus about local practices and the description of various form.

1.1. Sheep breeding of the 9th to the 19th centuries

In the Middle Ages sheep breeding is often exposed as being poorly maintained and rarely improving breeds, in comparison to cattle and horses (Moriceau, 1999). It seems, therefore, that the maintenance of breeding was not of great interest during the Middle Ages either for the care of the animal, the quality of the wool or the meat (Denis, 1993).

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Some breeders did try to improve production, for example with the importation of rams and ewes from Castile to Roussillon in the 14th century which generated “excellent herds” (Carlier, 1770, p. 177); we also have the first mention of Merinos sheep during the same period (Audoin-Rouzeau, 1997). Overall, however, the results were not conclusive (see the treaties of Carlier, 1770; Daubenton, 1810; Rozier, 1805; Tessier, 1810) (summary: Moriceau, 2005, p. 152). Sheep are the only producers of wool; the primordial material of the main medieval “industry” which was the subject of speculation from as early as the 13th century (Bompaire and Contamine, 2003; Fossier, 1997). The study of livestock management methods and in particular the slaughter age distributions carried out on bone assemblages in northwestern France (Clavel, 2001), indicates that between the 12th and 15th centuries sheep are first devoted to the wool production. By the 15th century, sheep will be more and more involved in the diet. This makes it possible to satisfy a double economic demand: the food and textile needs. This is the rise of speculative breeding.

In modern times, sheep herds were composed of many heads; therefore, losses or poor performance seem not to have generated much concern (Moriceau, 2005).

It is noted again in the 16th century that in a sickly and poorly maintained French herd (Carlier, 1770; Denis, 1993, p. 177; de Brie, 1879), the properties of wool were not fully optimized. As a consequence, the French wool merchants could not compete with the large cloth industries such as England, Flanders or Spain (Denis, 1993).

It will be necessary to wait for royal orders and the creation of the Rambouillet farm in the 18th century (see Denis, 1993; Guintard and Mazzoli-Guintard, 2004; Moriceau, 2005; Quemener, 1997) to see a real transformation of herds through merinisation (the interbreeding of French herds with Merino sheep) (Blanc and Laurans, 1964; Moriceau, 2005; Reveleau and Reveleau, 2004). The study of sheep dimensions, therefore, represent the major zootechniques reflecting the evolution of the medieval and modern economy. So, even if it proves that medieval sheep herds were already present in a variety of forms (e.g. Carlier, 1770), the appearance of current breeds, such as those producing good quality wool, have their origin in the 19th century (Quemener, 1997).

1.2. Sheep economy and morphology in the modern period

The link between sheep husbandry and economy throughout the ages seems strong (most notably during the golden age of the wool industries) and illustrates the need to undertake a scientific interest in sheep breeds (Audoin-Rouzeau, 1997a; Quemener, 1997). In effect, successive attempts to improve the herd demonstrate the preoccupations of agriculturalists for sheep production, particularly when the market for wool and mutton was exposed to speculation (Moriceau, 2005). Observed morphological modifications reflect the diffusion rate of these transformations, at the discretion of changes in the agro-pastoral economy, communication networks or the relocation of livestock (Audoin-Rouzeau, 1997a).

Such as study about the Agricultural Revolution in England, the link between form and size of domesticated and agricultural economics was clearly proved for the 18th century (Davis and Beckett, 1999). It appears as early as the mid-14th century an increase of the sheep size in some English location, correlated with changes in agricultural practice (Thomas, 2005; Vann and Grimm, 2010).

However, when these changes are attached to the evolution of sheep forms, the difficulty is that the main criteria for selection refers to physical qualifications (wool yield and quality, and animal size) (Audoin-Rouzeau, 1991). Nevertheless, the introduction (most notably in the 18th century) of new corpulent breeds such the Brabant, the Flandrin, and the Merinos can be observed by transformations in the dimensions of sheep within the medieval flocks composed of small sheep (Audoin-Rouzeau, 1997a; Carlier, 1770). Local practices of selection which generated changes in the skeleton are also potentially detectable through a morphological study.

The archaeological sheep remains found in France have not yet been the subject of morphological investigations to assess changes of form relating to the improvements or transformations of individuals. In fact, only a small number of studies have been carried out on the stature of sheep in the France (Audoin-Rouzeau, 1991; Clavel, 2001; Lepetz, 1996). Although this research remains limited due to the restricted dataset, its geographical spread, and that it only provides analysis of average statures, it does define an evolution in non-linear shoulder heights, with zootechnical transformations consistent from the 17th century. This poses the question of a real homogeneity of ovine forms from the 9th to the 17th centuries; consequently, it was necessary to widen the analysis of size increase in order to observe the zootechnical reasons and consequences on the flocks.

The latest research based on the morphology of sheep skeletons essentially analyses the differentiation between bones and teeth of *Ovis aries* and *Capra hircus* (a particularly difficult distinction which has curbed osteometric investigations), the sexing, lambing and conditions during life (e.g. Salvagno and Albarella, 2017), rather than the transformations of individuals from anthropogenic selection (e.g. Davis, 2000; Popkin et al., 2012; Salvagno and Albarella, 2017; Worley et al., 2016).

However, sheep are almost systematically represented in archaeological sites and are analyzed by zooarchaeologists (through the comparison of metric databases) studying food supply (Audoin-Rouzeau, 1991); therefore, they represent an area of important research due to their being resolutely present in the life of ancient populations. The study of small livestock is, perhaps, a support for the analysis of trade and commerce (either in the form of meat or live animals) during different periods of history.

2. Material and methods

2.1. Material

The database brings together 16,353 bones being measured from a total of 59,801 measurements (Table 1). The raw data are collected from the French archaeolozoological community and came from their own research (all data may be requested from each archaeologist or archaeozoologist quoted in supplementary material). We selected only measurements clearly identify with the protocol of Von den Driesch, 1976.[1] All data was collected by each archaeozoologist, in their own laboratory spread over France, with their tools and with their collection. Gathering this data set lead to an important bias because of the large number of analysts and methodology (28 archaeozoologists) (Lau and Kansa, 2018; Lyman and VanPool, 2009). But, this is not possible to evaluate the interanalyst variation because measurements originate from many archaeological sites studied by a lot of scientists (and sometimes students) since 30 years. However, the amount of data should minimize some spurious measurements (Lau and Kansa, 2018). Furthermore, all data was collected by using a calliper and following the measurements defined by Von den Driesch. We had to gather and analyze these measurements to study a large territory like France, but always by knowing the interanalyst biais.

Within these remains, only a few bones were clearly identified as belonging to sheep. In fact, the distinction between the teeth and bones of *Ovis aries* and *Capra hircus* is particularly difficult and subjective to the naked eye (Boessneck, 1969; Lau and Kansa, 2018; Salvagno and Albarella, 2017). However, studies on goat husbandry reveal an overwhelming predominance of sheep at the expense of goats, and a low share of goat meat within the food chain (Audoin-Rouzeau, 1993; Spindler, 2011; Vigne, 1988). In addition, each study on specific

[1] Each measurement is taken by the specialist who study the archaeological site, and thus is the property of each archaeozoologist. Only measurements following the Van Den Driesch protocol (1976) was selected and analyzed.

Table 1
Bones measured and number of measures per bone type.

	Number of bones measured	Number of measures
scapula	1420	4777
humerus	2162	5837
radius	2364	8332
ulna	154	376
naviculocuboid	111	111
metacarpale	1894	10,395
femur	146	423
tibia	2533	6750
calcaneus	263	1398
talus	334	822
metatarsal	1794	9598
phalanx 1	805	1287
phalanx 2	1498	7069
phalanx 3	875	2626
TOTAL	**16,353**	**59,801**

distinctions reveals a low representation or even an absence of *Capra hircus* (Audoin-Rouzeau, 1997a, 1986; Borvon, 2012). Therefore, in order to exploit the most data, we have assumed that the major part of the remains collected came from the species O*vis aries*.

The measurements relate to the limb bones and the scapula: a choice based on the frequency of the osteometric data at our disposal. We excluded bones that are rarely or never measured (i.e. skulls, mandibles, vertebrae, pelvis, ribs, carpal, and some tarsi) whose metric data is heavily dependent and relative to the operator taking the measurements (i.e. teeth and horncores). Instead we focused exclusively on, or on part of, the epiphyseal because we were not concerned with the exploration of bone growth, and the absence or near absence of post-epiphysis growth has already been demonstrated (except for certain areas of bone: humerus BT and HT; scapula SLC, GLP and ASG, radius BFp and BP, astragalus Bd, although in a limited way; see Davis, 1996; Popkin et al., 2012).

The osteometric data came from 194 archaeological sites distributed throughout France (Fig. 1). We chose a wide territory, without cutting the internal geography, in order to fully analyze the evolution of populations after the osteometric data has been collected. The geographical scope of this database allowed us to consolidate the maximum number of regions (cultural, administrative, geological), the natural environment, landscape, and context, etc., in order to bring together the most comprehensive sample of sheep diversity. Historical sources mentioned some variations of sheep form, depending on geographic areas (Carlier, 1770; de Brie, 1879) but the location and the anatomy description are more or less filled out. There is a gap between the written sources and our study. We need in a first step to analyze in a large territory if there is a global sheep form evolution in order to establish a local research in a second step (forthcoming publication).

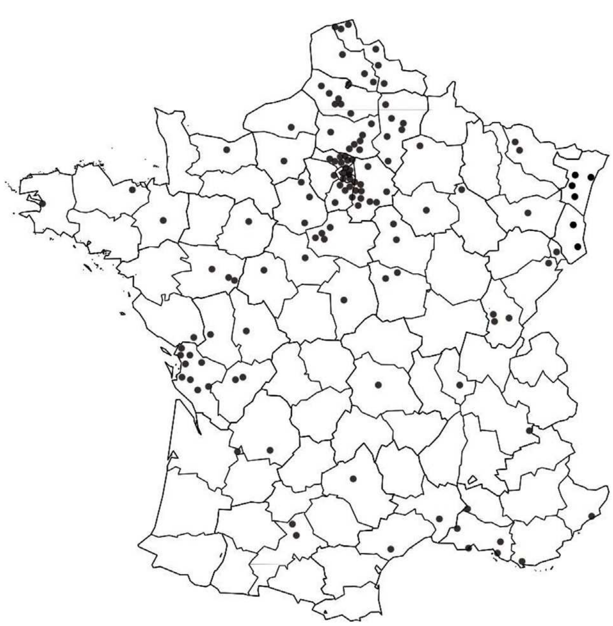

Fig. 1. Distribution map of the localities studied.

However, we did note an important bias concerning the distribution of data in some certain geographical areas. Hopefully, further studies focusing on the analysis of these denser areas of osteometric data will be forthcoming.

The chronological framework extends from the 9th to the 19th century. In order to explore the maximum measurements, chronological sequencing was achieved by overlapping two adjacent centuries. The 9th century was chosen as the lower limit because it is the moment when the unity of the Carolingian Empire is definitely defeated. It is a territorial break but also political. This reflects the strength of the recovery and the opening of new perspectives.

This fractionation, while being consistent with the archaeological dating specific to the 194 sites, also allowed us to study the evolution of forms with a certain chronological continuity. In effect, it was chosen to assess sufficiently broad enough intervals of time in order to consolidate a large amount of data, whilst also being reasonably restricted so as not to lose chronological information.

3. Methods

The form of the animal can be described in a number of ways and with the help of various tools (Davis, 1996; Popkin et al., 2012; Ruscillo, 2000; Salvagno and Albarella, 2017). Our study focused on two aspects of the form: the morphology and the size.

3.1. Shoulder height (SH) and the slenderness index (SI)

In order to describe the dimensions of the animal, the shoulder height and the slenderness index were estimated for each long bone measured.

After Teichert (1975), the stature of a sheep can be estimated by multiplying the total length of the bone (GL) by a calculated coefficient. However, although this method is regularly called into question because it only provides a rough estimate of the individual's size (e.g. Forest, 1998; Guintard, 1996; Von den Driesch and Boessneck, 1974), it does allows direct assessment of the sheep's dimensions to be obtained; therefore, it still remains one of the most used ways to describe form. Total available lengths were used to assess the shoulder height of each specimen. The slenderness index, an indicator of an individual's corpulence, was estimated using the ratio of the smallest width of the diaphysis (SD) along the greatest length of the bone (GL). The results were exposed in box plot and analyzed with the help of a simple mathematical description: average, median, minimum, maximum, and standard deviation.

3.1.1. Log size index (LSI)

Shoulder height and the slenderness index only describe individuals using two measures: the GL and the SD. In order to exploit the maximum amount of data, the osteometric data were analyzed using the LSI method. Implemented by Simpson (1941) and then reused in zooarchaeology by Meadow (1999), it calculates the difference of the decimal logarithms between each measurement taken from the sample (a) and matches it to the corresponding reference (b): LSI = Log (a) – Log(b).

The animal is described in three dimensions, according to three axis (according to the bone growth; see Davis, 1996): dorsoventral, mediolateral and anteroposterior (Fig. 2). In effect, it seems more relevant to distinguish between these three metric vectors because, as previously demonstrated by Davis (1996), the correlations of measurements are higher within the same axis than between different axes.

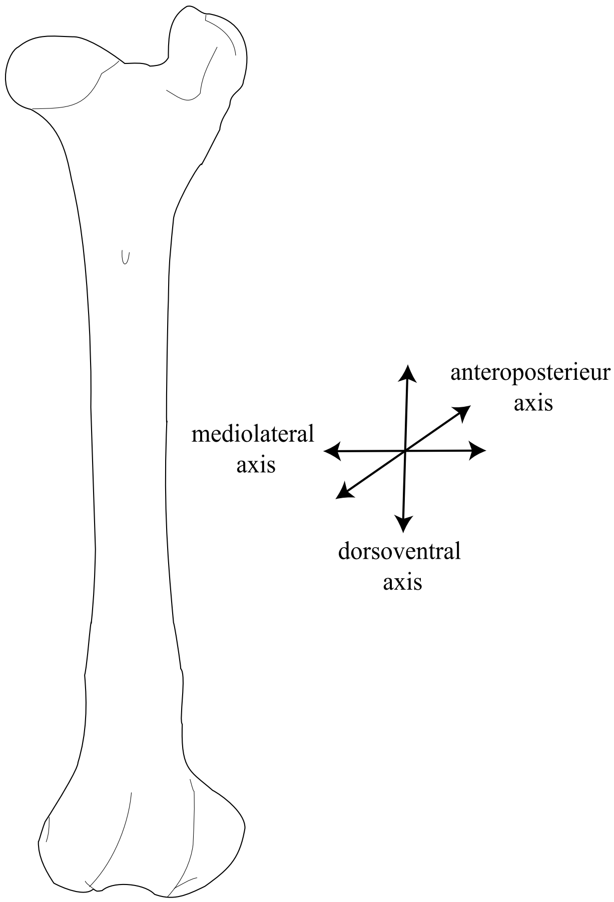

Fig. 2. Graphic of the three axis following the three growth dimensions used for the bones description (drawing by J.-C. Castel; archeozoo.org).

The collection of wild Soay sheep skeletons from the island of Hirta (58 complete skeletons and 651 isolated bones) housed at the Natural History Museum, London, were chosen as a reference (Clutton-Brock et al., 1990). This breed of sheep is reputed for being small and for bearing primitive characters (Ryder, 1983). All results were exposed in histogram and verified using the Mann–Whitney U test ($\alpha = 0.05\%$, $p < 0.0001$).

The LSI allows you to analyze the anatomy of sheep with alarge sample (Table 2).

4. Results and discussion

4.1. Shoulder height

The results are based on 2808 estimated shoulder heights.

Table 2
Dataset used for the log-ratio analysis per skeletal axis and by bone.

	Dorsoventral axis	Mediolateral axis	Anteroposterior axis
humerus	124	2053	439
radius	588	2302	1419
ulna	3	108	110
metacarpal	1002	1786	1470
femur	63	275	63
tibia	195	2393	2043
calcaneus	770	483	
talus	828	720	356
naviculocuboid		107	
metatarsal	955	1727	1338
Total	**4528**	**11,954**	**7238**

Table 3
Evolution of the shoulder heights of sheep estimated from long bones, 9th–19th centuries, France.

datations	average	standard deviation	median	min	max	n
9–10	58.187	3359	57.838	51.574	67.727	136
10–11	57.823	3121	57.702	47.922	66.113	123
11–12	57.941	4503	56.871	50.709	70.709	57
12–13	57.086	3920	57.204	47.034	66.308	91
13–14	57.256	4129	56.937	46.455	69.546	396
14–15	58.000	3924	57.792	45.445	74.670	343
15–16	57.472	4159	57.432	46.081	73.409	550
16–17	57.121	4254	56.963	45.672	74.817	893
17–18	59.011	5053	58.522	45.608	72.640	162
18–19	63.522	5010	63.210	50.145	72.955	57

According to the histogram, the stature of small livestock seems relatively constant between the 9th–10th and the 16th–17th centuries, oscillating between 57 and 58 cm on average (Table 3; 4 and Fig. 3). However, the Mann–Whitney U test showed two levels of statistically significant size increases: one during the 14th–15th centuries, and another more important increase at the beginning of the 17th–18th centuries. This increase in size to the modern period seems progressive: about approximately 2 cm during the 17th–18th centuries, then 4,5 cm during the 18th–19th centuries. The average size of a sheep increases from 59 cm during the 17th–18th centuries to 63,522 cm during the 18th–19th centuries.

The shoulder height estimates from the 17th to the 19th centuries' remains provided the biggest mean deviations, suggesting a greater number of individuals of composite size (overall of a larger scale).

With regards the minimums and maximums, the number of taller sheep seems to increase from the 14th–15th centuries. The large range of size persists until the 18th–19th centuries when the distribution seems to reduce, although the trend is moving toward larger individuals. In other words, there are less extreme sizes (very large or very small animals) but the frequency of individuals whose stature is around average increases.

It is also important to note that the maximum values for shoulder height found in the 18th–19th centuries were also present during the 14th–15th centuries; therefore, the emergence of large individuals dates to long before the modern period. The global increasing of size sheep of the 17th–18th and the 18th–19th centuries may correspond to a sustainable implementation of larger individuals at the expense of small medieval sheep, which seem to disappear from modern farms.

The analysis of shoulder height from the French remains reveals several zootechnical events and provides us with a precise image. During the 9th–10th and the 14th–15th centuries sheep sizes were relatively small (between 57/58 cm) and stable across Europe, as observed by Audouin-Rouzeau (1991). The first modifications in sheep herds appeared during the 14th–15th centuries, which are when notably larger individuals appear in archaeology, slightly modifying the average individual size. Although the size increase has been observed since the 17th-18th, the disappearance of smaller individuals during the 18th–19th centuries could lead to an overall increase in the stature of sheep populations.

4.2. Slenderness index

According to the average slenderness index, estimated from 2698 bones and the histogram the corpulence of sheep appears constant in the Early Middle Ages until the 16th–17th centuries (Table 5; 6 and Fig. 4).

But, according to the Mann-Whitney test, sheep become globally more slender from the 17th–18th centuries. However, the important oscillation of the minimum and maximum index does not support this appreciation of balance (Fig. 5). The spread of the data is variable, although the medians and averages are constants. If these results

Table 4
Comparison of the sheep shoulder height estimated from the long bones using Mann-Whitney U test, 9th–19th centuries, France (ns = not significant; ↗ = data of the earliest period are significantly lower; ↘ = data of the earliest period are significantly upper).

	9th-10th	10th-11th	11th-12th	12th-13th	13th-14th	14th-15th	15th-16th	16th-17th	17th-18th
9th-10th									
10th-11th	ns								
11th-12th		ns							
12th-13th			ns						
13th-14th				ns					
14th-15th					↗				
15th-16th						ns			
16th-17th							ns		
17th-18th								↗	
18th-19th									↗

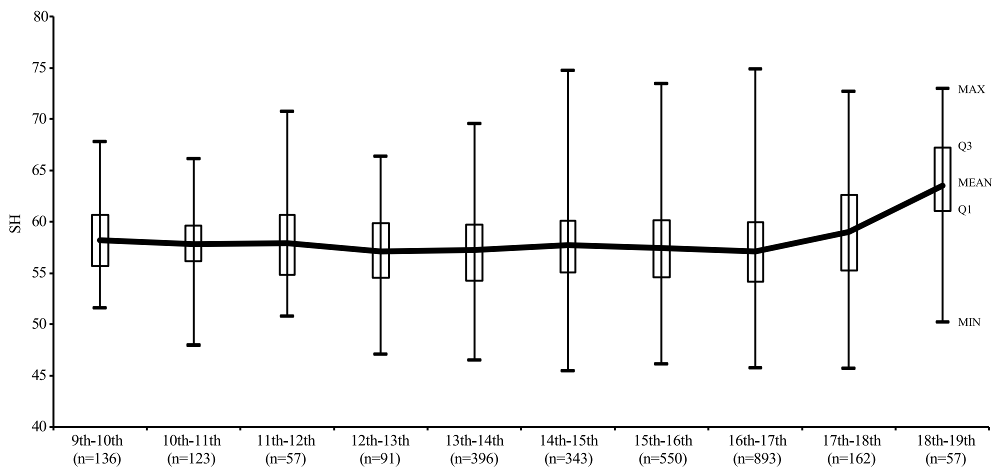

Fig. 3. Box plot of the evolution of sheep shoulder heights estimated from the long bones, 9th–19th centuries, France (In parenthesis: total sample size).

Table 5
Evolution of the slenderness index of sheep estimated from the long bones, 9th–19th centuries, France.

datations	average	standard deviation	median	min	max	n
9–10	10.155	1520	9507	7516	14.673	135
10–11	9790	1322	9577	7125	13.375	118
11–12	10.129	1694	9714	5155	13.967	54
12–13	10.173	1497	10.072	6208	14.374	94
13–14	10.148	1377	10.000	7308	15.357	384
14–15	10.001	1448	9722	6335	15.417	339
15–16	10.022	1418	9705	5328	17.179	521
16–17	10.217	1618	9807	4978	16.216	874
17–18	10.690	1837	10.056	8000	15.000	129
18–19	10.829	1924	10.259	7818	14.698	50

mainly demonstrate the variability of corpulence within French sheep flocks since the 9th–10th centuries, we nevertheless noted an observable shift. The most important data spread is between the 15th–16th and the 16th–17th centuries. In other words, these periods reflect the widest range of sheep robustness during the Middle Ages. There is also an increase in the slenderness of sheep from the 17th–18th centuries, parallel to the disappearance of stockier individuals. As with shoulder heights, the increase of slenderness is not due to the emergence of thinner individuals.

The increase in the standard deviation during the modern period reflects a more widespread heterogeneity of the indexes compared to those from the 9th to the 17th centuries.

Consequently, it reveals an increase in the variety and number of sheep morphologies. In other words, the increase in the slenderness observed in the 17th–19th centuries does not correspond to the arrival of newly proportioned individuals but to the intensification of the

Table 6
Comparison of the slenderness index of sheep estimated from the long bones using Mann-Whitney U test, 9th–19th centuries, France (ns = not significant; ↗ = data of the earliest period are significantly lower; ↘ = data of the earliest period are significantly upper).

	9th-10th	10th-11th	11th-12th	12th-13th	13th-14th	14th-15th	15th-16th	16th-17th	17th-18th
9th-10th									
10th-11th	ns								
11th-12th		ns							
12th-13th			ns						
13th-14th				ns					
14th-15th					↗				
15th-16th						ns			
16th-17th							ns		
17th-18th								↗	
18th-19th									↗

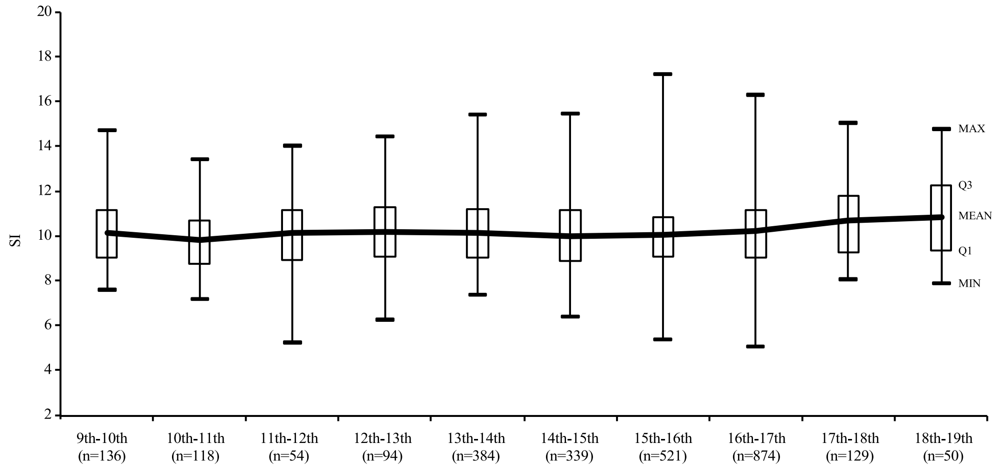

Fig. 4. Box plot of the evolution of the slenderness index of sheep estimated from the long bones, 9th–19th centuries, France (in parenthesis: total sample size).

number of thinner (but on average larger) sheep.

4.3. Log size index (LSI)

4.3.1. Dorsoventral axis

According to the variations in the total lengths and the Mann-Whitney test, during the 18th–19th centuries there is a displacement in the profile of logarithmic differences, representative of animals for who bone length increased (Fig. 5 and Tables 7 and 8). It also appears that the larger than average sheep, reached their maximum size during the 18th–19th centuries.

In light of the spread of data around the reference axis (Fig. 5), a larger range of data can be observed from as early as the 13th–14th centuries, which does not reduce until the 18th–19th centuries. A review of the LSI also puts forward a modification of the sheep flocks during the 16th–17th centuries: the observed minimum values being the lowest of all the samples. In other words, the modern period saw the appearance of individuals whose bone lengths were especially small and which, according to the statistical tests, profoundly transformed the entire herds.

There are more various sheep forms from the 13th–14th centuries, with the introduction or the emergence of new individuals with reduced

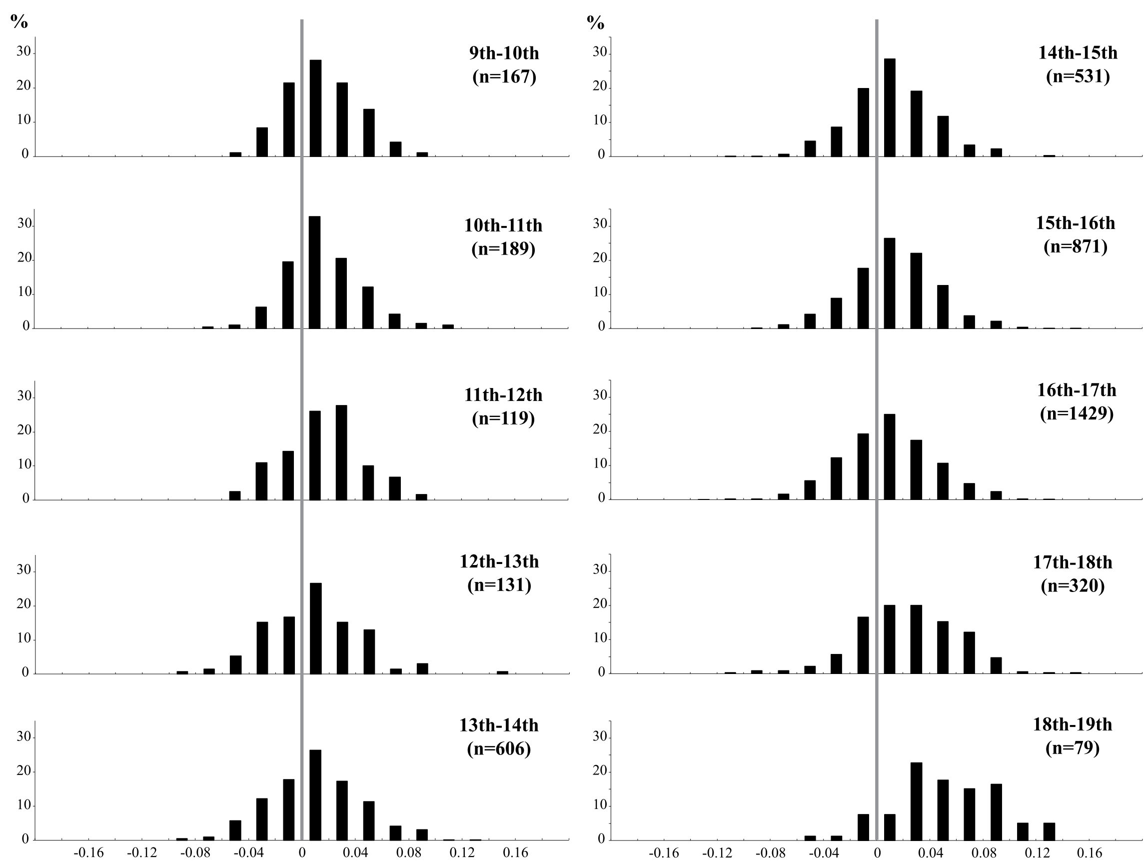

Fig. 5. Log-ratios histograms of sheep estimated according to the dimensions of the dorsoventral axis of bones from the France, 9th–19th centuries, compared to individuals from the island of Hirta.

Table 7
Evolution of the log-ratios of sheep estimated according to the dimensions of the dorsoventral axis of bones from the France, 9th–19th centuries, compared to individuals from the island of Hirta.

	average	min	max	standard deviation	n
9-10	0.015	−0.049	0095	0.027	167
10-11	0.016	−0.072	0111	0.029	189
11-12	0.016	−0.047	0097	0.029	119
12-13	0.009	−0.089	0146	0.035	131
13-14	0.010	−0.090	0122	0.034	606
14-15	0.011	−0.104	0124	0.032	531
15-16	0.013	−0.098	0142	0.033	877
16-17	0.009	−0.138	0132	0.035	1429
17-18	0.023	−0.113	0153	0.038	320
18-19	0.054	−0.045	0132	0.039	79

bone lengths. From the end of the Early Middle Ages to the modern period, the herds were more heterogeneous and consisted of much smaller sheep. This large range of form ends in the 18th–19th centuries, which is when we begin to see uniformity in sheep morphologies corresponding to the global breeding of much larger sheep.

4.3.2. Mediolateral axis

The evolution of bone widths, compared to the reference, differ from that observed for the bone lengths (Fig. 6 and Tables 9 and 10). According to the histograms, it would seem that, on average, sheep became thinner between the 10th–11th centuries and the 11th–12th centuries. Then, the mediolateral axis offers relatively stable dimensions up to the 18th–19th centuries; a period characterized by the appearance of the larger size.

The highest average (0.027) is observed from the beginning of the Early Middle Ages and the contemporary period. Between these two events, a decrease in the thickness of individuals is observed from the 11th–12th centuries (0.016) until it reaches its lowest point in the 17th–18th centuries (0.010); a period during which the sheep must have been particularly stunted.

In addition, the distribution of data is wider from the 13th–14th centuries until the 16th–17th centuries, when the bones become finer. This evolution is completed by a general upheaval of the herds during the 18th–19th centuries, with a distribution of larger and more homogenous bone widths. However, the highest mediolateral dimensions are observed from the 13th–14th to the 16th-17th centuries. Therefore, the contemporary period cannot, strictly speaking, provide new insights into the original values, as the sizes observed for the previous period were already present, and had been since the earliest period.

4.3.3. Anteroposterior axis

According to the histogram of the LSI frequency following the anterior to posterior axis and associated averages, oscillations appear to operate throughout the Middle Ages (Fig. 7 and Tables 11 and 12). However, the lowest average is observed during the 17th–18th centuries and the highest average during the 9th–11th centuries, as well as during the contemporary period (statistically significant results). The evolution of this axis presents two stages of decline during the 13th–14th and the 17th–18th centuries, each followed by a strong progression of the measurements (Fig. 7). As we can see on the histograms, these two levels of reduction in the dimensions correspond to periods when individuals had the thinnest anteroposterior values. Conversely, the largest measurements date from the 15th–16th and the 16th–17th centuries.

Again we noted a spread of the greatest values between the 13th–14th and the 17th–18th centuries. This more pronounced amplitude concerns both the individuals with the lowest and largest anteroposterior dimensions.

Finally, the increase in the average from the 18th–19th centuries goes hand in hand with a narrowing in the spread of the data: the values seem to regroup and concentrate, around the greater than average measures.

5. Discussion

When evaluating the results obtained from the shoulder heights, the slenderness index and the LSI, several significant phenomena stood out; regardless as to whichever method was employed, a "pattern" of common evolution appeared in sheep forms of the 9th to the 19th centuries, according to three stages:

-The first phase takes place during the 9th–10th and the 12th–13th centuries, and corresponds to a homogeneous sheep husbandry with an overall morphology close to that of the Soay sheep. These are therefore individuals of a relatively low size and stoutness. Also, the variability of forms within the herds is rather limited, and there seems to be coherence in the anatomy of all animal flocks bred for wool (Audoin-Rouzeau, 1991). The relative stability of sheep forms can be paralleled with a lack of interest in sheep husbandry observed from as early as the Early Middle Age (Denis, 1993; Quemener, 1997). It can be assumed, therefore, that this lack of interest toward rearing animals for wool prevented attempts at improvements that would generate morphological variations (e.g. adaptations to the environment, improvements in productivity, performance in secondary products).

- The second phase begins in the 13th–14th centuries with a slow decline of average sheep dimensions, regardless of the skeleton axis considered, which persisted until the 16th–17th centuries. The sheep, ewes, and rams are broadly of a thinner size and stoutness than the model Soay race, and are particularly stunted, as observed by J. de Brie and the Abbot Carlier (Carlier, 1770; de Brie, 1879; Moriceau, 2005). However, in spite of this overall decline, there is a greater variability of sizes across all anatomical dimensions. From the 13th–14th centuries, there is more various sheep forms, and we find many more smaller and thinner individuals from livestock of a generally strong model. This range of forms can have many causes such as adaptations to the environment, the sporadic introduction of new breeds, or attempts at local

Table 8
Comparison of the log-ratios of sheep estimated according to the dimensions of the dorsoventral bones axis using Mann-Whitney U test, 9th–19th centuries, France (ns = not significant; ↗ = data of the earliest period are significantly lower; ↘ = data of the earliest period are significantly upper).

	9th-10th	10th-11th	11th-12th	12th-13th	13th-14th	14th-15th	15th-16th	16th-17th	17th-18th
9th-10th									
10th-11th	↗								
11th-12th		↘							
12th-13th			ns						
13th-14th				ns					
14th-15th					↗				
15th-16th						↗			
16th-17th							ns		
17th-18th								↘	
18th-19th									↗

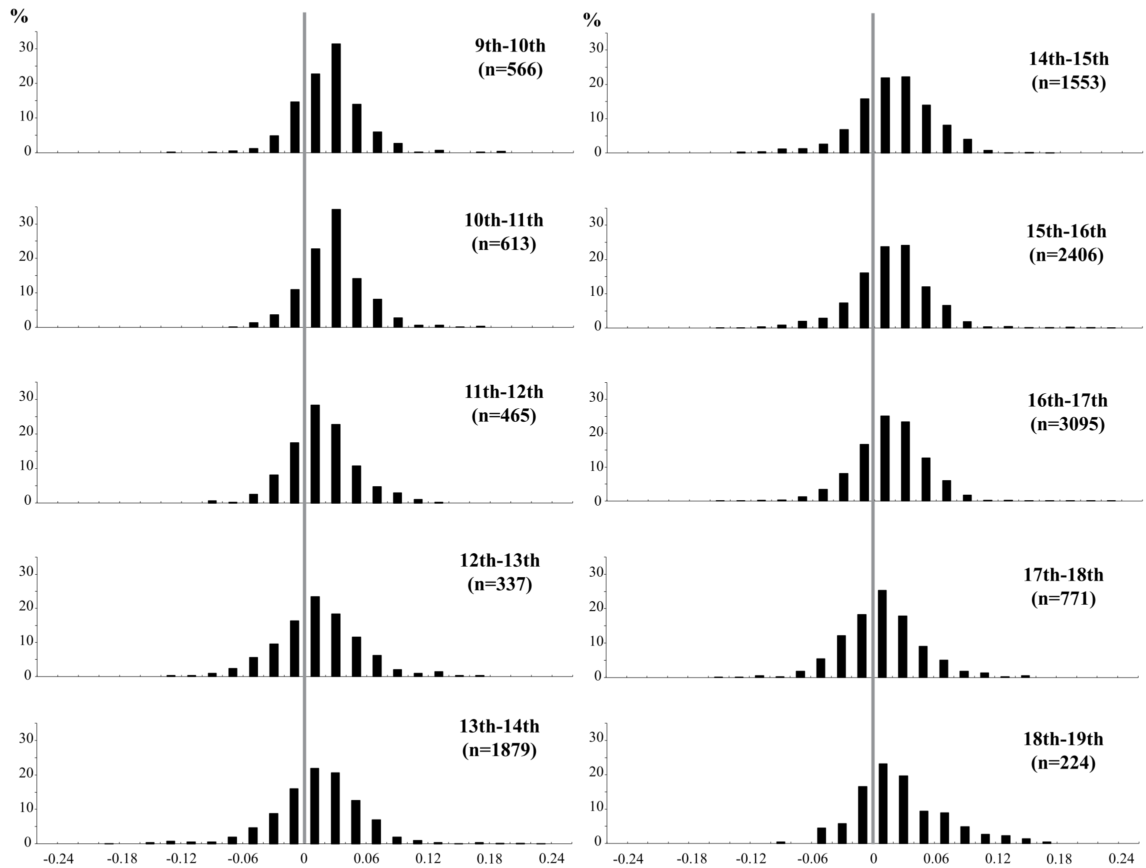

Fig. 6. Log-ratios histograms of sheep estimated according to the dimensions of the mediolateral bone axis from the France, 9th–19th centuries, compared to individuals from the island of Hirta.

Table 9
Evolution of the log-ratios of sheep estimated according to the dimensions of the mediolateral bone axis from the France, 9th–19th centuries, compared to individuals from the island of Hirta.

	average	min	max	standard deviation	n
9-10	0.023	−0.132	0197	0.033	566
10-11	0.027	−0.079	0167	0.031	613
11-12	0.016	−0.091	0133	0.033	465
12-13	0.013	−0.128	0168	0.041	337
13-14	0.013	−0.186	0228	0.044	1879
14-15	0.019	−0.138	0179	0.039	1553
15-16	0.017	−0.156	0235	0.039	2406
16-17	0.015	−0.149	0228	0.035	3095
17-18	0.010	−0.153	0159	0.039	771
18-19	0.027	−0.089	0174	0.043	224

improvement, in parallel with the start of speculating sheep for wool (Bompaire and Contamine, 2003; Moriceau, 2005). The diversity of forms based on the regions and landscapes were also underlined by Abbot Carlier in 1770 (four categories of sheep, from small to very large, according to the region and landscape). Also, regional studies based on historical sources show the extent of the forms which constituted the herds (e.g. Heude, 2012; Maneuvrier, 2000; Rendu, 2003). In addition, we know that there were occasional attempts to introduce new breeds (Carlier, 1770). And finally, there is a real change compared to the Early Middle Age represented by more various forms that are found punctually in some herds.

These results also reveal the presence of “bigger” and “fatter” individuals well before merinisation. The transformation of livestock in the modern period is illustrated by an increase in the number of large sized sheep and the disappearance from the herd of the more stunted animals. There is also a genetic modification of the sheep herd.

Table 10
Comparison of the log-ratios of sheep estimated according to the dimensions of the mediolateral bones axis using Mann-Whitney U test, 9th–19th centuries, France (ns = not significant; ↗ = data of the earliest period are significantly lower; ↘ = data of the earliest period are significantly upper).

	9th-10th	10th-11th	11th-12th	12th-13th	13th-14th	14th-15th	15th-16th	16th-17th	17th-18th
9th-10th									
10th-11th	ns								
11th-12th		ns							
12th-13th			ns						
13th-14th				ns					
14th-15th					ns				
15th-16th						ns			
16th-17th							ns		
17th-18th								↗	
18th-19th									↗

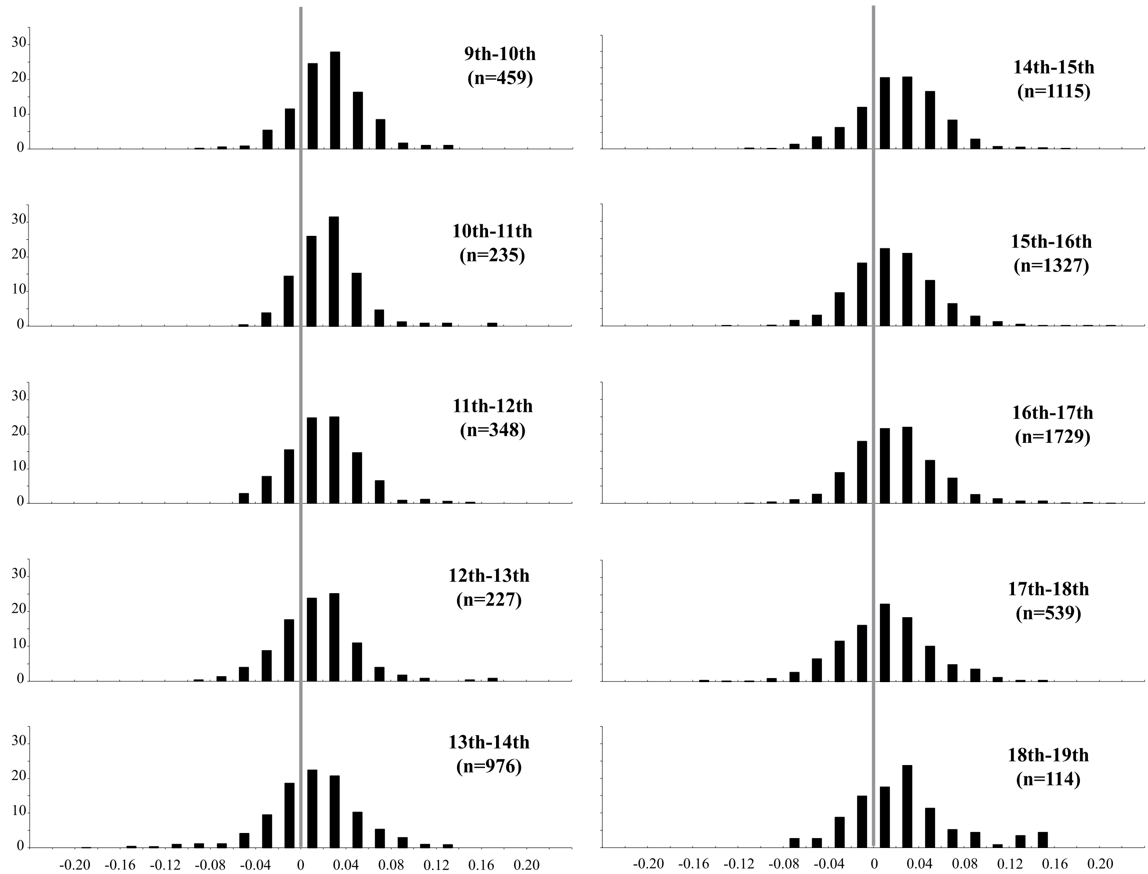

Fig. 7. Log-ratios histograms of sheep estimated according to the dimensions of the anterior/posterior bones axis from France, 9th–19th centuries, compared to individuals from the island of Hirta.

Table 11
Evolution of the log-ratios of sheep estimated according to the dimensions of the anterior/posterior bones axis from the France, dated 9th–19th centuries, compared to individuals from the island of Hirta.

	average	min	max	standard deviation	N
9-10	0.025	−0.084	0130	0.032	459
10-11	0.025	−0.053	0168	0.032	235
11-12	0.020	−0.056	0143	0.032	348
12-13	0.015	−0.083	0173	0.037	227
13-14	0.011	−0.181	0123	0.042	976
14-15	0.023	−0.109	0165	0.037	1115
15-16	0.017	−0.132	0205	0.041	1327
16-17	0.020	−0.106	0206	0.039	1729
17-18	0.008	−0.179	0144	0.047	539
18-19	0.027	−0.079	0147	0.048	114

However, sheep with a different and original morphology are relatively few in light of the observed average, but, even though their frequency remains low, there is no denying their presence. It may be, therefore, that we are dealing with a husbandry distinguished from time to time by the specificities from their own livestock (a regional study is planned using the database gathered). The final reasons for the failure of the sustainable implementation of this diversity during the 13th–14th to the 16th–17th centuries are numerous, as explained by J.M. Moriceau in 2005: "*As for these multiple failures, the explanations are complementary: the deterrent cost of imports, increased by smuggling; the inadequacy of breeding improved in the regions of small culture; the decline or the conversion of part of the proto-textile industry toward producers at the bottom of the range, such as muslin, which was emphasized by Claude Cailly regarding the failure of the Guerrier brothers in Le Perche.*"

It is important to emphasize that this period includes the individuals with the most extremes of the entire dataset, dated to the 9th–10th and

Table 12
Comparison of the log-ratios of sheep estimated according to the dimensions of the anterior/posterior bones axis using Mann-Whitney U test, 9th–19th centuries, France (ns = not significant; ↗ = data of the earliest period are significantly lower; ↘ = data of the earliest period are significantly upper).

	9th-10th	10th-11th	11th-12th	12th-13th	13th-14th	14th-15th	15th-16th	16th-17th	17th-18th
9th-10th									
10th-11th	ns								
11th-12th		ns							
12th-13th			↘						
13th-14th				ns					
14th-15th					↗				
15th-16th						↗			
16th-17th							ns		
17th-18th								↘	
18th-19th									↗

the 18th–19th centuries; such heterogeneity of forms is not found in the contemporary period.

- Finally, the evolution of sheep forms is concluded by a third phase of strong growth either the axis of the skeleton, in the 17th–18th and the 18th–19th century. This modification is realized over two or even three centuries, with a priori of profound change through the entire skeleton, and individuals becoming globally larger and more robust. This development in size is accompanied by a reduction in the range of sheep morphologies. In effect, we observed a number of less importantly varied individuals, especially among those whose dimensions were smaller (according to the three axis). It seems that the thinnest sheep, ewes, and rams disappeared from the husbandry herds of the French mainland. The sheep herds localized in France were certainly more homogeneous, consisting of populations of comparable forms; therefore, it seems that the rearing of animals for wool regained a degree of cohesion across a wide territory.

This homogeneity, accompanied by a decrease of various forms alongside an increase in dimensions, can be related, without difficulty, to the generalized merinisation and effective implementation of the herds which took place at the end of the 18th and the beginning of the 19th century (Quemener, 1997).

We have seen, particularly since Colbert in the 17th century, herds which provoke, among other things, the development of numerous agronomy treaties (e.g. Carlier, 1770; Daubenton, 1810; Tessier, 1810). And yet it is not until the official import in 1786 of 342 ewes and 48 rams from Spain, and the constitution of the royal farm at Rambouillet that there to is a national policy to improvement zootechnical matters (in this case royal): "*These first imports constituted the starting point of the true "merinisation" of French sheep during the end of the* 18th *and the beginning of the* 19th *century. In effect, if the Merinos sheep were multiplied as a pure breed, they were mainly used in crossbreeding, a phenomenon amplified by the creation, almost everywhere in France, of the Bergeries National whose role it was to provide rams to breeders.*" (Quemener, 1997).

It would seem, therefore, that our data reflects this transformation operated at a national level, in that farms become homogeneous across a large part of the territory, with a consequent decrease in the diversity, in particular, of the smallest individuals. Merinisation would have driven the loss of the thinner sheep which had persisted since the Early Middle Ages: "*At the scale of France, while it assisted in 1811 to a reversal of the economic environment of wool, the number of merino sheep is around 200,000 animals of pure race and 2,000,000 crossbreeds which means that there would have been 5000 merino sheep in 1799.*" (Moriceau, 2005).

This mutation of the bred sheep is in agreement with the problems that were raised by the agronomists and envisaged alternatives: they report a general sickly state of animals bred for wool and suggests crosses with English and Spanish breeds. "*If the decision was taken to proceed with the introduction of Spanish merino sheep in France, it was because the state of the indigenous herd could only assure a very slow pace of progress by selection. The extent of the merinisation was such that the northern sheep population was deeply altered.*" (Denis, 1993).

6. Conclusion

The objective of our research was to provide a support for the study of the morphological diversity of sheep from the 9th to the 19th centuries across the whole of the French mainland. The goal of this analysis was to assess the development of forms with the aid of accessible tools and practices, so that this type of work can be easily realized in future studies, in particular those that are geographically or chronologically limited.

Although a global evolution of sheep dimensions was expected to start from the 18th century, our study has enabled us to put forward three stages of morphological evolution:

1) From the 9th–10th and the 11th–13th centuries, French sheep were generally small, stunted and showed few varied forms. No local specificities were highlighted in this data, was the case for all sheep husbandry across France.
2) A phenomenon of amplification of the different forms of *Ovis aries* was put in place from the 13th–14th centuries until the 17th–18th centuries. In effect, all descriptions and selected estimates support the emergence of individuals of both larger and smaller dimensions (in the three skeleton axis). There is significant variety of sheep morphologies across the whole of France; however, this diversity is not supported by the number of individuals, but argues for a sporadicity which did not significantly change the nature of the herds. In other words, there were various local forms of animals being bred for wool but they did not deeply genetically transform the herds.
3) Finally, by the 17th–18th centuries the transformation of sheep herds seems proved. There is a decline in the diversity of sheep forms which is oriented toward larger and fatter individuals. This modification of the herds toward more corpulent individuals goes hand in hand with the depletion of sheep form diversity. In effect, we observed a greater homogeneity of morphologies focused around larger animals, and a period which saw the loss of sheep diversity, but which caused a cohesion of forms in France.

The zooarchaeological studies and the historical sources have previously demonstrated the frail character of sheep herds observed from the end of the Early Middle Ages (Audoin-Rouzeau, 1997a, 1991; Carlier, 1770; de Brie, 1879; Denis, 1993; Moriceau, 2005). The merinisation of herds associated with a royal policy of improvement wool yields is also recognized for having drastically changed the herds from the 18th century (Denis, 1993; Moriceau, 2005; Quemener, 1997). This study has allowed us to confirm these events using zooarchaeological data, whilst also highlighting new elements. For example, osteometric sheep analysis has highlighted, for the first time, a real diversity within French herds from as early as the 13th–14th centuries without having to discuss the zootechniques mastered.

The significant differences between the two periods studied also deserve to be highlighted. The Middle Ages is characterized by the existence of a moribund herd consisting of animals raised by various farming techniques, many of them not well mastered. The results reveal the early presence of "larger" and "fatter" individuals before the introduction, for example, of Merino sheep. The end of the modern period and the beginning of the contemporary era mark the development of a strategy for the improvement of sheep herds, an embellishment in relation to a genuine wool policy, conducted at the scale of the Kingdom of France.

A similar phenomenon was observed in England (Davis and Beckett, 1999; Thomas, 2005; Vann and Grimm, 2010). Although a global increase of English domesticated size was observed in the Agricultural Revolution, local improvements emerging from the 14th century, like in the Dudley Castle (Thomas, 2005). These forms modifications seem to be gradual and not uniform across the country, revealing a continuum of the development more than one event, evolving with economical, social and agricultural progress (Vann and Grimm, 2010).

Unfortunately, our study did not allow us to geographically target these morphological disparities; however, the analysis still remains comprehensive, although it suffers from a poor distribution of the localities studied. Therefore, the database needs to be updated in order to complete these more poorly documented geographic sectors.

Nevertheless, the establishment of this important database coupled with primary analysis has helped to put forward the comprehensive evolution and non-linear sheep forms from the Middle Ages to the modern period. It would now be appropriate to evaluate the diversity of forms at a local level, in particular those regions most dense in archaeological sites (i.e. north France, Ile-de-France, and Poitou-Charentes). Finally, these promising results encourage the study of morphologies using more sophisticated tools; not only to establish these assumptions, but also to describe the composite shapes which mark medieval sheep diversity.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jas.2018.08.017.

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