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Sheepfold caves under study: A review of zooarchaeological approaches to old and new-fashioned research questions

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ABSTRACT

Since the implementation of herding in the Neolithic period, specialized areas for livestock activities have emerged in the Western Mediterranean region, such as some caves and shelters, which were systematically used for the stabling of herds. By definition, this type of sites has a great potential for the study of the beginning of livestock practices and offer high-resolution information on the exploitation and management of herds. Different disciplines analyze these activities through the analysis of faunal, archaeobotanical or sedimentological remains from these sites.

In this paper, we offer a state of the art on the contribution to the study of early husbandry practices of zooarchaeological studies of faunal assemblages from sheepfold caves.

1. Sheepfold caves: object of knwoledge

The emergence of farming economies from the 12th millennium cal BP in the South West Asia had an enormous impact on cultural, social and organisational repercussions of human groups (Zeder, 2008; Tresset and Vigne, 2011; Perrin et al., 2018). Among other aspects, the presence of husbandry activities begins to be documented at the archaeological sites through the presence of stabling areas for housing domestic animals. Phytoliths, faecal spherulites or parasites markers present in micromorphological thin-section or geochemical analyses have enabled the identification of penning areas in some of the most significant Early Neolithic open air sites where livestock practices are attested (Koromila et al., 2018; Abell et al., 2019; Portillo et al., 2019, 2020; Stiner et al., 2022).

In Europe, pen areas are documented in caves and rockshelters sites, mainly located in the western Mediterranean. Some regions with high concentration of this type of sites are also observed: the French Midi (e.g., Brochier et al., 1994; Brochier, 1995), Pre-Alps (e.g., Perrin et al., 2002; Thiébault, 2005; Nicod and Picavet, 2009), Liguria (Rowley-Conwy, 1991, 2000), Adriatic Region (Boschian and Montagnari-Kolelj, 2000; Boschin, 2020b; Miracle and Forenbaher, 2005), Iberian Peninsula (e.g., Puchol and Aura, 2006; Fernández-Eraso, 2010; Clemente-Conte et al., 2016; Allué et al., 2022) (see Fig. 1).

The oldest evidences of pens in these sites date since the arrival of the first domesticates, from between the end of the 7th millennium and the beginning of the 6th cal BC, and mostly associated with Early Neolithic impressed pottery cultures (Klindžić et al., 2015; Binder et al., 2017). Nevertheless, dung deposits in cave and rockshelters sites are also present beyond Neolithic times, during the Early and Middle Bronze Age and, in some sporadic cases, in the Iron Age or even in the 20th century (Brochier et al., 1992; Acovitsioti-Hameau et al., 1988). The most common stablished consensus is that this sites and deposits are the result of stabling domestic caprines (sheep and goat), which is why they are generally known as sheepfold caves. However, there is also some evidence where cattle or pig stabling seems to be also or more important (Alcalde et al., 2002; Bonsall et al., 2009; Vega-Maeso et al., 2016).

The main defining feature of sheepfold caves is the specific sedimentary deposits known by the french term *fumier*. They consist of an accumulation of layers of burnt and unburnt dung giving rise to a characteristic sequence of sub-horizontal layers of ashes, coals and clay-like sediment without thermal alteration (Brochier, 1991; Courty et al., 1991; Angelucci et al., 2009). They also have abrupt terminations and frequent lateral changes (Angelucci et al., 2009; Friesem, 2016). Dung accumulated during the occupation of these caves by livestock and its

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volume depended on both the length of time they were housed and the size of the herds. The burning of these deposits was carried out with the aim of removing the parasites associated with the dung and the livestock and reducing the volume of dung (Acovitsioti-Hameau et al., 1988; Vergès et al., 2016).

The study of these deposits and their dung sequences has been carried out using different methods, from micromorphology to isotopy and DNA analysis or archaeobothanical approaches (Shahack-Gross, 2011; Lancelotti and Madella, 2012). From a micromorphological point of view, the *fumiers* are characterised, among others, by the presence of livestock excrements, mainly from sheep and goats (Brochier et al., 1992; Shahack-Gross et al., 2005; Lancelotti and Madella, 2012). In addition, recent biochemical studies of these deposits have determined the presence deposits of hormones and bile acids attributable to the stabling of pregnant females (Vallejo et al., 2022). Sheepfold deposits are also characterised by a significant number of burned plant remains (seed or charcoal) and micro-rests (phytoliths), related to the different activities carried out in these spaces, both domestic and those related to the feeding of the flock, the preparation of their bedding, or the accumulation of fuel used for burning the dung (Argant et al., 1991; Bergadà, 1997; Thiébault, 2005; Polo-Díaz and Fernández, 2010; Euba et al., 2016). Further, other elements add light to identify the use and function of these sites. In some sheepfold caves, walls related to livestock housing, milk extraction or milk processing are documented (Brochier et al., 1992; Acovitsioti-Hameau et al., 1988). Also, cave and rockshelter walls show sometimes a certain degree of polishing at the level of the floor where the livestock were housed, caused by the friction of the wool and skin of the animals (Brochier et al., 1992; Vergès and Morales, 2016).

The study of animal remains has provided also an important and complementary way to investigate sheepfold caves. Faunal assemblages recovered in these sites are characterised by a clear predominance of domestic species, in particular, of caprines. Indeed, zooarchaeological studies provided the main source of data to characterize the use of sheepfolds. Among others, these studies added fundamental data about herding strategies and domestic activities carried out in them by the herders. Although they are not dwelling areas per se, they also provide information on the domestic activities of the shepherds since they use the sheepfold as a waste disposal area.

These faunal assemblages present an optimal degree of preservation due to the rapid sedimentation rate of the deposits (Angelucci et al., 2009) that allow for high-resolution analyses. In the *fumier*, unlike other types of deposits, low density skeletal elements are preserved, such as those belonging to fetal or neonatal individuals (Martín et al., 2016; Boschin, 2020a), providing comprehensive age-at-death profiles. In addition, the remains offer an optimal degree of collagen preservation, which allows for chemical analysis (Del Valle et al., 2022).

By their very definition, faunal assemblages from sheepfold caves offer an unique framework for the study of processes like the beginning of livestock farming practices in prehistoric Europe. This paper sum up the potential and possibilities of the study of these sites to the study of past livestock practises, considering the most successful and appropriate approaches developed in zooarchaeology during the last years.

2. Animal remains as a source of information for the study of husbandry

The study of herd management strategies in prehistoric times has been carried out through different approaches, including the determination of the species that made up the herds and the reconstruction of their mortality profiles. The shepherds set in motion a series of mechanisms that try to optimize the obtaining of resources and the maintenance of the herds. To do this, they make a series of decisions related to the species that make up the herd and the percentage that each species represents in the herd, the age at which the animals are slaughtered, the season in which they are born and the food they are fed.

As in other types of domestic contexts, the faunal assemblages recovered in the sheepfold caves usually present a high degree of fracturing that hinders the taxonomic, anatomical and sex identification of the remains using means traditional criteria (non-proteomic). This is important in sheepfold caves where caprines are predominant in archaeozoological assemblages (Fig. 2). Sheep/goat fragmented remains (including teeth) are sometimes unidentifiable at the species level even enormous efforts are done by zooarchaeologist (Halstead and Collins, 2002; Balasse and Ambrose, 2005; Zeder and Pilaar, 2010). Diagnostic qualitative traits are not unique to each species (Zeder and Lapham, 2010). In addition, bone and dental criteria present a number of limits to be taken into consideration (Zeder and Pilaar, 2010). In recent years, the use of morphometrics (Salvagno and Albarella, 2017) and especially 2D or 3D geometric morphometrics (Haruda, 2017; Colominas et al., 2019; Jeanjean et al., 2022) has been incorporated. These works are mainly

Fig. 1. Map of location of the sites mentioned in the text. Abbreviations: EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic), Ch (Chalcolithic), Br (Bronze Age), Iron (Iron Age). List of sites: 1. Grotta Azzurra (Samatorza, Italy) (LN) (Boschian and Montagnari-Kokelj, 2000); 2. Grotta dell'Edera (Trieste Karst, Italy) (MN) (Boschin, 2020b); 3. Pupićina (Vela Draga Canyon, Croatia) (Miracle and Forenbaher, 2005) (MN); 4. Grotta dei Piccioni (Bolognano, Italy) (EN) (Iaconis and Boschian, 2007); 5. Grota Sant'Angelo (Montagna dei Fiori, Italy) (EN, Ch, Br) (Iaconis and Boschian, 2007); 6. Grotte Gardon (Ambérieu-en-Bugey, France) (MN) (Perrin et al., 2002); 7. Grande Rivoire (Isère, France) (EN) (Delhon et al., 2008); 8. Trou Arnaud (Saint Nazaire-le-Désert (France) (MN) (Brochier et al., 1999); 9. Arene Candide (Finale Ligure, Italy) (EN, MN) (Rowley-Conwy, 1991); 10. Abric de la Falguera (Alcoi, Spain) (LN, Ch) (Puchol and Aura, 2006); 11. Cova de les Cendres (Teulada-Moraira, Spain) (MN, LN, Ch, Br) (Bernabeu and Molina, 2009); 12. Cova Colomera (Sant Esteve de la Sarga, Spain) (EN) (Oms et al., 2013); 13. La Castañera (Obregón, Spain) (Ch) (Vega-Maeso et al., 2016); 14. Los Husos (Elvillar, Spain) (LN, Br) (Fernández-Eraso, 2010), 15. Cova d'en Pardo (Planes, Spain) (EN) (Soler et al., 2013); 16. Cova de Petrolí (Cabanes, Spain) (Br) (Aguilella i Arzo, 2003); 17. El Portalón (Ibeas de Juarros, Spain) (Ch, Br) (Carretero et al., 2008); 18. El Mirador (EN, MN, LN, Br) (Ibeas de Juarros, Spain) (Allué et al., 2022); 19. Font Juvénal (Conques-sur-Orbiel, France) (MN, LN) (Brochier, 1990); 20. Cova de Sa Tossa Alta (Escorca, Spain) (Br/Iron) (Valenzuela et al., 2010).

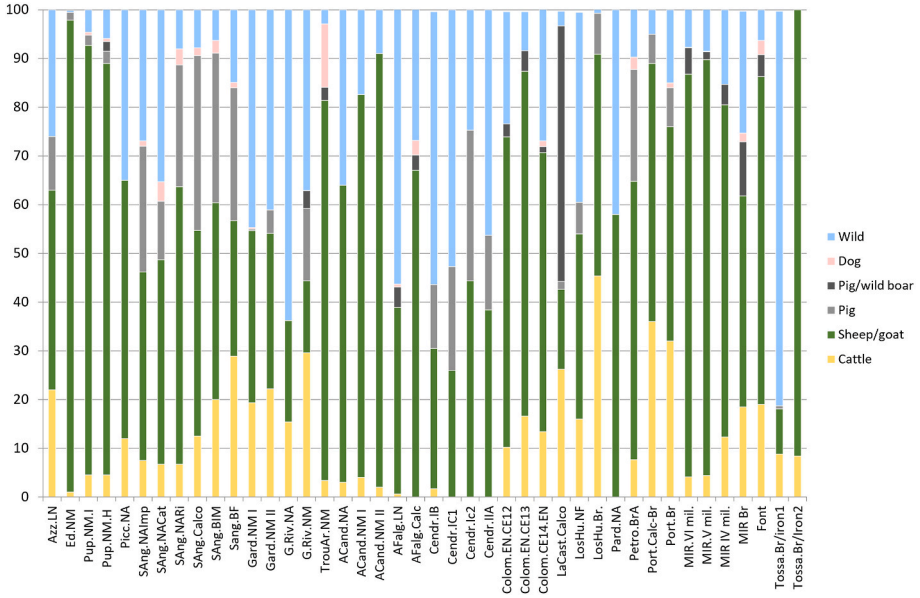

Fig. 2. Percentage of the identified number of specimens (%NISP) distributed by taxa, sites and chronologies. Abbreviations: Grotta Azzurra (Azz) (Rowley-Conwy et al., 2013); Grotta dell'Edera (Ed) (Boschin, 2020b); Pupićina (Pup) (Miracle and Pugsley, 2006); Grotta dei Piccioni (Picc) (Wilkens, 1987); Grotta Sant'Angelo (SAng) (Iaconis and Boschian, 2007); Grotte Gardon (Gard) (Chiquet, 2013); Grande Rivoire (G.Riv) (Nicod and Picavet, 2009); Trou Arnaud (TrouAr) (Blaise et al., 2009); Arene Candide (ACand) (Rowley-Conwy, 1991 & 2000); Abric de la Falguera (AFalg) (Puchol and Aura, 2006); Cova de les Cendres (Cendr) (Bernabeu and Molina, 2009); Cova Colomera (Colom) (Martín and Oms, 2021); La Castañera (LaCast) (Vega-Maeso et al., 2016); Los Husos (LosHu) (Altuna, 1980); Cova d'en Pardo (Pard) (Soler et al., 2013); Cova de Petrolí (Petro) (Aguilella i Arzo, 2003); El Portalón (Port) (Galindo-Pellicena, 2014); El Mirador (MIR) (Martín et al., 2022); Cova de Sa Tossa Alta (Tossa) (Valenzuela et al., 2010).

focused on astragali, although they have also been carried out on mandibles and teeth, because they are compact elements, with good preservation in archaeological assemblages, and little variability according to sex or nutritional status. Today, peptide mass fingerprinting (PMF) offered a new and fundamental way to confirm taxonomical identification (Buckley et al., 2009). Using a Matrix-Assisted Laser Desorption/Ionization coupled to a time of flight mass spectrometry (MALDI-ToF-MS) this technique fingerprints the differences between collagen sequences by detecting changes in the masses of the constituent amino acids (Buckley and Kansa, 2011).

The determination of age at death is fundamental to obtain information on herd management and utilization. The methodology used for age-at-death determination is also varied (e.g. Hillson, 2005; Gifford--Gonzalez, 2018). The more traditional methods, based on dental eruption and wear and on bone fusion sequences of the different domestic taxa, have been questioned and revised in recent years (Zeder, 2006; Lemoine et al., 2014; Zeder et al., 2015). However, they are still the most widely used as they are easily applicable methods and, unlike others, such as histological analyses, do not involve the destruction of the specimen. Nowadays, new proposals propose the possibility of determining the season of death from isotopic analyses, and in an explorative way, for sheep specimens, although its application is for the moment restricted.

The birth of ungulates defines the time at which a herd can give milk, since lactation periods are after parturition. Without human intervention, animals tend to regulate births at optimal periods for both mother and offspring and, in the case of higher mammals, at a single time of the year, which implies that there are parts of the calendar when there can be no milk consumption by human groups. This is one of the reasons why a herder might want to control the reproduction of his or her herds: to stagger the births of animals by controlling mating times in order to extend the lactation period, but also to regulate the availability of new births for meat or labor management purposes.

If environmental and animal physiology variables permit, the period can be extended to create several mating seasons, usually in autumn and summer, or different births throughout the year (Balasse et al., 2003). So the study of seasonality, season or timing and duration of births gives a key and very precise look at the structure of the economy and the strategies that pastoralists employed in the past with their herds.

Without studying the dietary patterns of domestic animals, it is not possible to understand the livestock strategies that pastoral societies employed in the past, since they allow us to understand how human groups interacted with the environment and coexisted with agricultural and livestock cycles. The most common isotopic compositions used to elucidate aspects related to food are $\delta^{13}C$ and $\delta^{15}N$. Isotopic signatures directly measured from faunal remains will vary according to the species or individual needs of each animal, as well as the level of control that the herders carried out on the livestock and the feeding strategy implemented.

Some pathologies can offer information about the condition of herds stabling. Animals living confined to enclosures can develop mesoscopic lesions in the ankle bone. Specifically, this pathology was observed in some adult and juvenile sheep from early Neolithic sites of Anatolia (Zimmermann et al., 2018). Biomechanical studies are also a good source of information for the study of stabling conditions and herd management. These studies make it possible to analyze the biomechanical stress suffered by the animals and to draw inferences about the mobility and efforts made by the herds, derived from their exploitation (Alcàntara, 2019).

3. Discussion

3.1. Sheepfold caves as seasonal or permanent breeding areas

In archaeology, determining the dynamics and rhythm of occupation of settlements is very useful information for understanding the organisational system of past communities. The occupations of shepfold caves usually are the result of a repeated and very intense use of the same space; however, this systematised use can be the product of a permanent or sporadic dynamic over time, also of a seasonal nature. One fact that may help to explain the temporal nature of the occupation is the function of the sheepfold cave as a place for giving birth.

The timing of birth is fundamental key aspect in herd management, even more so in extensive livestock systems. As herds and herders are mobile by nature, and in order not to exhaust food resources in one place, it is necessary to plan the timing of birth to the community's organisational system (i.e. movement, availability of resources, socialisation, among others). For this purpose, the sheepfold caves are exceptional areas for activities related to the birth and rearing of the newborns. The sheepfold caves allow a very intense control of the pregnant females, for example, their detailed maintenance, supplying the needs of mother and newborn in terms of protection and control of their feeding, among other tasks.

Synchronising the birth of the livestock is a pastoral strategy that

optimises resources, reduces risks and makes it easier to combine different tasks. In this scenario, the duration of births is short (several weeks to a few months) and may or may not lead to the deseasonalization of births. On the other hand, the timing of new births at different times of the annual cycle can lead to increased workload, risk and difficulty in combining their care with other livestock or other tasks. However, the continuous distribution of births throughout the year means that different animal products such as milk or meat from infant animals are available at different times of the year rather than at a single time of the year. In this case, this practice necessarily entails the deseasonalisation of the animals' natural reproductive rhythms (Tornero, 2011). This last factor implies introducing modifications in the dynamics of the mating of the animals, but also in their behaviour, feeding and selection of individuals.

In recent years, work has been carried out on a methodology that allows us to infer the season and seasonality of births in domestic caprines, especially sheep, from stable isotope analysis. The sequences of oxygen measurements obtained along the dental crown allow us to recognise similar or unequal seasonal patterns of birth among different individuals. From the use of current individuals with known date of birth it is also possible to infer the approximate season (i.e. month) of birth (Balasse et al., 2012; Tornero et al., 2013, 2016; Hadjikoumis et al., 2019). A seasonal use of the sheepfold as a lambing area should be represented by synchronised births, regardless of the exact time of the year. In contrast, a permanent or long-term use of the sheepfold as a lambing area should show births at various times of the year. To date, this type of approximation has only been carried out for the El Mirador cave (Atapuerca, Burgos) (Martín et al., 2021), showing a majority of sheep births during the Early Neolithic levels occurring during a short period of the year, between late winter and early spring, while the existence of births (two) outside this period, in mid-spring and even mid-autumn.

The possibilities of this type of study are yet to be developed. Although it is also important to remember that the possibility of modifying seasonal birth rhythms is closely associated with the development of livestock husbandry techniques and their capacity for implementation throughout history. This was probably more difficult to achieve at the beginning of the Neolithic and easiest as human groups became more experienced in their livestock management (Balasse et al., 2017). But then there are the physiological particularities and adaptive capacities of each species to be modified, which in the case of sheep is a very limited factor, specially in mid and high latitudes (Hafez, 1952; Chemineau et al., 2008; Gómez-Brunet et al., 2012).

3.2. *Presence of perinatals in sheepfold assamblages*

The presence of remains of perinatal individuals (fetuses and neonates) in cave pens is usually significant compared to open air sites, especially during the Early and Middle Neolithic (Helmer et al., 2005; Miracle and Pugsley, 2006; Martín et al., 2016; Boschin, 2020a; Yeomans et al., 2021). These are mainly sheep and goat perinatals although, in some cases, remains belonging to pigs or cattle are also recorded (Miracle, 2006; Miracle and Pugsley, 2006; Martín et al., 2022). In the case of caves, perinatal percentages are variable (see Fig. 3), as are usually the percentages of abortions and perinatal deaths in present-day herds (~2–50%) (see Payne, 1973; Redding, 1981; Cribb, 1987). In any case, in the sheepfold caves these percentages are significant taking into account the high fragility of these remains, makind their preservation difficult. Precisely, perhaps due to these low preservation rates, specific studies of this age group are still scarce in general, in archaeological sites.

However, these are remains that offer high-resolution information, as the qualitative and metric methods used to identify this age group are less influenced by conditioning factors, e.g., environmental, breed or nutritional factors, that do affect postnatals individuals (Hammond, 1940; Everitt, 1968; Ahmed, 2008; Suguna et al., 2008).

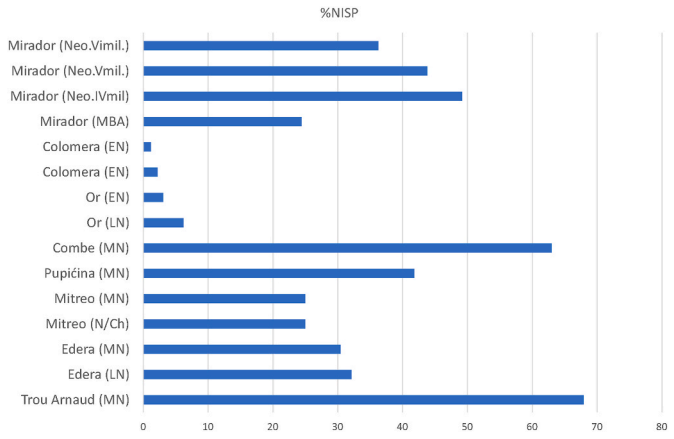

Fig. 3. %NISP of domestic caprines perinatals from sheepfold caves.

Although with exceptions, these individuals often appear scattered at *fumier* levels with no anatomical connection, along with other age classes and taxa, and sometimes show evidence of having been consumed (Helmer et al., 2005; Miracle, 2006; Miracle and Pugsley, 2006; Martín et al., 2016). These characteristics allow us to rule out a possible ritual sense of these animals, as observed in other contexts, and to relate them directly to livestock activity and the occupation of the sheepfold, and specifically, to the use of these spaces as breeding areas. The separation of pregnant females and their offspring from the rest of the herd, or at least of the breeding males, in specific pens or in specific areas of a corral, is a common practice of shepherds in order to provide them with greater attention (Rodríguez, 2001; Violant i Simorra, 2001). In the case of the prehistoric sheepfold caves, it is difficult to determine whether this division of the herds is taking place, since most of them have not been excavated to any great extent, so the information that would be provided by the spatial distribution of the remains is not available. However, recent biomarker analysis confirms the approaches made with the zooarchaeological studies and certifies the stabling of pregnant females in these spaces (Vallejo et al., 2022; in this volume).

The sheepfold caves thus became a refuge for the most sensitive part of the herd, such as the pregnant females and their young, which are very susceptible to low temperatures, high humidity and the threat of small and medium-sized carnivores (McCance, 1962). Although the term "cave" is generally used to designate these cavities, in many cases, they are large shelters or caves with a large space at the entrance that allows shelter for the animals but also access to sunlight, which favors good conditions for maintaining these members of the herd. Greek shepherds also used this type of corrals to separate the newborns and prevent them from accessing the pastures before their slaughter, since they provide the best rennet for making cheese (personal communication of Andreas Kapetanios cited by Miracle and Pugsley, 2006).

The low percentages of perinatals in open-air sites have led some authors to propose an exclusive use of sheepfold caves as breeding sites (Helmer et al., 2005; Bréhard et al., 2010). However, we must take into account the possible factor of differential conservation that may be affecting the open-air remains. What is certain is that, as we have already mentioned, the faunal assemblages from the sheepfold caves present an optimal state of preservation, both from a macroscopic and diagenetic point of view (Miracle and Pugsley, 2006; Del Valle et al., 2022). It would also be necessary to take into consideration the presence/absence of other domestic taxa in the sheepfold caves, in order to elucidate whether this is really a specialization or a priority but not exclusive use as a nursery.

Another noteworthy point of the abundance of perinatal individuals is that it makes the sheepfold caves optimal sites to study the management of this period so important for the survival of the herds, such as the prenatal stage. However, as we have already mentioned, specific studies

are scarce (Martín et al., 2016; Boschin, 2020a). Moreover, the causes of mortality in these animals are difficult to establish and they have been attributed to both human decisions and natural causes (Helmer et al., 2005; Mlekuž, 2005; Miracle, 2006; Boschin, 2020a; Pöllath et al., 2021). As mentioned above, the presence of evidence of processing consumption of neonatal individuals could be evidence of intentional culling for consumption of tender meat or milk utilization (Miracle and Pugsley, 2006). However, milk utilization does not necessarily entail the slaughter of the offspring and is a very risky decision for the maintenance of the herd. In many traditional cultures, the slaughter of these animals is reserved for special occasions. Neonatal death from natural causes cannot be ruled out and is common even in modern herds, associated with episodes of cold or humidity, attacks by other animals or a state of malnutrition of the pregnant mother resulting in the birth of a very weak calf, among other factors (e.g., McCance, 1962; Blaxter, 1964; García-González, 1979; Cambero, 1997; Represa, 1998).

Although processing and consumption marks are also present in fetal individuals (Miracle and Pugsley, 2006; Martín et al., 2016), these seem to be punctual episodes and related to an optimization of flock utilization. The intentional slaughter of pregnant sheep is more typical of more modern societies and/or with a cultural sense, such as the use, at present, of the skins of the Karakul sheep. In household exploitations, such as prehistoric ones, this type of practice can endanger the survival of the flock (Halstead, 1996) and they exploit (and hunt) many other taxa that can offer considerably more meat.

Considering that it is unlikely that these deaths are due to intentional culling, the natural causes that can lead to abortion of pregnant ewes are also very variable and similar to those just mentioned, which cause neonatal deaths, e.g., infectious diseases, physical or nutritional stress, adverse climatic conditions, carnivore attacks, or a combination of them. Since these caves are used as breeding caves, among the infectious diseases, brucellosis, which is excreted through the vaginal tract of females during abortions and births, could be highlighted (European commission Scientific Committee on Animal Health and Animal Welfare, 2021). Although the first evidence of human infection (in producing communities) with brucellosis is documented in the Bronze Age (D'Anastasio et al., 2011), recent modeling proposes an expansion of infection, much earlier, in the Early Neolithic (Fournié et al., 2017).

Some authors have also linked the abortions to aninexperience of the herders (Buitenhuis, 1997). In any case, this use of the sheepfold caves as lambing areas is confirming a clear interest by the shepherds to offer special attention to the females and their offspring and an organization of the pens with this intention. This fact would most probably be related to the fact that these shepherds consider this period of the reproductive cycle to be fundamental for the survival of the flock, so it seems difficult to think that they are inexperienced shepherds.

Along the same lines, the burning of the dung that gives rise to the characteristic *fumiers* of the sheepfold caves was carried out, among other aspects, for the elimination of parasites (Angelucci et al., 2009), also showing a clear knowledge of the herds and the problems they can pose, on the part of these shepherds.

3.3. Mobility and feeding habits: an open (seasonal) debate

Sheepfold caves are usually presented as sites of frequentation, usually of short duration and seasonal character (Miracle and Pugsley, 2006; Bréhard et al., 2010; Chiquet, 2013; Martín and Oms, 2021). Furthermore, the possible specialization of sheepfold caves as breeding sites has raised a debate on a possible functional complementarity between sheepfold caves and open-air sites, associated in turn with mountain and plain occupations, respectively (Boschian and Montagnari-Kolej, 2000; Antolín et al., 2018). Traditionally, occupation in these caves was considered to be, in addition to specialized in breeding, short and seasonal in nature, in contrast to the stable occupations of open-air sites (Helmer et al., 2005; Bréhard et al., 2010; Miracle and Pugsley, 2006). The former focused their study on the Chassey Neolithic (~4250 cal BCE) of the Pre-Alps area, with sheepfold caves located at more than 1000 m a.sl. They base their hypothesis on mortality profiles and sheep and goat exploitation, which these authors consider complementary. Those of the caves present, as we have mentioned, high percentages (>60%) of mortality of perinatal or very young individuals (classes A-B of Payne) (interpreted as dairy farms), while the mortality of the open-air sites shows a double mortality peak, in individuals located in the optimal weight and old individuals.

Another regional case study, are the Middle Neolithic (associated to Danilo/Vlaška pottery) occupations (5600-4600 cal BCE) in the sheepfold caves of the Trieste Karst and Istria, located at lower altitude above sea level (~340 m asl) (Mlekuž, 2005; Miracle and Pugsley, 2006; Bonsall et al., 2009). Different studies also based on eruption and tooth wear criteria, propose a seasonal occupation of the caves, forming part of a seasonal herd mobility system (Miracle and Pugsley, 2006) or integrated into a nomadic type organization (Mlekuž, 2005).

Without questioning these interpretative models, we consider that in addition to purely zooarchaeological information, other factors that condition the livestock practices of a group should also be taken into consideration. These include: i) the size of the caves (and therefore the potential area of the pen); ii) the location of the caves (the height above sea level ranges from about 300 m to more than 1000 m asl), the characteristics of the territory (more or less rugged), the proximity to natural resources such as pastures or water sources; iii) the economic characteristics of the group, whether they are exclusive herders or also farmers; iv) the importance of hunting. All these factors are decisive for a shepherd in determining the size of his flock, selecting a fold and deciding the length of his stay in it. Thus, based on some of these criteria, there are several caves that have been presented as livestock or agro-livestock occupations of prolonged occupation or with both short and prolonged occupations, such as El Mirador, Grotte Gardon or Combe Obscure (Perrin et al., 2002; Blaise, 2005; Helmer et al., 2005; Sierra--Sainz et al., 2019; Martín et al., 2021).

Beyond these dual models, it is worth considering possible intermediate forms of occupation. Thus, in the Triestine karst, both during Prehistory and historic periods, the caves were used for overnight stays when the pastures were too far from the villages. They are used during hot hours and during bad weather. This use is not related to movements over long distances (Mlekuž, 2005).

On the other hand, it should be noted that, for the moment, practically all the studies cited above base their analysis of the occupation of the sites on the data provided by the determination of the age of death (always goats and sheep) based on dental and bone criteria, and assuming 'natural' seasons of birth for investigated individuals. However, isotopic sequential analyses on dental enamel and dental wear are providing high-resolution information on the seasonality of birth of flocks (e.g., Balasse et al., 2003, 2012, 2017; Tornero et al., 2013). These studies are demonstrating the important degree of control that shepherds had over the reproductive cycle of their herds, achieving the deseasonalization of herds as early as the Early Neolithic in both Eastern and Western Mediterranean (Tornero et al., 2016, 2020). According to the conclusions drawn from these studies, it is difficult to extract information on the season of occupation of the sites based only on mortality profiles and the criteria of natural season of the herds because de-seasonality of birth and presence of systematic autumnal births, also present in sheep herds, is already present since prehistoric times (Tornero et al., 2020). This data makes difficult the estimation of the season of death in investigated specimens only considering information from wear stages of teeth.

The application of these studies in sheepfold caves is still incipient. For the time being, studies of the El Mirador herd cave have been published (Martín et al., 2021). The combination of mortality profiles, obtained through bone and dental criteria, together with isotopic analyses ($\delta^{13}C$ and $\delta^{18}O$) of sheep tooth enamel from several levels of the ancient Neolithic allow us to propose a possible use of the cave that was very stable throughout all or practically all of the annual cycle.

The duration of the occupations of these sheepfold caves is directly related, as we have already mentioned, to the feeding needs of the herds. The strategies that have been developed over time to provide food for the flocks are very varied and may involve both their mobility and their continued stay in the same territory. Sheep and, especially, goats, can quickly exhaust the plant resources of a territory, especially if the flocks have a certain volume. This often makes it necessary to rotate herds over short, medium or long distances. Another factor that conditions this mobility is the environmental and climatic characteristics of the surroundings of pens. The pastures of the Mediterranean region, where most of the sheepfold caves are concentrated (Angelucci et al., 2009), present a highly seasonal growth with two moments of scarcity, one more marked in summer and the other shorter in winter, which forces the shepherds to look for alternatives for feeding the herds. One of the most common cases is the search for new pastures located at higher altitudes and with wetter summers in order to feed the herds. The practice of a mixed farming economy, agriculture and husbandry, sometimes also forces herders to look for summer pastures even when they are available in the environment, in order to move herds away from crops (Forenbaher, 2011). Similarly, also in times of scarcity, especially in winter, it is a common practice among Mediterranean pastoralists to use arboreal forage to feed or supplement herd feeding (Zapata et al., 2003; Papanastasis et al., 2008).

The analysis of this practice in prehistoric times has been approached mainly by archaeobotanical disciplines, in different types of sites in general and in the sheepfold caves in particular, where archaeobotanical records are especially abundant. These studies, have proposed the use of leaf fodder for herd feeding since the Early Neolithic (Thiébault, 2005; Delhon et al., 2008; Allué et al., 2009; Battentier et al., 2016).

However, in recent years, the study of herd diet is also being addressed through the analysis of animal remains. Dental wear studies have proven to be a useful tool for determining the type of animal feeding from the fossil record. Studies with herbivorous animals and species with hypsodont dentitions allow us to infer not only long-term feeding patterns (meso-wear; see Solounias and Semprebon, 2002; Semprebon et al., 2004) but also high temporal resolution, e.g. seasonal (micro-wear; see Fortelius and Solounias, 2000; Mihlbachler et al., 2011). The number of studies carried out using this approach on domestic populations and caprines in particular is not yet very high due to the added complexity of livestock feeding systems, but specific studies with herds under control and in the Mediterranean area seem promising (Gallego, 2020). In this sense, the study of Sierra Sainz et at., (2021) and caprine dental remains recovered on the *fumier* Neolithic level 1b of Cueva de Chaves (Huesca, Spain) shows that the animals grazed in open, non-wooded areas, but it is not possible to elucidate the use of forage.

3.4. Use and composition of past herds

Mortality patterns from faunal assemblages of herd caves are very varied and, on many occasions, there is no consensus when interpreting them from an economic point of view of herd exploitation. As it was mentioned, the abundance of neonatal ovicaprines in some of these caves has been interpreted in some cases as an intentional culling intended to use the milk of the females, as in the case of Pupicina, Mitreo, Zingari or Vela Cave (Miracle, 2006; Radović et al., 2008). Recent studies have confirmed dairying in nearby Dalmatian coast sites, starting from 5700 BCE (McClure et al., 2018). In other occupations, such as that of Arene Candide, with a greater importance of juvenile individuals (Payne's classes B and C), they are interpreted as a meat-oriented exploitation (Rowley-Conwy, 2000). Mortality patterns of Edera resemble the theoretical model of milk exploitation and or natural mortality (Boschin, 2020a, 2020b).

Helmer et al. (2005) suggest an economic complementarity between the French caves and the open-air sites, considering the caves as production sites, based on the abundance of young individuals less than 6 months old (Payne's classes A and B), most probably also related to a dairy farm. These authors warn about the low viability of the herds with these mortality profiles and propose the possibility that a separation of the herds by sex and age is being practiced, returning to the aforementioned approach of an exclusive use of these caves as breeding areas.

In general, a call for reflection should be made on the interpretation of mortality profiles when perinatals are involved (Martín et al., 2016; Boschin, 2020a). The equifinality presented by these mortality profiles (Halstead, 1998) can lead to erroneous herd exploitation interpretations. As we have already mentioned, in many sites a detailed study of perinatal individuals is not carried out and no distinction is made between fetal individuals at term and neonatal individuals, which can introduce a lot of noise in these mortality profiles and their interpretation. Another major handicap when interpreting these mortality profiles is the scarce (or non-existent) information available on the sex of the animals. Thus, for example, it would be of great importance to have information on the sex of neonatal individuals. A mortality curve centered on males could be indicative of intentional culling for meat (Payne, 1973).

These limitations in interpretation are even more pronounced in the case of cattle and pigs as they are represented by a smaller number of remains. The few published mortality profiles of bovines are related to a use for labor, meat and milk. While the swine were slaughtered at an early stage, to take advantage of their meat (Miracle and Pugsley, 2006; Martín, 2015). Data provided by other disciplines are scarce. During the Chalcolithic and Early Bronze Age, the diet of humans buried in the El Mirador cave was low abrasive which could be related to the consumption of meat and other animal products as well as the consumption of processed plant products (e.g., in the form of flours) (Hernando et al., 2022). On the other hand, the use of milk has been identified in the corral levels (pre-Bell Baker) of the El Portalón cave (Sierra de Atapuerca, Burgos), through the analysis of ceramic residues (Francés-Negro et al., 2021).

Brochier (1991) called as "sheepfold-habitat" those caves where domestic activities were also developed (e.g., Miracle and Pugsley, 2006; Bonsall et al., 2009; Martín, 2015) providing information on the daily life and diet of the herders. As we have mentioned, the faunal remains of practically all taxa appear with a high degree of fragmentation, scattered and with evidence of processing (cut marks, evidence of fracturing, cooking) and/or consumption (human bites), the few anatomical connections that appear are of elements with a low meat content, such as, for example, the distal parts of the legs. This would imply that the shepherds would have carried out activities related to their feeding inside or in the vicinity of these sheepfold caves. Ethnographic evidence shows how some modern herders sleep with their herds, even inside the same caves that are used as sheepfolds (Solecki, 1979; personal communication of Forenbaher cited by Miracle and Pugsley, 2006). Occasionally, this overnight stay is done to remain close to the herd during the calving season.

The fact that the faunal remains reflect the animals consumed by the herders also provides information on their diet. The skeletal remains show clear evidence of processing and consumption of these carcasses, such as cut marks, fracture marks or bites. Both domestic and some of the wild species, herbivores and some carnivores (Miracle and Pugsley, 2006; Martín et al., 2014), present this type of taphonomic alterations. Hunting would have become a good resource to reduce the slaughter of domestic animals for animal protein.

The development of domestic activities in these caves may have been made possible both by a possible division of the spaces and by the periodic cleaning of the spaces that took place in these caves. The division of the spaces is difficult to document considering that, as already mentioned, a good part of the sheepfold caves have not been excavated in extension. The periodic burning of the accumulated dung served not only to reduce its volume (so that the cave could be reoccupied later) but also to sanitize it and eliminate parasites. The few paleoparasitology studies carried out show that these burnings were effective in eliminating a significant portion of the parasites associated with the dung

(Burguet-Coca et al., 2022). These data indicate a certain concern on the part of the shepherds to maintain the healthiness of these spaces, most probably in favor of both the livestock and the domestic activities carried out in these caves and/or their surroundings.

The movements of the herds must have been a fundamental aspect in the annual cycle of those shepherds who were forced to accompany their herds. According to ethnographic information that these displacements could be led by part (a few shepherds) or by the whole group (Miralles and Tutusaus, 2005; Forenbaher, 2011). From an archaeological point of view, it is the sheepfold caves that can provide the best information on this aspect of prehistoric herders' lives. Caves occupied seasonally and for short periods are usually associated with smaller faunal and material culture assemblages (e.g., ceramics and lithic tools). This evidence suggests that these caves could have been occupied by a small group of shepherds accompanying the herds in their movements (Martín and Oms, 2021). These groups carry with them the basic daily belongings and spend little time in these caves, which would explain the small volume of remains generated in these sites. As we have mentioned, these movements could involve long or short distance movements (Mlekuž, 2005).

On the contrary, in those occupations that are more stable and long-lasting, the archaeological assemblages present a higher volume of faunal remains and materials that could be related both to the duration of the occupation itself and to the size of the group of shepherds accompanying the herds (Perrin et al., 2002; Martín et al., 2022). These occupations usually also show evidence of agricultural practice, so it would not be surprising if they were related to complete family groups that lived, if not directly in the cave, then in its immediate vicinity. Overall, these described occupation models reflect a complex organization of groups and pastoral life adapted to the needs of the herds.

4. Balance and future research horizons

Sheepfold caves are archaeological contexts with a high temporal resolution, rare in other archaeological records, and they are also very identifiable thanks to the *fumier* sequences. By their very definition, they are also a high-resolution context for the study of prehistoric husbandry in the Mediterranean area and faunal samples, recovered in these sites and generated by herders activities, were one of the main resources to reconstruct them.

Zooarchaeological studies confirm that these sites were mainly used for sheep and goats stabling and that the management of the herds was adapted to the characteristics of the territory and the needs of each human groups. Herders occupied the sheepfold caves for both short and long periods of time and herds were used for meat and milk. The results obtained through the application of new methodologies such as isotopy and tooth wear are promising but are still at a very early stage. An early deseasonalization of births has been documented in addition to a possible use of fodder, although, for the moment, no herd movements have been documented, at least, over long distances. The implementation of these new methodologies is essential to deepen the study of herd feeding and reproduction strategies. On the other hand, there is still much to be done with other approaches that have not yet been applied to sheepfold assemblages, such as proteomics, paleopathology biomechanical or geometric morphometrics. These techniques would make it possible to identify the specific configuration of herds with a higher resolution than that provided by traditional methods. However, the application, especially of geometric morphometrics, can be complex due to the limits presented by these faunal assemblages because their high degree of breakage, resulting from human activities and livestock trampling.

Caves specialized in the stabling of species other than sheep and goats are still largely unknown. It would be very interesting to publish systematic zooarchaeological studies that would shed light on the management of these livestock and allow comparison with the sheepfold caves.

Despite the excellent resolution of the *fumier* sequences, there are still many doubts about their formation process (time of manure burning, characteristics of the burning, etc.). Therefore, it is necessary to continue with experiments that help to understand this process and the one that led to the accumulation of archaeological remains, such as faunal remains.

Author contributions

Patricia Martín: Conceptualization, Writing-Original draft preparation, Reviewing and Editing. Carlos Tornero: Conceptualiztion, Writing, Reviewing and Editing.

Data availability

All necessary data is included in the manuscript.

Declaration of competing interest

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

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