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Skeleton decay of *Cervus elaphus hispanicus* carcasses in Mediterranean ecosystems: biostratinomy at Sierra Norte of Seville natural park (SW Spain)

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Abstract Taphonomic studies of faunal assemblages from archaeological and palaeontological sites need biostratinomy research to endorse their results. Many papers have studied the relationship between the differential conservation of anatomical parts and the animal responsible for the deposits. In this paper, we present the biostratinomy results from 18 *Cervus elaphus hispanicus* carcasses (Hilzheimer 1909) in a Mediterranean ecosystem (the Sierra Norte Mountains in Seville Natural Park). We also describe the skeleton decay related to scavenger community, where *Sus scrofa* (Linnaeus, 1758) is maybe the most important bone scavenger in our study area. These results of this research were compared to those obtained from a similar study carried out in Doñana National Park (Huelva) and confirmed that post-mortem tendencies are similar in both ecosystems.

Keywords Biostratinomy · Mediterranean ecosystem · Taphonomy · *Cervus elaphus* · Scavengers · Anatomical parts

Introduction

The differential preservation of anatomical parts can be used as a marker of human and animal behaviour (Binford 1978; Klein 1989; Lupo 2001; Yravedra 2006; Davis 2008; Martín-Arroyo et al. 2009; Blasco et al. 2011). However, there are several diagenetic and biostratinomic factors that affect skeleton preservation in a taphocoenosis (Denys 2002; Hedges 2002). This fact could be corrected by inferring the results obtained in actualistic analyses. Thus, there is biostratinomic research on bone assemblages produced by animals (hyenas, owls, etc.) and humans building deposits as lairs, nets, rubbish dumps, etc. (Sutcliffe 1970; Andrews and Evans 1983; Domínguez-Rodrigo 1998; Mondini and Muñoz 2008; Muñoz et al. 2008; Lloveras et al. 2008a, b, 2009; Lansing et al. 2009; Montalvo and Tallade 2009). Other researchers also analyse the characteristics, preservation and dispersion of bone assemblages that do not form specific deposits (Hill 1979; Hill and Berhensmeyer 1984; Estévez and Mameli 2000; Bernaldez, 2002, 2009; Ioannidou 2003; Pasda 2005; Barceló et al. 2006; Cáceres et al. 2009; Gal 2009; Ballejo et al. 2016), the same situation that we will show in this paper.

Skeleton preservation status depends on the carcass body mass (Bernáldez et al. 2017). In fact, studies in Doñana National Park (Spain; Bernáldez 2002, 2009) and Amboseli National Park (Kenya; Behrensmeyer and Boaz 1980) show that only species with more than 50 kg of body mass are well represented in the thanatocoenosis. In an ecosystem with scavengers, bones from species with more body mass are more likely to be preserved (Western and Berhensmeyer 2009). Likewise, Bernáldez (2002, 2009, 2011) described three classes of animals in relation to the *fossil potentiality* of the carcass: Class I, carcasses over 200 kg; Class II, carcasses from 50 to 200 kg and Class III, carcasses from 5 to 50 kg. In this paper, we limit ourselves to analysing the post-mortem process of a Class II species: *Cervus elaphus hispanicus* (Hilzheimer 1909), a subspecies from the Iberian Peninsula and smaller than other *C. elaphus*. Males of this species are 2 years old, they are 90–120 cm tall and weigh 80–160 kg, while females are 90–110 cm tall and weigh 50–100 kg (Carranza 2011).

Although the analysis of the preserved anatomical parts is not sufficient to define the behaviour trends of scavengers (Domínguez-Rodrigo 1999), the objective of our work is to show the trophic preferences by bones of this species by the scavenger community and some of the skeleton preservation trends in Mediterranean ecosystems. This study is complementary to those carried out at Doñana National Park between 1989 and 1995 (Bernáldez 2002, 2009, 2011, Bernáldez et al. 2017).

Study area

The Sierra Norte Natural Park of Seville (SNS) is located in the south of the Iberian Peninsula and extend from 260 to 968 asl, specifically in the Sierra Morena Mountains (Fig. 1). It is one of the most important areas for Mediterranean flora in Spain (Menor 2008). The fauna community is one of the most diverse on the Iberian Peninsula and is composed of 300 vertebrate species (Menor 2008). Of these species, we should note three possible bone scavengers: wolves (*Canis lupus*), foxes (*Vulpes vulpes*) and wild boar (*Sus scrofa*). The influence of the two carnivores on bones is lower, in the first case because there are no individuals in our study area and in the second due to the morphology of foxes, which only can consume and transport small bones (Estévez and Mameli 2000; Pasda 2005). Therefore, the wild boar is the scavenger (Domínguez-Solera and Domínguez-Rodrigo 2009) that consumes the most bones (Bernáldez 2011; you can see this video https://www.youtube. com/watch?v=1YP48YqR5uM&t=71s).

Methodology

In the Sierra Norte Natural Park, we studied 18 *C. elaphus* carcasses with different gender, age, location and date of death characteristics (Table 1). We analysed the data from eight selected carcasses to obtain general patterns related to skeleton destruction processes because their bodies were completed at the beginning of the study. The rest of the carcass was incomplete because the hunters were cut their heads and the final parts of the limbs, and these 10 carcasses were used to compare the trends observed.

Biostratinomic studies need to describe the producer agent and the postdepositional processes in a thanatocoenosis. Vultures (*Gyps fulvus*, *Aegypius monachus*), foxes (*V. vulpes*) and wild boar are the most important scavengers in this Mediterranean ecosystem. To try and ascertain whether carcass destruction time differs between these scavengers, we moved some carcasses to places that vultures were unable to reach. It is important to note that skeletal destruction could be caused by biotic or abiotic factors (Lyman 1994). In autumn, increased water flow was responsible for moving and burying the last bones of two carcasses located in a seasonal stream (UPA2 and UPA5). However, this interference was always recorded during the last phases of skeletal destruction and did not affect the results of our research.

The samplings of each carcass were more continuous during the first months (Phases I and II, Bernáldez 2002, 2009, 2011; Bernáldez et al. 2017; Fig. 2); after this time, during Phase III, the destruction process was slower. We used the Skeleton Conservation Index (SCI) to calculate the preservation status of the skeletons at different times:

$\mathrm{SCI} = (\mathrm{NB} / (\mathrm{NS}\ x\ \mathrm{NI}) \times 100$

where NB is the number of bones observed in the carcass at each observation, NS is the number of bones that make up the skeleton of an individual and NI is the number of individuals.
This index is useful to homogenize results from skeletons and anatomical parts with different numbers of bones (Bernáldez 2011). A suid skeleton has 30% more bones than that of a red deer (269 bones in a suid skeleton and 205 in that of a red deer, Bernáldez, 2009). Also, in a whole red deer skeleton, the probability of finding axial and appendicular bones is higher than that of finding skull bones (Table 2).

Specifically, in red deer, 8.78% of all the bones are in the head, 36.10% in the axial skeleton and 55.12% in the limbs. The same difference in the skeleton preservation of these species would be found in the archaeological record if the pre and post-depositional conditions were the same. The SCI was calculated for the cranial, axial and appendicular skeleton (Schmid 1972; Barone 1999; Table 2).
On the other hand, in an attempt to quantify the preservation per bone, we used the MAU (Minimal Animal Units) defined by Binfort in 1984 (in Lyman 2008):

$\mathrm{MAU} = \mathrm{MNE}i/\text{number of times } i \text{ occurs in one skeleton}$:

$\%\mathrm{MAU} = (\mathrm{MAU} \times 100) / \text{major MAU value}$

where MNE is the minimum number of skeletal element in the sample, and i denotes a particular skeletal part. Although this index was created as an alternative to MNI, %MAU can be used as a conservation index (Ballejo et al., 2016). The basis of this index is similar to SCI, as the number of preserved bones is compared to the potential number. In similar conditions, the anatomical part composed of more bones has more probability of fossilization.

Results

General decay trends in Class II carcasses: *C. elaphus*

The results from eight selected *C. elaphus* carcasses were used to measure and define the trend described by Bernáldez (2002, 2009, 2011) during the biostratinomic phase (Fig. 3). In this case, we can distinguish the wild boar activity attending to different prints around the carcasses and some typical suid tooth marker (Fig. 4); also, we assumed that wild boar is the only scavenger that could consume big bones in our study area.

Phase I can take around 2 months (11UPA, Table 3) during the hunting period (when there is more carrion); the average for Class II carcasses is 0.5 months (Bernáldez et al. 2017). A special case is B8 UPA^, where Phase I lasted 3 months because the carcass was under water.

In Phase I, vultures only produced a small amount of skeletal destruction, while only wild boar could consume some of the bones at the same time (Fig. 5). In conclusion, in Phase I, it was possible to detect no high differences depending on the type of scavenger in which the SCI was between 95 and 99%. The skeleton decay rate was highest in Phase II (Bernáldez 2011) and took an average of 5 months from the date of death (Bernáldez et al. 2017), with our data showing a range between 0.30 to 14.77 months. The SCI values were in a range of 20.92 to 96.09%. We were also able to observe that this tendency is related to the preservation of soft tissue. Skin and tendons hold the bones together and delay the destruction of the skeleton (Bernáldez 2002, 2009) and the scattering (Hill 1979).

The bone destruction rate was lowest during Phase III and took between 4 and 41 months from the time of the animal's death; in addition, we observed 1.95% SCI of "3 NAVAS" after 42 months.

Description of the skeleton decay processes

There are several factors to interfere in the skeleton decay processes: the size of carcasses, climatic conditions, vegetable covertures, faunal community, etc. A combination of all of them produces changes in times of the cited phases and in the kind of bones that could be consumed first. Nevertheless, general trends in the scattering and skeleton decay were observed in this analysis using the data of the eight carcasses completed at the beginning of the samplings (Table 3); the rest of the data were used to check some observations. These samplings were carried on in different times, but we can unify data from the four main moments: Phase I (first 90 days), the final of Phase I (around 90–150 days of exposition), Phase II (around 300 days of exposition) and the final of Phase III.

During the first 20 days, almost the skeleton was complete, and the scavengers have eaten or moved some ribs, vertebrae and sternum plates. In some cases, all the ribs and sternum plates were consumed. There are anatomical parts joined with soft tissue. Small bones of the limbs were consumed after the second month of exposition; maybe small carnivores as red fox could be also responsible. It is interesting to highlight the carcass UPA2 because the forelimbs were consumed before 85 days of exposition. In addition, in Fig. 5, it is possible to observe the way that the scavengers have opened the carcass; in this ecosystem, only wild boar has the mandible capacity to break a carcass in this way. The maximum dispersion was checked in UPA1 where we found the skull plus atlas to 11.5 m from the point of death. In addition, we have observed that the complete carcass UPA9 was moved in three different moments during the first 60 days. These movements imply the action of wild boars because they are strong enough, and we have observed characteristic marks of pig-rooting, and the carcasses were displaced 6.5mup the slope. Also, in the areas of UPA6 and UPA7, we checked the activity of wild boars during Phase I as pig-rooting, footprints and boar path marked in the bushes.

When the time of exposition was around 90–150 days, some vertebrae and ribs could be located around the carcasses, the majority of them joined between themselves by soft tissue. In this moment, we can observe the first evidences of consumption of large bones of the extremities, but the loss of small bones was faster. There are some anatomical parts with soft tissue. The bones were almost complete, and we checked tooth marks in pelvis, scapula, epiphyses of long bones and nasal bone of skulls. The maximum dispersion area was around 20 m of ratio in UPA1.

Around 300 days of exposition, no ribs, sternum plates and sacrum were found around the carcasses. Anatomical parts with soft tissue preserved the small bones of the limbs. There were bite marks in the epiphysis of long bones and in mandibles. The maximum dispersion area observed was around 21 m in UPA4.

At the end of the sampling (423–820 days), we had only found rests of skulls, vertebrae and long bones of the limbs; not all of them were completed. Also, there were one astragalus and one phalange of UPA1 and UPA4. There are several fragments related with weathering processes. The dispersion area was around 20 m, probably due to the vegetation present in the study area.

Preservation of anatomical parts

We used two indexes to study the preservation of the different anatomical parts in red deer:

Skeletal Conservation Index. As with the above results, only the selected carcasses were used to obtain trends to compare with the rest of the individuals. We selected the Skeletal Conservation Index (SCI) values in phases II and III, when skeleton destruction is greater (Bernáldez 2002, 2009; Bernáldez et al. 2017). In both phases, the SCI of the skull (SCIskull) was higher (Table 4). The average SCIskull value in phase II was 65%, while the SCIs of the axial (SCIaxial) and appendicular skeleton (SCIappendic.) were less than 40%. Although the SCI decreased during Phase III, we also corroborated some differences between the preservation of the skull; the SCIskull is 58%, and the rest of the anatomical parts, SCIaxial and SCIappendic., were less than 20%. The same trend was observed in the rest of the carcasses, despite the fact that seven males were missing the heads due to the fact that these are frequently taken as hunting trophies.

Minimal animal units. This index was calculated with data from the same individuals during phases II and III. When SCI is around 50% (Phase II), the best preserved bones are from the limbs and skull with MAU over 80% (mandible, humerus, pelvis, tibia, astragalus and metapodial). Nevertheless, during Phase III, the long limb bones have the highest %MAU value (over 70%; femur, tibia and metacarpus). The results for the rest of the individuals at the end of the destruction process were the same, with the tibia and femora having the highest %MAU values (Table 5). In fact, after 42 months, only a femur fragment was left from the 3 NAVAS carcass.

The better preservation of skulls (looking at SCI) could be related to their morphology and scavengers' preferences. On the one hand, the skull is made up of a few bones that are very well joined, while the limbs are formed of several small bones (sesamoids, phalanges, carpals, tarsals) which are easily eaten and transported. Scavengers prefer the spongy bones because they have more fat and are brittler (Thompson and Lee-Gorishti 2007). This author was able to verify that scavenger activity decreased when the bones were boiled because they had lost fat. In the long limb bones (femur, tibia, humerus, radius), the marrow is accessed through the epiphysis. Scavengers do not need to crack the rest of the bone; for this reason, these bones are the best preserved individually or at least the diaphysis is. In Doñana, the scavengers eat the soft tissue and then the bones; the skull may be the anatomical part with the least energy balance due to that this is a compact box difficult to break, and for this reason, it is the best preserved (Bernáldez 2009).

Discussion

We only studied the skeleton preservation patterns in Class II ungulates in SNS. The most similar research was undertaken in Doñana National Park (Bernáldez 2002, 2009; 2011). The author observed the same preservation trend in Type II species at Doñana; the skull is the best preserved anatomical part by SCI and the long limb bones when studied bone to bone (MAU). Could this be a common pattern in Mediterranean ecosystems where wild boar is the main scavenger? We compare our results with other actualistic studies on ungulate carcasses in ecosystems without wild boar populations. On the Iberian Peninsula, Caceres et al. (2009) found that after 30 months, red deer carcasses preserved a large part of the skeleton, including ribs and vertebrae. In Greenland, reindeer carcasses (*Rangifer tarandus* Linnaeus, 1758) also kept their vertebrae and ribs for years (Pasda 2005) and the same is seen in Argentina (Estévez and Mameli 2000) with guanaco carcasses (*Lama guanicoe* (Müller, 1776)). In fact, in the last two of these papers, the authors described the foxholes (*Alopex lagopus* Linnaeus, 1758 in Greenland and *Lycalopex griseus* (Gray, 1837) in Argentina) where it is usual to find distal limb bones (metapodial and phalanges). Foxes are only able to move small bones or anatomical parts. This evidence could support the theory that foxes cannot be the main responsible for the skeleton destruction observed either in the Sierra Norte Mountains in Seville Natural Park or in Doñana National Park. In our biostratinomic study, every scavengers located in the study area could participate in the carcass decay, but we have deduced that wild boar is the main bone scavenger in both ecosystems (Bernáldez 2011; Bernáldez et al. 2017).

Although skeleton preservation is different in places without large scavengers that can eat big bones, in both Greenland (Pasda 2005) and southern Spain (Bernáldez 2002, 2009; Serrano et al. 2006), the skull and the long limb bones are usually the best preserved. These long bones are also the densest bones (Lam and Pearson 2004). In fact, at some archaeological sites, the MAU values were statistically correlated to the density values (Valensi and Psathi 2004; Lyman 2008). This correlation depends on scavenger consumption preferences and bone characteristics such as shape, size, cortical thickness and hardness (Kreutzer 1992; Lam and Pearson 2004).

In relation to other Iberian scavengers such as brown bear (*Ursus arctos arctos* Linnaeus 1758) and wolf (*Canis lupus* Linnaeus 1758), wild boar behaviour produce some differences and similarities in the skeleton decay evidences (Domínguez-Rodrigo et al. 2012; Yravedra et al. 2011, 2012; Sala and Arsuaga 2013: Arilla et al. 2014). The fist difference is the characteristic tooth marks that wild boars make with incisors and perforations with "L"-shape pattern due to the premolar shape probably (Domínguez-Solera and Domínguez-Rodrigo 2009). In our analysis, we have not quantified tooth markers but no tooth mark produced by wolves or dogs were identified. Nevertheless, there were boar marks in the bones, the most of them located in epiphyses of long bones, skulls, scapula and pelvis. In this way, it is interesting to note that bears rarely fragment long bones and they do not regularly use their teeth to puncture (Sala and Arsuaga 2013, Arilla et al. 2014); in contrast to wolves (Yravedra et al. 2011, 2012, Domínguez-Rodrigo et al. 2012), we have observed that suids also crack long bones (Domínguez-Solera and Domínguez-Rodrigo 2009). The second difference with brown bear is related to the scattering. Studies of brown bear behaviour showed that the most of the carcasses are not scattered (Sala and Arsuaga 2013, Arilla et al. 2014) while wolves and wild boar are a dispersal agent of animal carcasses (Bernáldez, 2002, 2009, 2011; Yravedra et al. 2011, 2012).

Finally, it is important to note that in archaeological records, suid behaviour could interfere in the location of bones in human deposits as other carnivorous and scavengers (Camarós et al. 2013). The effects of the behaviour of wolves, bears, lions and hyenas was analysed by Camarós et al. (2013), but there are no similar analysis with wild boar. Attending to our results, wild boar behaviour could also cause problems in the interpretation of archaeological record because this animal produces modifications of natural bone assemblages. Wild boar is an ungulate that consume and disperse bones from carcasses of ungulates more than 300 m from its original location (Bernáldez 2011; Bernáldez et al. 2017). There are some factors to imply bone movements into the fossil assemblage after (Albarella 2016) or before the fossilization (Binford 1981; Rosell and Blasco 2009; Camarós et al. 2013; Gutiérrez et al. 2016; Ballejo et al. 2016) where suids should be taken into account as a taphonomical agent to consume, move and modify bones (Bernáldez 2002, 2009, 2011; Domínguez-Solera and Domínguez-Rodrigo 2009).

Conclusions

The first conclusion of this study is that the skeleton destruction pattern of Class II species is similar in both Mediterranean ecosystems: the Sierra Norte Mountains in Seville Natural Park and Doñana National Park (Bernáldez 2002, 2009, 2011).

In addition, we were able to verify that the main scavenger participating in the thanatocoenosis preservation status in our study area could be wild boar. It is one of the few Mediterranean scavengers with the ability to consume bones from species with around 100 kg of body weight. Foxes (*V. vulpes* Linnaeus, 1758) remain in the background as a bone scavenger, after comparing our results with other studies in which foxes are the main scavenger. This carnivore only consumes and transports small bones, while wild board can consume the rest of bones of an ungulate carcass. We consider that suids are a taphonomical agent that researchers should be taken into account in palaentological and archaeological bone assemblages.

According to SCI values, the skull, as a bone set, and long limb bones, as a minimal anatomical unit (tibia, femur, metapodial), are the most resistant to scavenger activity. Similar results were obtained by Stiner (2004) analysing bone density where the same bones are the densest. In fact, the bones with a higher density are those that last longer on the ground. These bones are the biggest and heaviest and have less meat on them.

Finally, the fossil potentiality (Bernáldez 2009, 2011) of a bone or anatomical part depends on the characteristics of those bones, on scavenger preferences and on the number of bones that make up a skeleton. In the same biostratinomic and diagenetic conditions, the probability of finding axial bones is higher than that of finding cranial bones, as the former have more ribs and vertebras. Moreover, this probability difference can be found among different species, with carnivores and suids having more bones in their skeletons than equids. These differences must be noted in archaeozoological and palaeobiological analyses.

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Fig. 1 The Sierra Norte Mountains in Seville Natural Park are located in the SW of the Iberian Peninsula (black area). The biostratinomic study was developed in two public areas (UPA and Las Navas) located in the *white circle*. Figure adapt from a Wikipedia image, based file: Andalucia-loc svg by user Miguillen.

Fig. 2 Graph showing the three phases of the skeletal destruction trend, based on Bernáldez. (2011)

Fig. 3 During the monitoring, there are only tooth marks related with wild boar activity. In this pelvis, there are some parallel marks produced by the incisors of suids.

Fig. 4 Skeleton destruction trend of carcasses located in the Sierra Norte Mountains in Seville Natural Park, all of which show a similar trend. See Fig. 2 (Bernáldez, 2009).

Fig. 5 Differences between wild boar and vulture scavenging in Phase I. *Above*, wild boar activity on the 2 UPA carcass, and *below*, vulture activity on the 10 UPA carcass located in an open area. You can see that in this phase, the vultures did not destroy the axial skeleton.

Table 1 Carcasses studied in the Sierra Norte Mountains in Seville Natural Park: reference of the carcass (ID), gender (F, feminine; M, masculine), age (A, adult; S, subadult), absence or presence (O or C, respectively) of tree coverage around the carcass (Tree), months of study, state of conservation of the carcass at the first observation (State: C, complete; S, without soft tissue; H without head) and location (P, plane; S, slope, F, temporal water flow; L, Lake).

Table 2 The number of bones in a *Cervus elaphus* skeleton is 205. We are counted phalanges from relic fingers II and V.

Table 3 Skeleton decay processes.

Table 4 Time (months) and SCI values per phase of carcass destruction: state of conservation of the carcass at the first observation (start: C, complete; S, without soft tissue) and reference of the carcass (ID).

Table 5 %MAU values from all the carcasses at different times of the skeleton decay process.