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Ascertaining the manner of death: Distinguishing killing from carcass scavenging

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ABSTRACT

This study presents a documented case of a bear (*Ursus arctos*) predator attack on a foal, employing osteological analysis to determine the manner of death. By analyzing bone surface and structural modifications, we distinguish between injuries inflicted during the killing event and those resulting from scavenging or post-mortem consumption. A variety of bone modifications are recorded and documented, with a particular emphasis on a linear fracture on the body of the C4 vertebra and a double arc puncture on the proximal metaphysis of the left metatarsal. The former wound signifies a direct attack, while the latter signifies a defensive injury. This study case underscores the importance of taphonomic analysis in detecting instances of wild animal attacks on domestic livestock. Particularly in scenarios where visual evidence and conventional necropsies concentrating on soft tissue examination fail to confirm mauling occurrences, taphonomy provides valuable insights.

1. Introduction

In this paper we present a taphonomic analysis of a horse foal carcass which had no obvious evidence of struggle or traumatic injury. The application of research areas of taphonomy from the field of archaeology to veterinary medicolegal investigation is crucial to the study. These areas include the processes of decay and fossilization or preservation of organisms, but also scene reconstruction and studies of transportation and dispersion, as well as selective representation, bone modification due to perimortem trauma, scavenging, and diagenetic processes. Utilizing these methodologies to determine the manner of death, can result in greater understanding of the predator-prey relationship, facilitation of conservation initiatives and establishment of compensation frameworks for instances of species-related damage.

1.1. Background

The native brown bear (*Ursus arctos*) became almost extinct in the Central Pyrenees (Catalonia, Spain) around 1990 and the last fully Pyrenean bear disappeared in 2010. Different actions, such as the reinforcement of the population with specimens from Slovenia, which are genetically similar to those of the Pyrenees [1–3] and eventually the Piros LIFE Project Catalonia, have been implemented to stabilize a population in the Pyrenees (Fig. 1). However, the species as a whole has suffered problems not only with its own complicated viability but with its very existence due to the animosity of the livestock farmers and agricultural sectors of the area towards its reintroduction [4–7].

The brown bear's high level of adaptability in practically every aspect of its life makes it a flexible opportunist, including with its diet. The digestive system and gastrointestinal tract of the brown bear categorize it as a carnivore. However, evolutionary modifications of the dentition which allow it to consume both animal and plant matter classify it as an omnivore. The proportion of meat consumed varies depending on the environment they live in, the season of the year and the availability of vegetation suitable for consumption. Studies performed on feces left by the species in the Pyrenees show a varied food spectrum, with a percentage of vegetation between 70% and 80%, and a mammal contribution of 10% which is a percentage similar to that of insects eaten [8].

Conflicts between humans and large wild carnivore species frequently arise due to differing perceptions and values held by distinct stakeholder categories such as farmers, beekeepers and public in general [9,10]. These conflicts are generally related to the fact that these species can pose a threat to livestock and the rural economy, compete for space

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with human populations, and even potentially pose a threat to people themselves [11]. Given these challenges, tolerance towards large carnivore species is a key factor in promoting harmonious coexistence and ensuring the sustainability of their populations, as well as the success of conservation efforts.

The coexistence of humans and brown bears is possible, but it is not without its challenges [12,13]. Conflicts related to the use of the territory and the presence of brown bears must be minimized as much as possible to ensure peaceful coexistence. This can be difficult given that the brown bear will occasionally attack domestic animals [14,15]. Although healthy domestic animals are not commonly preyed upon by brown bears in the Central Pyrenees, livestock can become vulnerable to predation due to various factors, such as sickness, malnourishment, inclement weather, and poor management practices. It is important to note that the presence of predators or signs of their activity, such as hair in droppings, and the disappearance of livestock do not always indicate that predation has occurred. Other factors, such as illness or natural causes, can also contribute to the disappearance of animals. Therefore, it is important to conduct a thorough investigation to determine the cause of livestock losses before attributing them to predation. An effective investigation of a predation complaint is reliant on the amount and quality of evidence available. In the present study, the preliminary visual inspection by specialized rangers revealed neither evidence of struggle, nor traumatic injury to the animal remains, or other information to indicate a manner of death. The physical damage present did indicate scavenging of the remains.

2. Materials and methods

The domestic horse foal fed on by brown bear was predated or scavenged in the region of Val d'Aran (Pyrenees, Catalonia, Spain) in summertime (06/26) of 2021. The foal, aged one month, had a weight of less than 100 kg and was last observed alive on the day preceding the recovery of its remains. The retrieval of the remains occurred one day after the feeding episode, prompted by a timely notification from the livestock owner to the ranger teams.

The taphonomic study of the foal remains presented here includes the analyses of bone surface damage. All bone specimens were examined under a stereo light microscope with a magnification of up to 110x. 106 skeletal elements were located and recovered, including almost the entire spine (7 cervical vertebrae, 18 thoracic vertebrae, 6 lumbar vertebrae, 4 sacral vertebrae) the 2 innominate bones, 31 ribs, the 2 femora, the 2 tibiae, the 2 metatarsals, 8 patella/sesamoid bones, 12 tarsal bones, 8 phalanges and 4 splint bones. The osteological sample was cleaned to expose bone surfaces using non-aggressive procedure, such as boiling in a mixture of water and non-enzymatic detergent as the periosteum conceals the majority of the inconspicuous marks [16]. To categorize tooth marks, the studies of several authors are followed. Tooth marks are classified according to their morphology as pits, punctures and scores [17–20]. Pits are superficial marks or depressions on the surface of the bone cortical, while punctures are marks that perforate into the underlying tissue of the bones [17,20–22]. Scores are elongated marks caused by the drag of a tooth along the bone's surface [20,21]. Furrowing is the removal of cancellous tissue on the end of long bones although it can be observed in other bones of the skeleton, while crushing occurs when concentrated areas of bone collapse due to an external force, forming short cracks and splits [18,19,21]. Fractures refer to the interruption of cortical tissue [23]. Crenulated edges occur when the biting force exceeds the density and strength of the bone tissue, resulting in notched edges. Peeling, or bone breakage by bending, is the removal of superficial compact bone when bones bend and break and can be recognized by the presence of rough surfaces with parallel grooves or a fibrous texture along the transversal edges of the fractures [24]. A range of measures have been established for pits to enable comparisons with those provided by other researchers [25,26].

3. Results and discussion

The assemblage displays a diversity of bone toothmark modifications including pits, punctures and scores, crushing, fracturing, furrowing, peeling and crenulated edges. Table 1 summarizes the bone damage of the study organized by skeletal elements and bone damage-type. Of the total number of recovered skeletal specimens (n = 106), 58 elements (54,7%) show at least one bone alteration, with most of the altered specimens deriving from the girdles (n = 2; 100%) and axial (n = 53; 80,3%) regions followed by the appendicular skeleton (n = 3; 7,9%). No bones of the basipodium, acropodium or patellae were damaged.

Here we present the overview of types of bone surface modifications and anatomical locations (Fig. 2). Note the co-occurrence of more than one alteration on some of the elements:

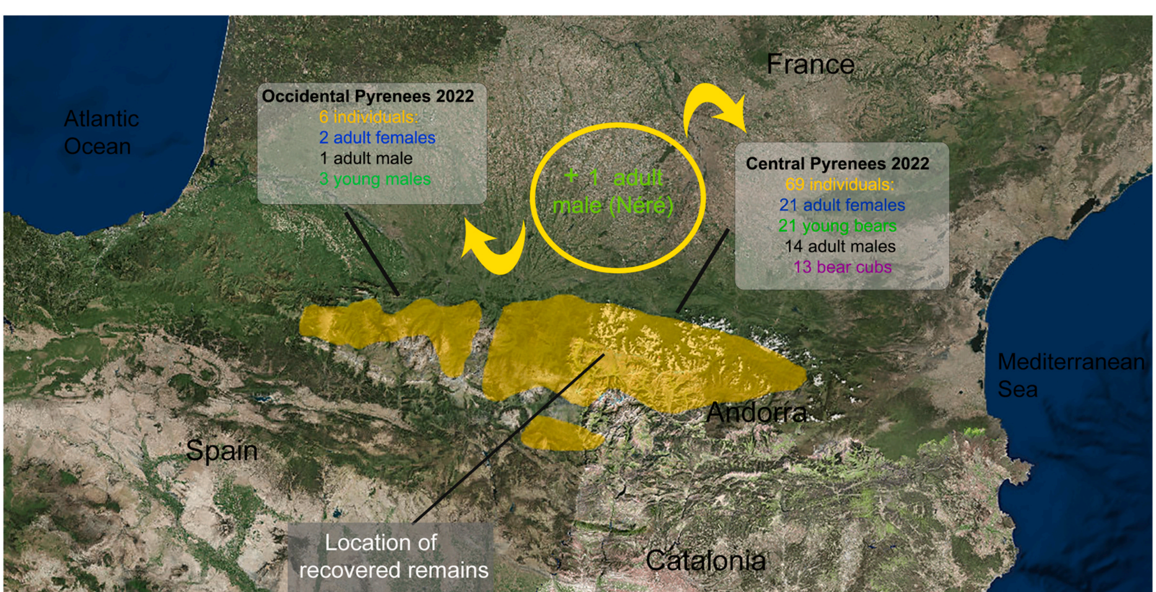

Fig. 1. Cartographic representation indicating the areas of bear presence in the Pyrenees and the location point of the equine specimen under investigation. Source: Rapport du Réseau Ours Brun de l'Office Français de la Biodiversité (OFB).

Table 1
Recovered bones vs damaged bones by skeletal elements split by different bone damage type. Note that one single skeletal element can bear more than one type of bear inflicted-damage.

	Recovered	Damaged	Pits/Punctures	Scores	Crushing	Fracture	Furrowing	Peeling	Crenulated edge
Vertebra: Atlas	1	1	-	-	1	-	-	-	-
Vertebra: Axis	1	-	-	-	-	-	-	-	-
Vertebrae: Cervical	5	5	-	-	5	1	-	-	-
Vertebrae: Thoracic	18	15	-	-	14	1	-	-	-
Vertebrae: Lumbar	6	6	-	-	6	-	2	-	-
Vertebrae: Sacrum	4	4	-	-	3	-	1	-	-
Ribs	31	22	1	-	14	8	-	1	1
Innominate bone	2	2	1	1	-	-	2	-	-
Femur	2	2	-	-	-	-	2	-	-
Tibia	2	-	-	-	-	-	-	-	-
Patella/Sesamoideum	8	-	-	-	-	-	-	-	-
Tarsals	12	-	-	-	-	-	-	-	-
Metatarsus	2	1	1	-	-	1	-	-	-
Residual/Lateral metapodium	4	-	-	-	-	-	-	-	-
Phalanges	8	-	-	-	-	-	-	-	-
Total	106	58	3	1	43	11	7	1	1

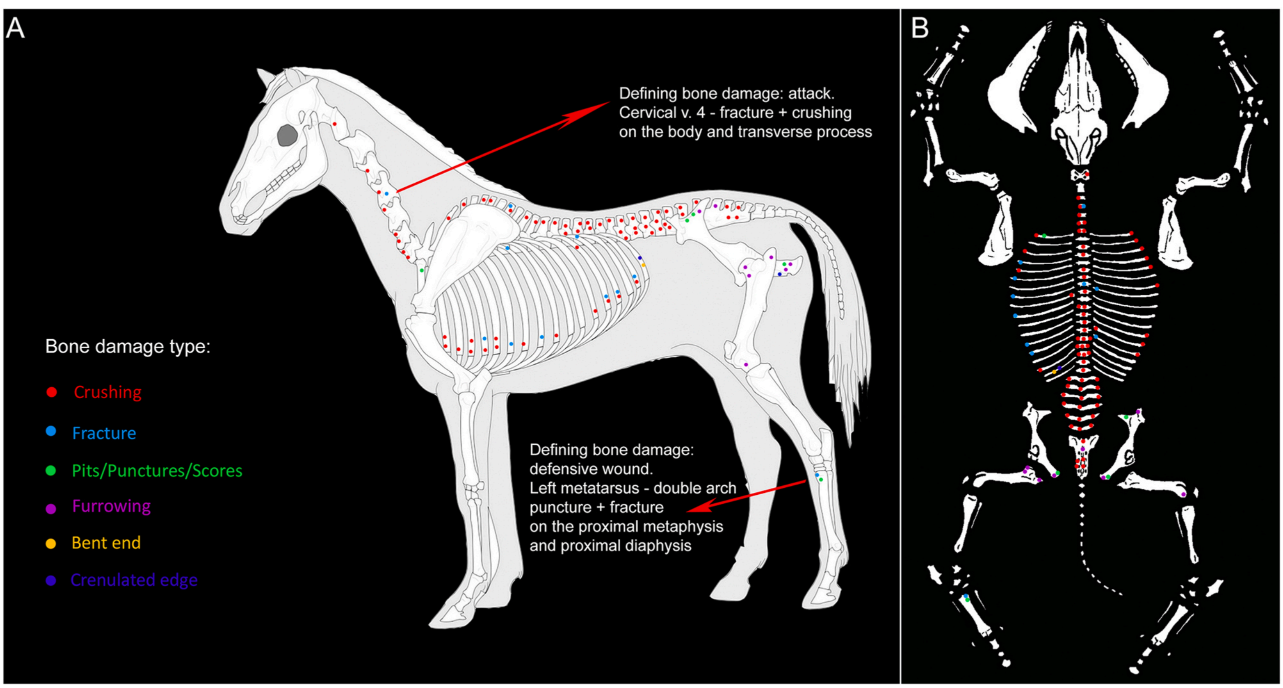

Fig. 2. A) General locations of different bone modifications and specific areas of defining bone damage. Double points of the same color represent to left and right locations on the skeleton. B) A comprehensive view of the complete skeleton displaying the location of bone modifications.

Pits or punctures are detected on 2,83% (n = 3) of the sample being equally recorded on the girdle region (n = 1), axial (n = 1) and appendicular skeleton (n = 1). The right innominate bares two opposed pits, one on the medial aspect of the iliac crest and one on the lateral aspect. There is also a single pit on the lateral aspect of the ischial body (Fig. 3A). One single pit is registered on the cranial aspect of the sternal end of the left first rib (Fig. 3B) and one double-arch puncture is recorded on the medial aspect of the proximal metaphysis of the left metatarsus. Scores are minimally represented at 0,98% (n = 1) and appear on only the ventral aspect of the left ischium.

Furrowing is noted on 6,86% (n = 7) of the sample including the girdles (n = 2), limbs (n = 2) and axial skeleton (n = 1). On the innominate bones, there is furrowing of both ischia and the right ilium. Both femurs exhibit furrowing: on the head, neck and greater trochanter one of them (left), and on the distal epiphysis of the other (right). Concerning the axial skeleton, only one sacral vertebra (second) bares furrowing on the spinous process.

Fractures are the second most common bone modification in the assemblage, with a total of 11 (10,78%) modified elements. The most significant values are from the axial skeleton (n = 10; 15,2% related to recovered specimens of the same anatomical regions). Only the left metatarsus shows this type of modification on the medial zone of its proximal diaphysis. Regarding the axial skeleton, one cervical vertebra has been fractured on the body and transverse process and one thoracic vertebra has the fracture localized to the spinous process. Seven ribs exhibit fractures on their sternal ends and two ribs bare fractures on their head and tubercles. The sternal end of one rib exhibits bent ends (incipient peeling) and crenulated edges (Fig. 3C). All the fractures are complete except for the left metatarsus, which has an incomplete fracture. The only fracture associated with crush damage is that of C4 vertebra. All other fractures are unrelated to other modifications.

Within the sample, damage from crushing occurs at the highest incident rate and affects 43 elements (40,57%) of the axial skeleton. There are six cervical vertebrae with crush damage. Five of these

Fig. 3. Examples of bone modifications: A) Pit located on the later aspect of the ischial body; B) Pit associated with crush damage on the sternal end of a rib; C) Crenulated edges and incipient peeling on the sternal end of a rib.

modifications are located on transverse processes and one is on an articular process. Fourteen thoracic vertebrae have crush damage to their spinous process, four of which also have this modification on the transverse processes. Six lumbar vertebrae bare crushing damage on their spinous processes and both transverse processes. Three sacral vertebrae have crush damage to their spinous processes and two transverse processes. A total of fourteen ribs have crush damage. Eleven ribs have modifications located on their sternal ends, one on a rib head and two on their sternal ends and heads.

Without a comprehensive inquiry, the bone damage observed on the axial skeleton (ribs and vertebrae) and the appendicular skeleton would be compatible with a consumption and/or scavenging pattern inflicted by the brown bear (*Ursus arctos*). Based on a neotaphonomic study, localized crushing in the area of the spinous processes of thoracic vertebrae is common in brown bear scavenging patterns [26]. This same study showed that since crushing is widely distributed throughout the axial region, it is thought to be linked to both activities related to opening the ribcage and general feeding or chewing [26]. Similar to crushing on the vertebral spine, fractures associated with crushing of the distal shaft of the ribs is likely to be related to evisceration, which involves the detachment of ribs from the sternum due to prying by the bear. This particular action marks the beginning of the consumption sequence, proceeds with the consumption of internal organs and culminates with the exploitation of the musculature of the humerus and femur [26]. The latter involves the localized furrowing observed on the appendicular skeleton. Specifically, furrowed proximal and distal epiphyses of the femur are a frequent occurrence in the consumption patterns of various large carnivores, including brown bears, in order to gain access to intrabone nutrients and red marrow [26]. The presence of furrowing on the ilium and ischium of the innominate bones is also consistent with this pattern of general feeding and chewing activities on soft tissues after the viscera removal.

We highlight two critical bone injuries that provide insights into the nature of the incident. The first one is a linear fracture on the body of the fourth cervical vertebra. The fracture initiates at the caudal aspect of the vertebral body and extends towards the cranial aspect, reaching the neurocentral suture. On the lateral side (right) of the complete fracture, inconspicuous crushed-edges are observed on the thin cortical bone, with indications of inward directionality (Fig. 4). The positioning and morphology of this vertebral fracture is consistent with a bite mark located on the midline of the cervicodorsal region, a typical pattern-injury of predatory bear attacks that result in severe damage to the spinal column and surrounding tissues [27,28]. In animal interactions, bites inflicted in the upper cervical region are indicative of the attacker's dominance over the prey [29]. In addition, this specific fracture is linked to the documented crushing of the transverse processes located on cervical vertebrae 1 (Atlas), 3, 6, and 7 as well as on the articular process of cervical vertebra 5.

This observation prompts us to assess the second defining bone damage which is a double-arch puncture associated with a small incomplete fracture on the proximal diaphysis/metaphysis of the left metatarsal (Fig. 5). Double arch punctures are a type of bitemark generated mainly by animals with bunodont dentition that leave two consecutive and curved punctures on the bone surface [30–33]. Such marks are made by the upper and lower teeth of carnivores, which penetrate the bone at an angle to create the double-arched shape. This pattern is also occasionally observed on the bones of prey animals hunted by large carnivores such as hyenas and big cats [34]. Double-arch punctures can be valuable clues for scientists in the fields of paleontology and archaeology who examine the relationship between predators and their prey, but they can also be utilized by forensic odontologists to investigate animal bites in criminal investigations [35,36]. In this study, there was no external conspicuous sign of this wound. Once the metatarsal was skinned, a hematoma was visible on the inner surface of the skin, close (~2 cm) to the previously described bone damage. The hematoma that forms after a fracture can be located immediately adjacent to the fracture or in the surrounding vicinity, depending on the extent of the injury and the individual's healing response [37–39]. The presence of the hematoma in relation to the described bone modifications (puncture and fracture) is indicative of a perimortem injury. Considering this, it is important to mention that non-durophagous carnivores typically do not feed on metapodials, as they consist mainly of skeletal material with little soft tissue and require hard gnawing but supply minimal nutritional return [32]. Based on these factors, it is speculated that the injury found on the metatarsus is a defensive wound [40–42]. These types of injuries are sustained when the

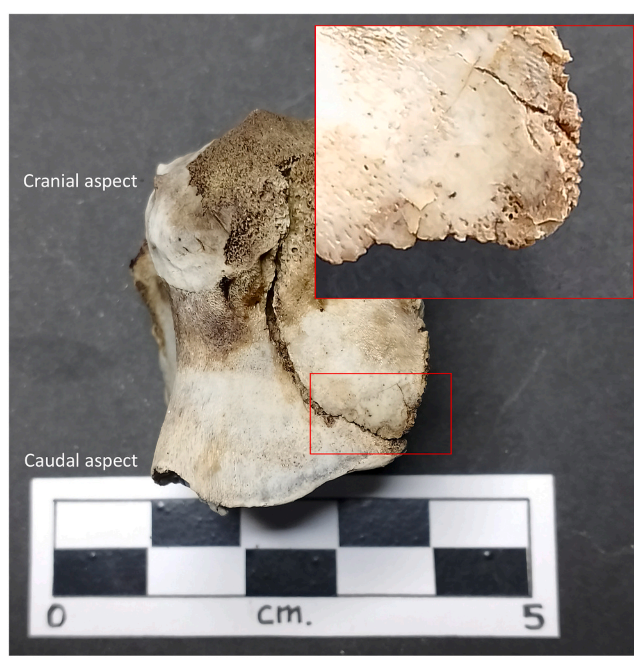

Fig. 4. Image of the fracture on the body of the C4 vertebra, with a detailed view of the crushed edges in the upper right corner.

Fig. 5. View of the left metatarsus with detail of the defensive wound consisting of a double-arch puncture associated with a small incomplete fracture on the medial area of the proximal metaphysis/diaphysis (right) and the hematoma (indicated by an arrow) related to the same injury (left).

victim is defending itself against an attacker or predator. Defensive injuries can vary in severity and location depending on the species of carnivore and the nature of the attack [43]. Some common types of defensive wounds in animals include scratches, bites, bruises and fractures. All of which can be a useful indicator of the nature of an attack or predator. In our study case, the presence of the defensive wound suggests that the foal was eventually on the ground lying on its right side with the dominant carnivore in a controlling position, and when the foal kicked with its left leg in self-defense, the bear responded by biting its proximal metatarsus in order to fully immobilize it, avoiding being kicked.

Based on these findings, we can eliminate the possibility of small carnivores being responsible for the documented modifications, since these particular types of alterations are not seen in their usual patterns of consumption [44]. The morphology of the depression, its location in the case of the metatarsus, and the force required to cause the fractures make them compatible with a pattern of predation/attack carried out by a large carnivore. Additionally, although the percentage of pits, punctures and scores is very low, the average measurements of those teeth marks (3.18 mm length and 2.43 mm width, and 1.2 mm width respectively) also indicate predation by a large carnivore since similar averages have been produced by the brown bear [32] on spongy tissue (cancellous tissue) and thin cortical bone (Fig. 6).

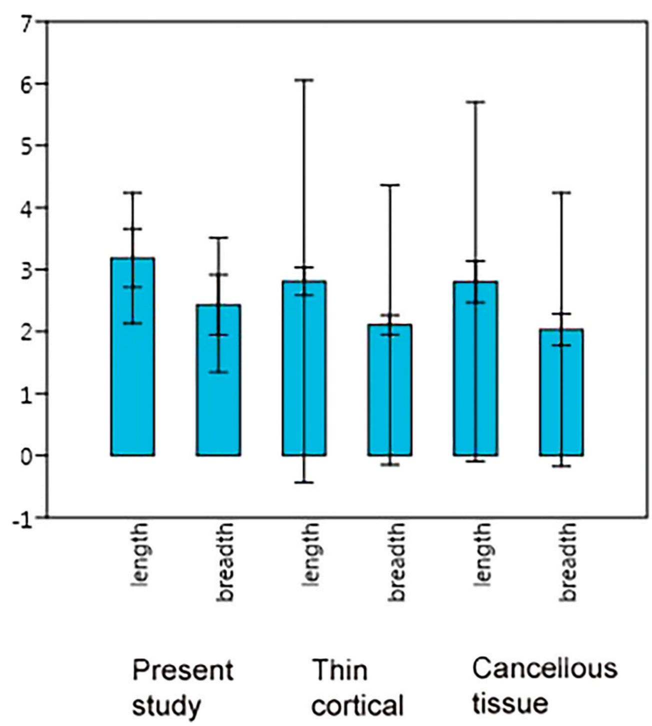

Fig. 6. Average measurements of pits and punctures inflicted by brown bears on thin cortical and cancellous tissue [26] and average measurements of the present study.

4. Conclusions

Our case study highlights the importance of utilizing taphonomic analysis to identify cases of wild animal attacks on domestic livestock, particularly in cases where visual evidence (such as wounds, excrement, hair, blood, etc.) and conventional necropsies that rely on examining soft tissue (such as skin punctures and bruises) are unable to confirm the mauling. When evidence is unclear, forensic taphonomy and skeletal analysis are crucial for clarifying the agent(s) of carcass modifications. Perimortem trauma provides valuable information for determining the manner of death and identifying the agent responsible for causing it. The findings of this study have important implications not only for archaeological research, but also for forensic investigations involving animal remains. Specifically, the observed patterns of animal attack and predation provide valuable insight into the behavior and ecology of brown bears. Moreover, the ability to accurately identify the cause of bone damage is critical in a variety of fields, including archaeology and veterinary science, where precise determination of the nature and timing of injuries is necessary for interpreting and evaluating the evidence.

Ethical statement

The carcass used for the present case study was retrieved by the specialized agents from the competent government entity, *Conselh Generau d'Aran (Val d'Aran, Spain)*, who managed the administrative permissions required, including the owner's permission.

No animals were damaged or sacrificed during the present project.

CRediT authorship contribution statement

MA, JR, RB designed the project. MA conceptualized, coordinated and wrote the manuscript. MA analyzed spatial and taphonomically the specimen. IAJ provided contextual data. All authors discussed and commented on 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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