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# The use of Micro-Photogrammetry and Geometric Morphometrics for identifying carnivore agency in bone assemblages

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ABSTRACT

Before sedimentation, bones are exposed to an important amount of biostratinomic taphonomic processes. One of them is related to the action of carnivores, which is reflected in conspicuous tooth marks, such as pits, scores, punctures or furrowing. Different carnivores damage bone assemblages differently. Thus, several researches have tried to identify carnivore agency based on different parameters such as skeletal profiles, tooth mark frequencies and dimensions, breakage patterns, or more recently, taphotypes. Here we propose a new methodology based on the analysis of tooth scores to determine the carnivore type involved in bone modification. For this purpose, we have built 3D models of several tooth scores produced by wolves, lions, jaguars, foxes and hyenas using photogrammetric techniques. These models were later analyzed by means of Geometric Morphometrics and multivariate statistics. We show that although there is a high degree of overlap in tooth mark morphology, the combined action of tooth score dimensions and morphology enables the identification of some of the tooth scores made by lions from those of the other carnivores with a higher degree of confidence than any other inter-carnivore comparison.

## 1. Introduction

Archaeological and paleontological bone assemblages are the result of potential longitudinal exposure to a variety of destructive processes. Different physic, fossil-diagenetic and biologic phenomena can affect fossil integrity and ultimately bias produce the taphonomic process. Carnivores are one of the most destructive biological agents, so they have been subject of research by several authors (e.g. Hughes, 1954; Sutcliffe, 1970; Haynes, 1980, 1981; Binford, 1981; Brain, 1981; Solomon and David, 1990; Cruz Uribe, 1991; Domínguez Rodrigo, 1999; Selvaggio and Wilder, 2001; Brugal and Fosse, 2004; Coard, 2007; Egeland, 2008; Kuhn et al., 2010; Domíguez-Rodrigo and Pickering, 2010; Yravedra et al., 2011; Gidna et al., 2013; Arriaza et al., 2016).

Bone modifications and accumulations produced by carnivores are distinguishable from those produced by humans (e.g. Cruz Uribe, 1991; Kuhn et al., 2010). Conspicuous tooth marks produced by carnivores include pits, scores, punctures and furrowing (Sutcliffe, 1970; Haynes, 1980; Binford, 1981; Shipman, 1981) (Fig. 1). All carnivores are capable of producing such surface modifications, and consequently the identification of the carnivore responsible for the bone assemblage based on the appearance of tooth marks is rather difficult.

Some authors have tried to distinguish between carnivores based on the characteristics usually left by each type of carnivore on different element and bone portions (Brugal et al., 1997; Brugal and Fosse, 2004; Domíguez-Rodrigo and Pickering, 2010; Domínguez Rodrigo et al., 2012; Domínguez-Rodrigo et al., 2015; Gidna et al., 2013; Arilla et al., 2014). Felids, hyaenids and canids create different skeletal profiles (Brugal and Fosse, 2004; Domíguez-Rodrigo and Pickering, 2010; Domínguez Rodrigo et al., 2012), tend to accumulate different preys (Brugal and Fosse, 2004), and break bones differently. For instance, hyenas fracture bones more intensively than felids (Domínguez-Rodrigo et al., 2007, 2015; Domínguez Rodrigo et al., 2012). Domínguez-Rodrigo et al. (2015) developed a new technique based on the

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**Fig. 1.** Main surface modifications produced by carnivores.

**Table 1**
Main characteristics of the sample used in this study.

| Carnivore | State | Section | No bones | No scores | Prey |
|---|---|---|---|---|---|
| Lion | Captivity | Shaft | 12 | 30 | Horse |
| Hyena | Captivity | Shaft | 12 | 33 | Horse |
| Jaguar | Captivity | Shaft | 9 | 34 | Horse |
| Wolves | Wild | Shaft | 1 | 30 | Horse |
| Fox | Wild | Shaft | 6 | 21 | Sheep |

identification of "*taphotypes*", which allows the differentiation between hyenas, lions and jaguars based on anatomical patterning of bone damage. In addition, the action of certain carnivores can be indentified due to exclusive behavioural patterns exhibited by specific carnivores, as is the case among bears. The bears break axial elements producing peeling, a pattern that has not been documented among other non-human carnivores (Arilla et al., 2014). Thus a body of research has led to the effective distinction among carnivores based on the traces they leave on bones.

However, sometimes evidences are not conclusive enough. For instance, the dimensions of pits or scores have long been used distinguish between carnivores (Selvaggio and Wilder, 2001; Domínguez-Rodrigo and Piqueras, 2003; Coard, 2007; Delaney-Rivera et al., 2009; Andrés et al., 2012), but these studies have not managed to properly isolate the marks produced by each carnivore, and have rather established carnivore groups according to their size (e.g. large carnivores like hyenas or lions, and small carnivores like foxes or intermediate-small felids).

Here we present a new technique with the aim of differentiating carnivores at the taxon level. Our methodology implies the three-dimensional reconstruction of scores and the use of Geometric Morphometrics to statistically analyze marks.

## 2. Materials and methods

### 2.1. Materials

For the present study, we have analyzed scores produced by wild carnivores and carnivores in captivity. Recent works have demonstrated that studies based on carnivores in captivity have to be carefully interpreted since their behaviors differ from those in the wild (Gidna et al., 2013; Arilla et al., 2014; Sala et al., 2014a). However, such cautions do not affect our study because score morphology and size do not present morphological differences depending on the environment but are the physical results of the application of forces and bone surface modification.

The samples consist of bone assemblages modified by captive lions, hyenas and jaguars from the Cabárceno Reserve "Parque de la Naturaleza de Cabárceno", in Cantabria (North of Spain). Carnivores in Cabárceno live in large open areas of several thousands of square meters (http://www.parquedecabarceno.com). For more details about the lion sample see Gidna et al. (2013), and for the hyena and jaguar samples see Domínguez-Rodrigo et al. (2015).

The sample of scores created by wolves was obtained in the Campelo Mount, near Sobrado Dos Montxes, Galicia (see Yravedra et al., 2011, 2012), and the one generated by foxes comes from Ayllón (Segovia), in the interior of the Iberian Peninsula.

Table 1 summarizes the sample composition used in this study (Table 1). A total of 148 scores produced by lions, hyenas, jaguars, wolves and foxes were analyzed. Most of the carcasses exploited belong to adult horses, except for one juvenile equid consumed by wolves, and 6 sheep consumed by foxes. Surface modifications produced by foxes on large carcasses are not significant (Yravedra et al., 2014), therefore small carcasses were selected for this study. We also selected scores identified on shafts for two main reasons: 1) diaphyses are denser than epiphyses, so teeth tend to penetrate less through the cortical layers of the first ones, and 2) diaphyses show a higher survival rate in the archaeo-paleontological record, so the use of a sample based on shafts would be a more useful framework for future analogies. Bone epiphyses usually are more exposed to different natural processes related to the action of carnivores (e.g. furrowing) or of water runoffs (Lyman, 1994), and tend to disappear faster.

### 2.2. Methods

The methodology applied in the analysis of scores is based on a previous study where we employed photogrammetry (Structure from Motion) and Geometric Morphometrics for the analysis of cut marks (Maté-González et al., 2015). Scores are similar to cut marks, as both marks share some characteristics. Scores, as well as cut marks, are longer than they are wide, though they differ in depth: scores present a shallower "U" shape, while cut marks are characterized by a "V" section that is deeper, narrower (although highly variable) and more rectilinear (Maté-González et al., 2016).

Scores were selected on the basis of their preservation and general conditions. We excluded those scores that present a bad cortical preservation or some type of post-depositional alteration. Neither superficial nor inconspicuous tooth marks that provided a bad resolution were selected for the study.

High-resolution images obtained through Micro-Photogrammetry and computer vision techniques were used for the three-dimensional modelling of scores sections. Following the methodology of Maté-González et al. (2015), Micro-Photogrammetry was used to generate precise metrical models of scores when using images taken with oblique