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Taphonomic Effects of a Grassland Fire on a Modern Faunal Sample and its Implications for the Archaeological Record

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The main objective of this paper is to characterize the pattern of thermal alteration in a sample of modern bones collected after a natural grassland fire in the Pampas region (Argentina). A total of 917 bone remains were recovered, including a variety of different body size taxa. Results suggest that natural grassland fires affect bone remains in a more severe way than previously documented. In general, a high proportion of bones with thermal alteration (70%) was recorded for the different body size categories, with calcined bones dominating the sample. Some differences in relation to the size classes were found; specifically, a higher extension of burning was recorded for the smaller-sized taxa. For the small animals, the homogeneous distribution of the burning damage in long bones and mandibles could help to differentiate a natural grassland fire from cooking, in which the burning pattern would be more heterogeneous.

Keywords: NATURALISTIC TAPHONOMY, GRASSLAND FIRE, VERTEBRATE BONES, THERMAL ALTERATION

Introduction

The presence of burnt faunal remains in archaeological sites is commonly used as evidence of human exploitation, especially in the absence of less ambiguous cultural modifications such as cut or percussion marks (*e.g.*, Pardiñas, 1999; Joly *et al.*, 2005; Medina *et al.*, 2012). However, the thermal alteration can be generated by different processes, both cultural and natural. Some of these include: disposal of food waste

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(*e.g.*, Spennemann & Colley, 1989; Cain, 2005), use of bones as fuel (*e.g.*, Théry-Parisot, 2002; Costamagno *et al.*, 2005, 2010; Joly *et al.*, 2005; Théry-Parisot *et al.*, 2005; Morin, 2010), cooking (*e.g.*, Gifford-González, 1989; Wandsnider, 1997; Lloveras & Moreno-García, 2009; Medina *et al.*, 2012; Frontini & Vecchi, 2014), burning for ritual purposes (*e.g.*, Tchesnokov, 1995; Vaté & Beyries, 2007), accidental burning by proximity to hearths (*e.g.*, Stiner *et al.*, 1995; Bennett, 1999; Cain, 2005), and wildfires (*e.g.*, Brain, 1981; David, 1990; Bellomo, 1993; Buenger, 2003; Keough *et al.*, 2015). In this paper, we focus on this last process, and compare wildfire effects with anthropogenic thermal alteration.

Wildfires can be expected to occur in areas with any natural fuel, such as grasslands and woodlands. Archaeologists working in these types of settings must take into account the possibility of natural fires affecting the archaeological record. The Pampas region of Argentina is a vast open prairie where the dominant vegetation includes several types of tall growing grasses (pampas-grass) and numerous species of the genus *Stipa*. The climate is warm and temperate and the rainfall increases during the winter. The average annual temperature in the Pampas is 12 °C and the rainfall average is between 600 and 1000 mm (Burgos, 1968; Cabrera, 1976).

Average soil surface temperature on grassland fires is a linear function of the amount of available fuel, but normally temperature varies between 102 °C and 388 °C (Wright & Bailey, 1982). In extreme cases, some tall grass fires have been recorded at temperatures up to 900 °C (Stott, 1986; Gibson, 2009). The residence time (when flames persist) is short, between 5 and 20 seconds. The smouldering time (when flames are absent but the fuel continues to burn) is also brief, usually less than two minutes (Bailey & Anderson, 1980; David, 1990; Bellomo, 1993; Buenger, 2003). In order to provide a better understanding of the effects of wildfires on faunal remains, this paper presents the results of the analysis of a modern sample of bones recovered in a hill sector of the Pampas region after the occurrence of a natural grassland fire. The main objective is to characterize the pattern of thermal alteration generated on the bone assemblage, focusing on the type of modifications in different body sized animals.

Previous studies

There is scarce background about the effects of natural grassland fires on bone remains. Most studies are experimental and have been conducted with bones from large-sized mammals (David, 1990; Buenger, 2003; Keough *et al.*, 2015). For example, David (1990) conducted two experiments in order to evaluate the fire effects on bones considering different firing regimen: bushfires and campfires. The bushfire experiment was conducted in an open environment with grasslands and trees in Australia (Black Mountain National Park), where two dry kangaroo tibiae were placed under a fire at 450-500ºC for 3 to 4 minutes. The analyses of bone damages allowed identifying the presence of line, spiral, and transverse fractures. Regarding color, black charring associated with carbonization was the predominating feature. Brown color was scarce, and there was no evidence for calcination (grey and white). Taking into account these results, David (1990) proposed that for calcination to occur, bones should be exposed to temperatures higher than 450-500 ºC or burned for more than 3 to 4 minutes, or a combination of both conditions.

Buenger (2003) also conducted experimental studies in the field and laboratory in order to identify the effects of different types of natural fires (prairie grasses and woodlands) on distinct classes of archaeological materials (ceramic, lithic, bone, and wood). For the experiment conducted in the field, burnt 2x2 m and 1x1 m units were used. The materials (deer, elk, and cattle bones, ceramic, and lithic) were placed inside the units together with thermocouples to measure the temperature. Results obtained for the prairie grasses showed that the average maximum temperatures considerably varied from 80 °C to 400 ºC, with an average of 161.8 ºC. This author concluded that the combustion of this type of vegetation does not generate high temperatures and that residence time is low (between 1 and 3 minutes). Organic materials (bone and wood) exhibited minimal thermal alteration, showing brown color and black charring along the borders. Fracturing, spalling, deformation, or surface cracking were not observed.

More recently, Keough *et al.* (2015) conducted an experiment in South Africa with the aim of evaluating the effects of a veldt fire on human bones in order to determine the initial condition of a corpse when burned. This experiment consisted of exposing 25 pig carcasses in different decomposition states (fresh, early, advanced, and skeletonization stages) to the fire during 30 minutes (data about temperature are absent). Results showed a low frequency of thermal alteration with the presence of brown color and scarce fragmentation for carcasses in the initial decomposition stages where flesh and muscular tissue protected the bones. For carcasses in more advanced decomposition stages, calcination and carbonization predominate, as well as cracking and extreme fragmentation. The main trends for this experiment demonstrated that: first, a higher degree of decomposition results in higher modifications by the fire, and second, the presence or absence of tissues is the most important variable that generates different grades of thermal alteration.

Materials and methods

The bone sample was recovered in September 2015, along a low hill (maximum of 300 m asl) close to the town of Sierras Bayas (Olavarría county, Buenos Aires province, Argentina) (Figure 1). The burnt area (1.75 km^2) contained natural grasses that were almost completely consumed by the fire. The exact date of the fire was unknown; however, contextual data –vegetation, ash cover, etc.– suggests that it occurred less than two months before the fieldwork. Within the surveyed area we also identified several rock outcrops and archeological lithic workshops that were affected by fire.

The survey was conducted through nine transects approximately 10 m wide and 500 m in length, covering an area of 45,000 m^2. Each transect was composed of 10 samples (50 m in length) where the following characteristics were recorded: sediment type, slope, burial potential, type and distribution of vegetation, bioturbation, presence of animals or human activity, presence of archaeological materials, and visibility.

Our study was focused on the bones that were visible on the ground and no excavations were performed. Most of these remains were lying on the surface; however, some of them were partially buried (covered by less than 50% sediment), or almost buried (covered by more than 50% sediment but still visible). All these specimens were part of the sample presented in this paper.

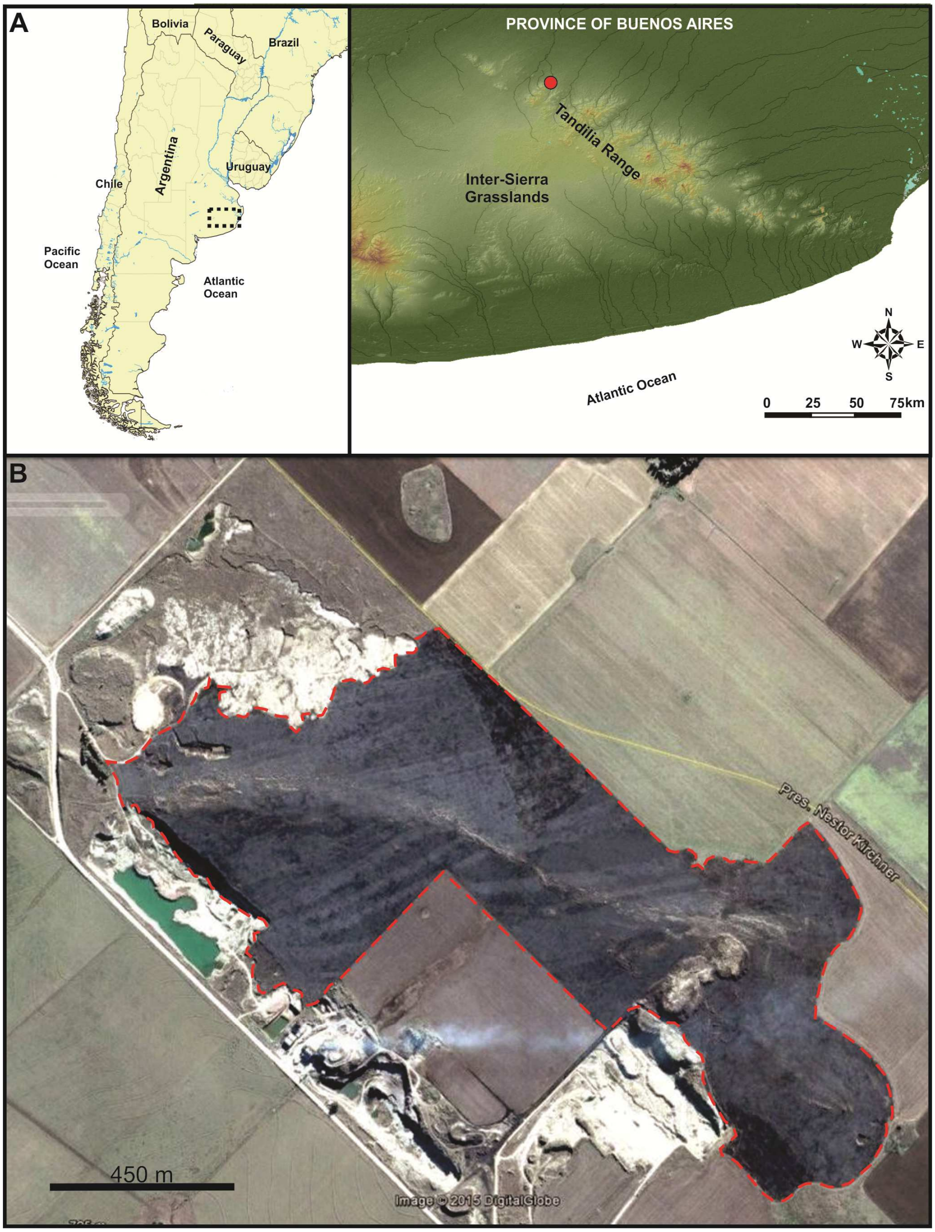

Figure 1. (A) Location of the study area, and (B) satellite image (Google Earth, 2015) of the burnt area.

The bone remains were collected in the field, and the following variables were analyzed in the laboratory: taxonomic class; presence/absence of soft tissue; anatomical unit; grade of completeness; articulation among elements; weathering stage (Behrensmeyer, 1978; Andrews, 1990); and other taphonomic modifications, such as carnivore and rodent marks, root etching, manganese staining, trampling, among others (*e.g*., Haynes, 1980; Binford, 1981; Olsen & Shipman, 1988; Lyman, 1994). It is important to mention that the weathering stages described by Behresnmeyer (1978) and Andrews (1990) were proposed for unburnt remains; and in some cases, the effects of thermal alteration could mimic the features originated by weathering (Hanson & Cain, 2007; Junod & Pokines, 2013; Pokines & Symes, 2013). Consequently, results on this last variable could have varied regarding the original state of the sample.

The sample was classified in three body size categories: small-sized vertebrates (<1 kg), medium-sized vertebrates (1 to 20 kg), and large-sized vertebrates (>20 kg). The identification of thermal alteration was based on the bone color. Although the current literature on bone thermal alteration describes numerous variables, especially those studies in the field of forensic taphonomy (Symes *et al*., 2008, 2013; Keough *et al*., 2015), in this article we focused on the color because it is the more common variable used by archaeologists to infer burning. Likewise, some modifications produced by thermal alteration, such as fractures, can be originated by additional taphonomic processes (*e.g*., weathering and carnivore action). Since the sample studied here is a naturalistic assemblage, with unknown original conditions, we could not distinguish if the observed fractures were a direct consequence of burning, previous taphonomic processes, or a combination of both.

According to the color, three burning stages were used: scorched (brown, reddish, and orange), carbonized (black), and calcined (white and blue-gray) (Brain, 1981; Shipman *et al.,* 1984; Johnson, 1989; Stiner *et al*., 1995; Galeano *et al.,* 2014). This variable was described using the Munsell color system (Shipman *et al*., 1984; Nicholson, 1993; Cain, 2005; Asmussen, 2009; Galeano & García-Lorenzo, 2014). Following Lyman (2008:275), a burning profile was constructed by tallying specimens by their maximum burning stage. Changes of texture produced by burning were recorded using the following categories: glassy, cracking, and powdery (Nicholson, 1993; Cain, 2005). The percentage of the bone surface with thermal alteration was recorded considering intervals of 20%: 1-20%, 21-40%, 41-60%, 61-80%, 81-100%. These categories represent a visual estimation of the damage extension. The anatomical location of the burning was recorded for complete mandibles and long bones to compare with burnt patterns produced by cooking (Pardiñas, 1999; Costamagno *et al.,* 2005; Medina *et al*., 2012).

Results

Environmental context

The overall visibility along the nine transects was excellent (almost no vegetation cover). There was a moderate slope, between 9% and 18%. The sediment type was loose sandy silt with ash, and rock outcrops were present mainly in the higher altitude transects. The potential for burial of faunal materials was classified as moderate to high (by eolian sedimentation). No live wild or domestic animals were present, but there were evidence of livestock dung, carcasses, and tracks.

Taxonomic representation

A total of 917 faunal remains were recovered from the transects. In only one case, articulated elements joined by tendons were identified. The remaining bones were skeletonized and disarticulated with no soft tissue. Although most of the remains were scattered on the ground, some of them were concentrated in small areas. Based on the proximity of the elements, the skeletal representation and the fusion state we were able to identify the presence of one carcass of Colubridae, two of *Lepus europaeus*, two of *Eudromia elegans*, one of *Milvago chimango*, one of *Conepatus chinga*, and three of *Bos taurus*. However, it is important to mention that these individuals were in a low state of completeness and were not in anatomic relation.

From the total sample, 312 specimens correspond to isolated bone plates (309 are Hairy armadillo and 3 are Long-nosed armadillo). Moreover, a fragment of armadillo carapace (composed of 32 plates) corresponds to Hairy armadillo. General observations on burning damage were made on individual plates (n=344); however, they were not included in the taxonomic and taphonomic quantification because they over represent the sample of medium-sized vertebrates. Eggshells and terrestrial gastropods were also recorded during the surveys, but they are excluded from the quantification because they were not systematically collected.

In the bones and teeth sample (n=604), 45.2% correspond to small-sized animals, 30.8% to medium-sized animals, and 18.4% to large-sized animals, while 5.6% of the specimens could not be assigned to any size category. The small sized-animals include a variety of mammals (n=73), amphibians (n= 10), reptiles (n=45), and birds (n=117) (Table 1). The medium and large-sized animals are exclusively mammals, mainly represented by European hare (n=106) and cow (n=96), respectively (Table 1).

Bone modifications

Bone modifications are described only for specimens assigned to a size category (n=570, Table 2). All stages of weathering were identified in the bone sample. The majority of bones from small and medium sized vertebrates were unweathered (stage 0) while a small proportion were in stage 1 (3.4% and 10.7%, respectively) and stage 2 (0.4% and 3.4%, respectively). In the bone sample of large-sized animals, most of the bones were in the stage 1 (41.6%) and stage 2 (28.1%), with just a few specimens in the stage 3 (11.2%) and stage 4 (1.1%) (Table 2).

The majority of the small-sized faunal remains were unburied (97%). For medium-sized animals, unburied specimens were also prevalent (55.9%), but partially-buried (31.2%) and almost buried (12.9%) remains were also well represented. In the case of large-sized animals, unburied and partially buried bones were abundant in a similar proportion (45.1% and 40.5%), followed by almost buried remains (14.4%) (Table 2).

Bone completeness was higher for small-sized animals (68.8%). The highest percentage of fragmented specimens was recorded for medium-sized animals (55%). Finally, carnivore modifications were identified in all size classes. The higher frequency was

Table 1. Taxonomic representation of the analyzed sample. References: ()=Plates and carapace fragment.

Taxa		N
SMALL VERTEBRATE		
Amphibian	Anura	10
Reptile	Colubridae	45
Bird	Indeterminate bird	44
	*Milvago chimango (*Chimango caracara)	6
	Anseriformes	1
	Passeriformes	22
	Tinamiformes	2
	Eudromia elegans (Elegant crested-tinamou)	28
	Nothura maculosa (Spotted nothura)	9
Mammal	Indeterminate mammal	14
	Monodelphis dimidiata (Yellow-side opossum)	1
	Rodentia	44
	Cricetidae	7
	Necromys lasiurus (Hairy-tailed akodont)	2
	Akodon azarae (Grass mouse)	7
	Oxymycterus rufus (Red hocicudo)	8
	Cavia aperea (Wild guinea pig)	3
	Galea leucoblephara (Yellow-toothed cavy)	1
Indeterminate		19
	Total Small	**273**
MEDIUM VERTEBRATE		
	Indeterminate mammal	16
	Lepus europaeus (European hare)	106
	Conepatus chinga (Hog-nosed skunk)	14
	Canidae	3
	Dasypodidae	2
	Chaetophractus villosus (Hairy armadillo)	14(310)
	Dasypus hybridus (Long-nosed armadillo)	(3)
Indeterminate		31
	Total Medium	**186**
LARGE VERTEBRATE		
	Indeterminate mammal	8
	Bos taurus (Cow)	96
	Ovis aries (Sheep)	1
Indeterminate		6
	Total Large	**111**
TOTAL ASSIGNED TO A SIZE CATEGORY		**570**
INDETERMINATE VERTEBRATE		**34**
TOTAL		**604**

Table 2. Bone modifications identified in the analyzed sample.

Variable	Stage/State	Small vertebrate (n=273)	Medium vertebrate (n=186)	Large vertebrate (n=111)
Total		273	186	111
Weathering	Stage 0	96.3	85.9	18.0
	Stage 1	3.4	10.7	41.6
	Stage 2	0.4	3.4	28.1
	Stage 3	-	-	11.2
	Stage 4	-	-	1.1
Burial state	Unburied	97.4	55.9	45.1
	Partially-buried	2.2	31.2	40.5
	Buried	0.4	12.9	14.4
Grade of completeness	Complete	68.8	45.0	55.7
	Fragmented	31.2	55.0	44.3
Carnivore marks		15.4	20.4	3.6
Burning stages	Unburnt	27.8	32.3	27.9
	Scorched	1.1	3.8	0.0
	Carbonized	17.9	24.2	20.7
	Calcined	53.1	39.8	51.4
	Total of burnt bones	**(n=197)**	**(n=126)**	**(n=80)**
Extension of surface burning	1-20%	10.2	25.4	45.0
	21-40%	4.6	11.1	20.0
	41-60%	6.6	5.6	13.8
	61-80%	4.6	9.5	3.8
	81-100%	74.1	48.4	17.5
Burnt texture	Glassy	55.8	54.8	10.0
	Cracking	25.8	14.3	43.8
	Powdery	0.5	-	1.3

recorded in medium (20.4%) and small (15.4%) animals. The large animals presented a low frequency of carnivore marks (3.6%). No other taphonomic modifications were identified in the sample (Table 2).

Thermal alteration

A total of 403 specimens (70%) were identified with thermal alteration. The proportion of burnt specimens was similar in all the size classes (Table 2). The majority of the bones were calcined (39.8% to 53.1%), while a smaller proportion was carbonized (17.9 to 24.2%). A low percentage of bones from small and medium sized-animals were scorched (1.1% to 3.8%) (Figure 2).

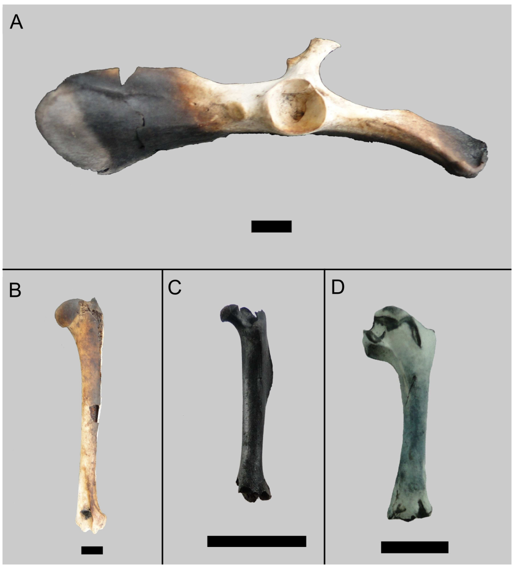

Figure 2. Specimens with thermal alteration. (A) *Lepus europaeus* innominate with all three burning stages. (B) Scorched *Lepus europaeus* humerus. (C) Carbonized Rodentia femur. (D) Calcined Indeterminate bird humerus. Scale=1 cm.

The extension of thermal alteration was higher for the small sized category, where a high proportion of the specimens (74%) were burnt in more than 80% of the surface. On the contrary, for large animals, most of the remains (45%) were burnt in less than 20% of the surface.

Changes in texture by burning were similar for small and medium-sized-animals, where glassy texture was the more common (55.8% and 54.8%), followed by cracking (25.8% and 14.3%). On the other hand, the frequency of cracking was higher in the large-sized animals (43.8%). However, for this size category, cracking and whitening by weathering could have been misguidedly taken as the result burning.

Regarding the anatomical location of burning, only two complete mandibles of small and medium sized-animal were recorded, and these specimens presented burning along the entire surface. In the case of long bones; in general, we observed homogeneity in the distribution of modifications, which altered both the epiphyses and diaphyses (Table 3).

Finally, in the Dasipodidae bone plates, sixty specimens (17%) exhibited thermal alteration (Table 4). Most of the plates were scorched on the dorsal surface or carbonized

Table 3. Anatomical location of burning in long bones.

Anatomical location	Small vertebrate	Medium vertebrate	Large vertebrate
Epiphyses	3	6	1
Diaphyses	0	0	0
Epiphyses+ Diaphyses	28	6	2
Total	32	12	3

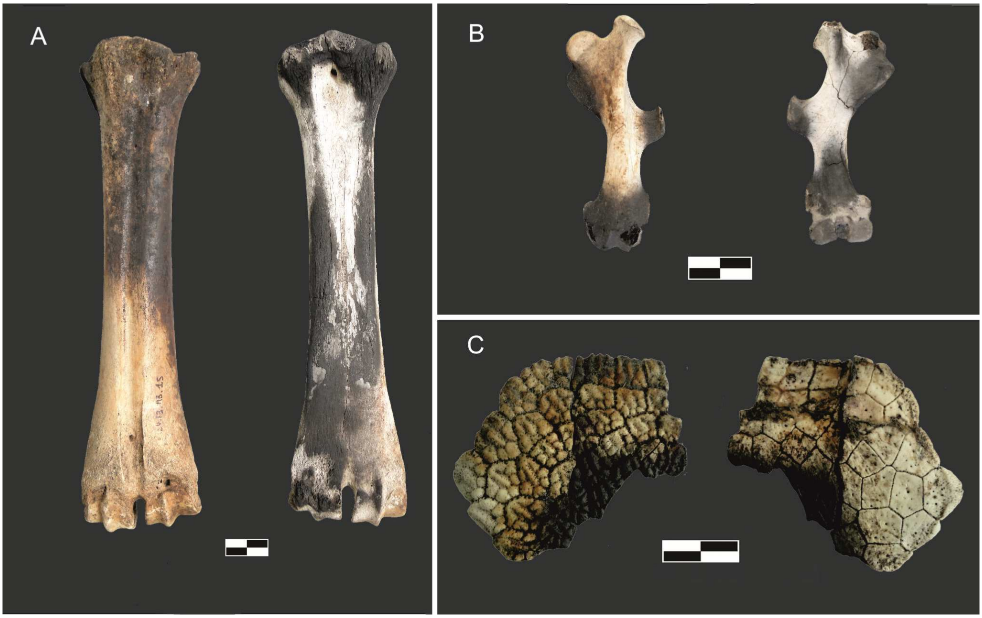

Figure 3. Differential thermal alteration on three bone elements. (A) *Bos taurus* metapodial (left image=scorched anterior view; right image=carbonized posterior view). (B) Dasipodidae femur (left image=scorched anterior view; right image=carbonized posterior view). (C) Scorched fragment of Dasypodidae carapace (left image=dorsal surface; right image=ventral surface). Scale=2 cm.

on both sides. However, all the plates scorched on the dorsal surface were part of the single piece of carapace (Figure 3C).

Table 4. Thermal alteration of Dasipodidae plates.

	Dasipodidae plates			
Burning State	Both surfaces	Dorsal surface	Ventral surface	**Total**
Scorched	3	27	1	31
Carbonized	24	4	1	29
Calcined	0	0	0	0
Total	27	31	2	60

Discussion

Our case study of a grassland fire in the Pampas region indicates a high proportion of bones with thermal alteration (70%), with calcined bones dominating the sample of all sizes (40-53%). These results were unexpected considering that in previous studies of grassland or bush fires, calcination was not frequently recorded (David, 1990; Buenger, 2003, see exception in Keough *et al.*, 2015). This particular grassland fire could have had exceeded temperatures of 500 ºC, or prolonged burning, thus allowing bone more calcination. However, other variables beyond temperature, such as exposed surface and initial state of the bone, could have also conditioned the reached degree of thermal alteration (Symes *et al.*, 2008; Keough *et al.*, 2013).

Our study showed some differences in relation to the size class and burning damage. In particular, a higher extension of burning was recorded for the smaller-sized taxa. Some of the factors that could have conditioned these differences are the number of buried bone, and the state of the specimens prior to the fire (*i.e.*, dry, fresh, defleshed, etc.). Even though we do not know the original characteristics of the bone sample, the different weathering and burial stages suggest varied taphonomic histories. The higher frequency of unweathered and unburied specimens in the sample of small and medium sized animals could indicate that the time between bone deposition and the fire was short. In this sense, during this event, some of these specimens may still have had bone fat or soft tissue. If so, the presence of grease can act as fuel, enhancing the effect of burning. However, the more uniform distribution of thermal alteration observed in the specimens of the smaller animals would suggest that most of them were probably defleshed when exposed to fire (Asmussen 2009; Keough *et al.*, 2015). On the other hand, the more intense weathering profile and a slightly higher percentage of buried bones in the large-sized bone sample suggest a longer accumulation history. The advanced weathering profile supports that at least a significant part of this sample was dry prior to the fire. Moreover, the covering with sediments could have protected them from the fire (Figure 3A-B). In this sense, all the remains of large mammals with more than 80% of their burnt surface were unburied, while most of the bones (78%) with less than 20% burning were buried or partially-buried. Also, during fieldwork it was observed that in the cases where bones were partially-buried, only the exposed portion was affected by the fire. However, this information was not systematically recorded in the field.

Two other types of modifications produced by thermal alteration, besides the color, are fragmentation and changes in texture. Although we payed special attention in recording both variables, it was problematic to differentiate if these changes were produced by thermal alteration, or a previous taphonomic process. In particular, carnivore action (mainly for small and medium-sized animals) and weathering (mainly for large-sized animals) could have produced these fractures. Also, this last process could have generated a cracking-like texture.

The burnt pattern caused by a grassland fire shows some differences with human induced fires (*e.g.*, cooking). Experiments with small animals indicate that burning –usually carbonized– is concentrated in the epiphyses of the long bones, as well as sectors of the maxilla, the mandible, and the incisors; as these are the portions less protected by muscle tissues (Henshilwood, 1997; Lloveras *et al.,* 2009; Medina *et al.*, 2012). On the contrary, in our study, the majority of the bones were uniformly burned –carbonized and calcined–, which could be the result of the absence of flesh. However, these characteristics can also be present in assemblages of bones used as fuel or directly disposed in hearths. However, in this last case higher frequencies of fractures would be expected. Another important result of our study is the burnt pattern of armadillo plates, which shows heterogeneity. Scorched, carbonized, and calcined plates were recorded, in one or both surfaces. In the sample of isolated plates, a high proportion was carbonized on both surfaces. Nevertheless, most of the plates in the carapace fragment were burnt on the dorsal surface. Experimental cooking studies of these animals by direct fire and charcoal showed that the external surface of the osteoderms was more affected than the internal surface due to the position of the animal in the fire (Frontini & Vecchi, 2014). Our results indicate that natural fires can mimic the burning damage in armadillo plates produced by cooking when the fire acts on the carapaces or fragments of this anatomical unit. In this particular case, the distribution of the thermal alteration is related to the upward or downward position of the carapace.

Final comments

This study showed that some natural grassland fires affect bone remains in a more intensive way than previously recognized. In our case, the high percentage of calcined bones could have been the result of a combination of elevated temperatures, prolonged burning in, and a dry state of the specimens. However, since the original characteristics of the vertebrate assemblage and the fire are unknown (*i.e.*, maximum temperature, residence and smouldering time, plant biomass, etc.), we cannot determine the exact factors that generated the high degree of thermal alteration. The data presented here suggests that archaeologists working in areas where wildfires can reach high temperatures must be aware of the possibility of natural burning in the fossil record. The taphonomic history of the bone remains should also be considered in interpreting the degree of burning, particularly burning of smaller-sized mammals. More controlled experiments using prescribed methods to simulate natural fires will help to clarify some these issues.

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