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Ten years of actualistic taphonomic research in the Pampas region of Argentina: Contributions to regional archaeology

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A B S T R A C T

Over the last decade, we have conducted an actualistic taphonomic research program in the Humid Pampas of Argentina, in order to build a corpus of information about the taphonomic agents and processes characterizing this sub-region. In this paper, we present a summary of our results after ten years of actualistic taphonomic studies in the Pampas. Our program includes both naturalistic and experimental research. Some of the controlled experiments consist of studies with different-aged guanaco bones, including sub-aerial weathering in a controlled environment, and water transport with disarticulated bones. Other studies were conducted at a local zoo, where we offered different types of prey to native small-sized carnivores (canids, felids, mustelids, and mephitids). Our naturalistic observations include the development of taphonomic transects in different environments. Through this method, we were able to study different topics among which some of the more significant are the movement of bones by small-sized carnivores and the distribution of beached Magellanic penguin specimens along the coast. Particular studies included the analyses of the content of dens occupied by small carnivores, the effects of a grassland fire in a vertebrate assemblage, the modifications produced by a local rodent -vizcacha- in the landscape, and the damage generated by pumas in guanaco carcasses. After ten years of systematic research we contributed to identify the potential mixture between modern bones and the archaeological record in relation to the environment; to determine bone preservation biases according to the properties of the record; to recognize agents responsible of bone accumulation and alteration; and to establish diagnostic criteria in order to differentiate cultural from natural patterns.

1. Introduction

Our main archaeological research is a long-term study with the aim of evaluating the evolution, population dynamics, and historical trajectory of the hunter-gatherer societies that occupied the Pampas grasslands of Argentina during the Late Pleistocene and Holocene. During this long time span, several changes occurred in the technology, subsistence, mobility, demography, and social organization of human groups. We adopt two research perspectives in order to conduct our investigations: regional archaeology and actualistic taphonomy. In terms of regional archaeology, we study chronology, subsistence, mobility, lithic and ceramic technologies, settlement patterns, and the mortuary practices of hunter gatherers (Massigoge, 2007; González, 2010; Gutiérrez et al., 2011; Álvarez et al., 2013; Kaufmann and González, 2013; Gutiérrez and Johnson, 2014; Politis et al., 2016; Rafuse, 2017). In parallel, we carry out actualistic taphonomic studies (naturalistic and experimental *sensu* Marean, 1995) in order to generate frames of reference to understand patterns of accumulation, preservation, modification, and destruction of bone assemblages. This knowledge is critical when interpreting human subsistence practices and paleoenvironment properties from archaeofaunal assemblages. In this paper, we present the main results of the different lines of research that make up this long-term taphonomic program. Some of these lines are finished, while others are currently under development; consequently, the scope of the results differs among them.

The advance of taphonomy in Argentina began in the second

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half of the 1980s. In Pampean archaeology, this field became important during the end of this decade, particularly when faunal studies were incorporated within an interdisciplinary framework. During these early years, the collaborative work between Pampean archaeologists (including the first author of this paper) and Dr. Eileen Johnson promoted the incorporation of a taphonomic perspective in the archaeological research (Johnson et al., 1998), and was the starting point for the development of an integral taphonomy program which continues today. At first, we focused on the analysis of bone modifications in zooarchaeological assemblages for building taphonomic histories of archaeological sites (Gutiérrez, 2009). Beginning in the early 2000s, we performed isolated experiments to test hypotheses emerging from our studies of archaeological sites. These experiments, which can be viewed as the beginning of the actualistic stage of our research, lead us to change our interpretation of the sites. As a consequence, faunal assemblages once considered anthropic in nature were the result of natural formation processes (Gutiérrez and Kaufmann, 2007; Kaufmann and Gutiérrez, 2004). Since 2006, actualistic taphonomy has been systematically engaged in our archaeological research, and new topics were incorporated. In this paper, we present a summary of our results after ten years of actualistic studies in the Pampas.

2. Study area

Our actualistic studies are carried out in the plains and coastal areas of inter-sierra grasslands and the Tandilia hills of the Pampas region of Argentina (Fig. 1). The interior plains are characterized by eolian and floodplain deposits. The eolian deposits are comprised of sandy loess, very fine sand sheets, and dune fields (Zárate and Blasi, 1993). The coast environments include extensive beaches with large dunes, rocky cliffs, and shallow freshwater lakes which house a variety of birds and mammals (Marcomini and López, 2013). The foothills of the mountain ranges lie on a Precambrian base with shallow dry soils and steep terrain which prevents the deposit of loess (Zárate and Folguera, 2009). The regional landscape is greatly affected by farming and urbanization. The climate is temperate and humid, with an average rainfall of 900 mm (Stutz et al., 2010). The area is characterized by low archaeological visibility and a near absence of native ungulates (i.e., *Lama guanicoe*) that once constituted the main prey of prehispanic hunter-gatherers (Martínez and Gutiérrez, 2004).

3. Bone intrinsic properties: mineral density analysis

Since previous research has shown that bone mineral density (BMD) is an important variable influencing the bones response to many taphonomic processes (Brain, 1981; Lam et al., 2003; Lam and Pearson, 2005; Lyman, 1984), the focus of our research program was to study changes in this intrinsic property in relation to age. Density analysis was conducted on metacarpals (n = 46) and femora (n = 45) of modern guanacos (*Lama guanicoe*) of different age classes (unborn, newborn, juvenile, subadult, adult, senile). One of the most relevant aspects of our research was the large mineral density variability detected in the analyzed skeletal parts. While an increase in density values in relation to age was observed for the metacarpal, this trend was not registered in the case of the femur (Gutiérrez et al., 2010). Contrary to our expectation, this variability would not be primarily related to the ontogenetic development of the species; as possible other biological variables could have affected bone mineral density in some degree.

Our study from a large sample of these two skeletal elements showed that bone density is highly variable for each element, mainly for the younger individuals. Taking into consideration the observed variability, part of which could be a response to ontogenetic development, we had proposed in previous articles (Gutiérrez et al., 2010; González et al., 2012) that the bone density indices currently used in zooarchaeology underestimate the variability in BMD values for each skeletal element or portion. Most of these

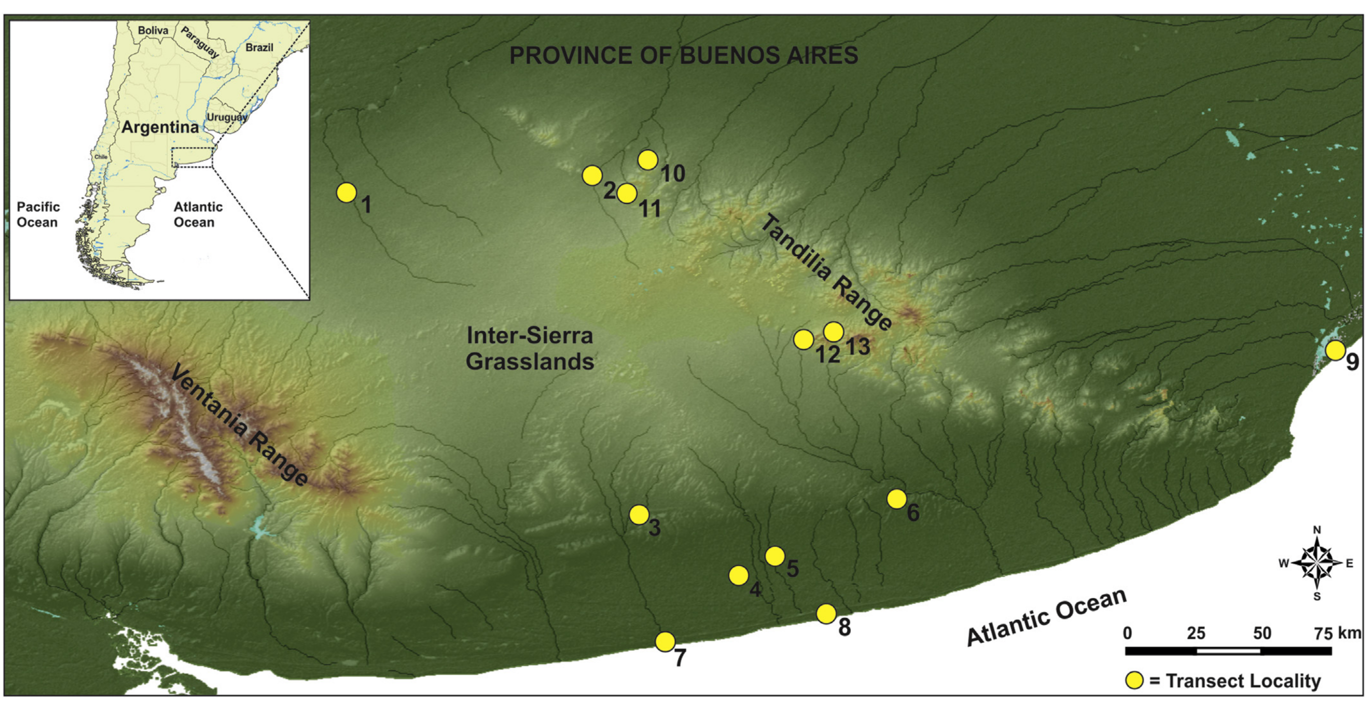

Fig. 1. Map of the study area with the location of the actualistic studies. Plains, river valleys, and lakes: (1) General La Madrid, (2) Olavarría, (3) Arroyo Seco, (4) Orense, (5) San Cayetano, and (6) La Dulce. Coast and lagoons: (7) Claromecó, (8) Balneario San Cayetano, and (9) Mar Chiquita. Hills: (10) Cerro Largo, (11) La Vertiente, (12) Cerro La Tinta, and (13) Siempre Verde.

indices are built upon a limited number of individuals. For this reason, we suggested to construct bone density indices by using a large sample of individuals and excluding immature animals. In accordance, when applying these indices to archaeological assemblages, we proposed correlating the %MAU with density values only for fused elements (Gutiérrez et al., 2010).

4. Controlled experiments

4.1. Bone hydrodynamic behavior

Fluvial transport of bone in archaeological sites located near water sources is an important process to consider when studying the fossil assemblage (Behrensmeyer, 1975; Coard, 1999; Pante and Blumenschine, 2010; Trapani, 1998; Voorhies, 1969). We have conducted an experiment to evaluate the potential of hydrodynamic sorting of disarticulated guanaco bone elements using an artificial channel. Dry and wet specimens from newborn, juvenile and adult individuals were placed in controlled flow velocities (30 cm/s and 15 cm/s) (Kaufmann et al., 2011). This experiment showed that the dry bone elements from all three age categories were more frequently transported in lower flow velocities than wet specimens. In both the wet and dry conditions, the unfused long bone epiphyses, vertebrae, phalanges, and podial bones from the newborn and juvenile individuals were the more easily transported elements. Also, larger and denser bone elements such as the skull and mandible have low chances of being transported in low energy fluvial context (Kaufmann et al., 2011). Consequently, the age and state (wet or dry) of the bone element is a relevant variable in fluvial transport. In archaeological sites which are impacted by fluvial transport, the original mortality profile could be affected with underrepresented newborn and juvenile individuals (Kaufmann et al., 2011).

4.2. Bone weathering

Since 2006 we are conducting a long-term experiment with the objective of evaluating the effects of weathering (*sensu* Behrensmeyer, 1978) on guanaco bones of three different age groups (newborn; juvenile; and adult). The aim of this experiment is to explore how bone weathering can alter skeletal and mortality profiles in bone assemblages. The skeletal elements, without soft tissues, were placed on a sandy and well-drained substrate lacking vegetation. In 2011, a skeleton of an adult individual of the flightless bird, Greater rhea (*Rhea americana*) was included in our study. So far we have published partial results during the first eight years of exposure for the guanaco and the first three years of Greater rhea (González et al., 2012; Gutiérrez et al., 2016a; Massigoge et al., 2010).

The results indicate that after two years of exposure, all bone elements of the guanaco skeletons registered weathering, and that after eight years, weathering stage 1 was no longer present, and stage 2 was only present in the adult (Gutiérrez et al., 2016a). Our experimental study supports the idea that the bones of immature animals weather at a higher rate than those of adults. After eight years of exposure, the two carcasses of the younger individuals reached stage 5, unlike the adult which reached stage 4. Stage 5 weathering occurred by the third year of exposure in the juvenile, and sixth year of exposure in the newborn. The weathering profiles of the younger individuals show a predominance of bones in stages 4 and 5, whereas in adult, stages 3 and 4 prevail. Some elements of the newborn were completely destroyed after reaching stage 5 (skull, mandible, cervical vertebra and rib) (Gutiérrez et al., 2016a).

Comparing the results of the guanaco and Greater rhea skeletons, our expectation was that the weathering rate of the bird would be higher than that of the mammal. Our observations indicated that the adult individuals of guanaco and Greater rhea showed different trends in the evolution of weathering stages after three years of exposure. The maximum weathering stage reached by both species was 3, although the Greater rhea presented a greater number of elements in this stage. Also, the Greater rhea reached stages 2 and 3 before the guanaco (first and second year, respectively). On the other hand, some bird bones were still in stage 0 after three years of exposure (Gutiérrez et al., 2016a).

The elements most affected by weathering were skull and mandible of all the guanaco skeletons. The weathering rate was higher in the skulls and mandibles of newborn and juvenile individuals. The cranium and the mandible of the newborn were completely destroyed after six years of exposure (Fig. 2; Gutiérrez et al., 2016a: Figs. 6 and 8). As for the juvenile, the skull lost its morphology by the fourth year of exposure, and two years later only scattered fragments were left. After six months of exposure the teeth of newborn individuals lost their integrity, so they would be absent or underrepresented in mortality profiles. The crowns of some teeth of the juvenile individual fractured completely by the fifth year; however, some loose premolars and molars could still be identified after eight years of exposure (Gutiérrez et al., 2016a; Massigoge et al., 2010).

From our experiment two important results stand out: the intensity of the bone weathering was greater in the youngest individuals. This trend suggests that biases can be recorded in the mortality profiles of zooarchaeological assemblages. In addition, our results warn about some aspects that need to be considered by the analyst, such as differential bone preservation by age class and intra-individual. As the exposure time advances, the guanaco axial skeleton presents slightly higher stages of weathering than the appendicular. These aspects have been registered in naturalistic studies in Patagonia (Borrero, 2007; Cruz, 2007; Cruz and Muñoz,

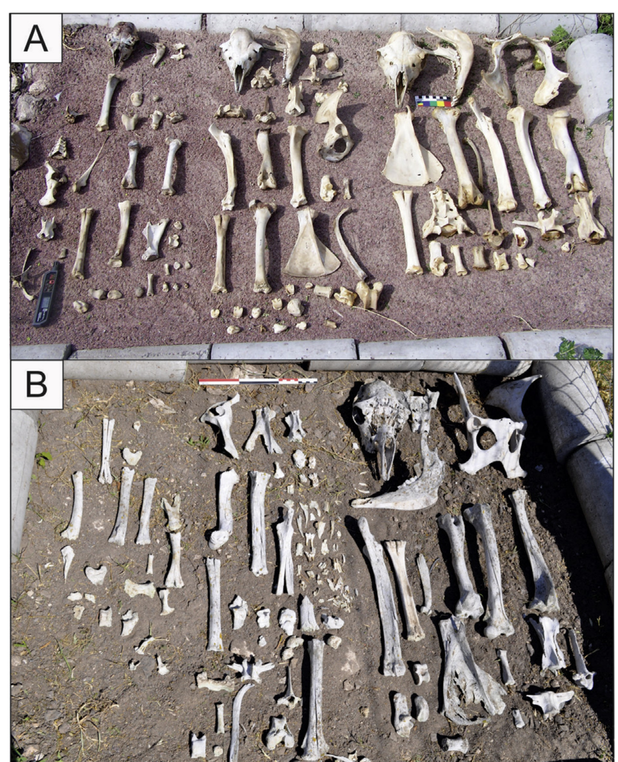

Fig. 2. Weathering experiment of three guanacos. (A) 2006; (B) 2014. From left to right: newborn, juvenile, and adult.

2010).

4.3. Small-sized carnivores

Carnivores are considered one of the primary taphonomic agents that can accumulate and modify bones in archaeological sites (Andrews, 1990; Andrews and Evans, 1983; Borrero et al., 2013; Fernández-Jalvo and Andrews, 2011; Martin, 2013; Mondini, 2000). They introduce and extract bones, scavenge food remains, and fracture bones during and after human occupations (Bertino et al., 1994; Binford, 1981; Blumenschine and Marean, 1993; Camarós et al., 2013; Haynes, 1980; Lyman, 1994; Martin and Borrero, 1997; Mondini, 2004; Stiner, 2004; Yravedra, 2010). Carnivore modifications are frequent in many archaeological sites in the Pampas region, however, few actualistic models exist for the area which permit evaluating the significance of these agents. For this reason, since 2010 several feeding experiments with native Pampean carnivores (Geoffroy's cat, Pampas fox, puma, Lesser grison, Hog-nosed skunk) have been conducted in a local zoo to generate a model of destructive behavior for these animals on small preys. Until present, we have analyzed and compared the results of the non-ingested samples of Pampas fox and Geoffroy's cat fed with domestic rabbit (*Oryctolagus cuniculus*). Although this leporid is not native to the region, its size and bone structure is similar to many small wild mammals in the area (e.g., Plains vizcacha, Patagonian hare, and coypu). The variables considered during the analysis of the rabbit remains included anatomical representation, breakage, and bone surface modifications (Álvarez et al., 2012; Massigoge et al. 2014; Rafuse et al., 2014).

The results indicated that both carnivores generate significant bone destruction on rabbit remains. The average relative abundance and indices that assess skeletal representation showed that the two predators destroy bone elements similarly. The skull, mandibles, pelvis, and long bones (mainly the femur and the tibia) presented good survival rates. Axial elements, such as the vertebrae and ribs, showed very low survival rates. In both samples, there was a positive correlation between the relative abundance of skeletal parts and bone density, which suggests that this bone property is one of the factors that condition bone destruction. Regarding the bone surface modifications, our results demonstrated that both carnivores generated the same types of tooth marks and in similar proportions, in particular pits and scores. Also, the dimension of the pits produced by both predators is similar. In accordance with other colleague's results (Andrés et al., 2012; Delaney-Rivera et al., 2009; Domınguez-Rodrigo and Piqueras, 2003), the size of the tooth marks only allows an approximation to the size of carnivore involved. According to the results reached so far, none of the mentioned variables proved to be a good diagnostic criterion to distinguish the action of these two predators.

5. Naturalistic observations

5.1. Taphonomic transects

5.1.1. Field methods and general results

We are conducting a long-term naturalistic study that includes the development of systematic taphonomic transects in a variety of environmental contexts that are representative of the study area (Fig. 1). These are hills, shallow lakes, lagoons, coast, plains, and river valleys. The specific objectives of this study are: a) to identify the taphonomic processes and agents present in major geomorphological formations of the mentioned environments, b) to evaluate how these agents and processess contribute to the accumulation, destruction and burial of faunal remains in these environments, and c) to recognize the diversity and regularity of the taphonomic agents in order to establish specific patterns that permits the identification of these agents in archaeological contexts. This line of research is in progress and continually incorporates new environmental contexts or expands the already sampled areas.

In each locality, 10 m wide transects of variable lengths were surveyed. Each transect was divided into 50 m samples which recorded the sediment type, slope, potential for burial of faunal material, type and distribution of vegetation, bioturbation, presence of living animals or modern human activity, archaeological materials, and visibility based on vegetation land cover. Each individual finding was recorded on a standardized data sheet with specimen or carcass ID numbers and the corresponding variables. The following variables were recorded for each vertebrate remain: taxon; presence of soft tissue; element; fusion state; completeness; articulation among elements; burial state (following Behrensmeyer and Dechant Boaz, 1980); inclination; stage of weathering (Behrensmeyer, 1978; Behrensmeyer et al., 2003); and other taphonomic modifications such as sedimentary abrasion, carnivore and rodent marks, root etching, manganese stains, and trampling (Behrensmeyer, 1978; Binford, 1981; Grayson, 1984; Gutiérrez and Kaufmann, 2007; Haynes, 1980; Lyman, 1994; Olsen and Shipman, 1988; Shipman, 1981).

The survey covered a total surface of 937,320 m^2 (93.7 ha) (Table 1). The highest visibility was recorded at the coastal localities and the lowest was registered at the river valleys. Vertebrate remains were classified as disarticulated bones ($n = 2674$), occurrences of articulated bones ($n = 72$), and carcasses ($n = 20$). The shallow lakes and hills presented the maximum density of remains and plains and lagoons the lowest. Different taxonomic classes were identified, including fish (2.3%), amphibians (0.1%), reptiles (0.1%), birds (19.5%), mammals (67.6%), and indeterminate taxa (10.4%). The highest taxonomic richness occurred along the coast, and the lowest taxonomic richness in the plains. Along the coast, European hare (*Lepus europaeus*) and Magellanic penguin (*Spheniscus magellanicus*) were the most frequent species. In the lagoons, river valleys and shallow lakes, large mammals were predominant (mainly cattle). In the hills and plains, medium-sized mammals were the most frequent (European hare and Plains vizcacha, respectively). According to the number of natural processes modifying the faunal remains, the margins of the shallow lakes are one of the most highly dynamic environmental settings. This is a very important aspect for regional archaeology since many sites in the Pampean region are located in these settings. In these contexts, the probability of natural processes affecting the archaeological assemblages would be higher. Regarding the types of modifications, the most frequent process in all environments was weathering; particularly in the plains and along the coast. Sedimentary abrasion was prominent along the coast; however, this modification was absent in the plains, and presented low frequencies in the remaining environments. All the environments showed evidence of carnivore modifications; the highest percentage was recorded in the hills, and the lowest percentage along the coast. With the exception of chemical deterioration in the lagoons and manganese staining in the shallow lakes, the remaining types of taphonomic modifications were registered in very low proportion.

5.1.2. The movement of bone by small-sized carnivores

During our taphonomic transects, we identified clear evidence of bone movement by small-sized carnivores in two environments: coast and hills. In the hills locality of Cerro Largo (Fig. 1), the criteria used to indicate movement were the presence of domestic farm animal bones from a nearby ranch house with evidence of human processing (modern knife marks) and carnivore marks. Along the survey transects bordering the top of the hill (*ca.* 300 masl) we

Table 1
Bone frequency and taphonomic modifications from transects.

Environments	Hills		Shallow lakes		Lagoons		Coast		Plains		River valleys		Total	
Sampled area m^2	70,500		136,670		65,000		501,900		27,950		135,300		937,320	
Total number of remains	305		646		121		1344		48		302		2766	
Taphonomic modifications	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Weathering	97	31.8	261	40.4	14	11.6	715	53.2	33	68.8	121	40.1	1241	44.9
Root etching	8	2.6	19	2.9	1	0.8	12	0.9	1	2.1	17	5.6	58	2.1
Carnivore marks	123	40.3	89	13.8	19	15.7	128	9.5	6	12.5	33	10.9	398	14.4
Rodent marks	2	0.7	2	0.3	2	1.7	0	0	0	0	0	0	6	0.2
Trampling	1	0.3	19	2.9	1	0.8	1	0.1	0	0	6	2	28	1
Chemical deterioration	14	4.6	19	2.9	22	18.2	8	0.6	0	0	14	4.6	77	2.8
Thermal alteration	0	0	0	0	0	0	0	0	0	0	1	0.3	1	0
Abrasion	2	0.7	51	7.9	33	27.3	809	60.2	0	0	14	4.6	909	32.9
Manganese staining	0	0	83	12.8	6	5	1	0.1	0	0	3	1	93	3.4
Calcium carbonate coating	0	0	34	5.3	0	0	0	0	0	0	0	0	34	1.2
Butchering marks	3	1	14	2.2	5	4.1	12	0.9	1	2.1	13	4.3	48	1.7

identified sheep (*Ovis aries*) and chicken (*Gallus gallus*) bones with evidence of these modifications. Here, bones were transported and deposited (probably directly from the house garbage dump nearly 500 m away) by native carnivores or domestic/free-range dogs. Another example of bone movement by small carnivores was observed in the costal localities of Mar Chiquita and Balneario San Cayetano (Fig. 1). We inferred carnivore transport by identifying marine vertebrates (fish, sea-turtle, penguins, and seals) with carnivore marks deposited 650 m from the coastline in an active dune sub-environment. In a subsequent field work, in order to observe the type of carnivores involved, we positioned a game camera along the coastal locality of Claromecó (Fig. 1), where abundant penguin carcasses were identified. Here, we captured a video of a local fox (Pampas fox, *Lycalopex gymnocercus*) interested in a penguin carcass (Fig. 3 and Supplementary Data 1).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.quaint.2017.09.025.

Results from our taphonomic transect data suggests that a broad range of aspects interplayed in the bone movement and accumulation processes. The rock shelters of the hills appear to have acted as areas of refuge for small-sized carnivores, as well as the final locus for the accumulation of prey. On the other hand, the broad open environment of the coast suggests multiple bone movement and accumulation possibilities, including tidal action and scavenging birds. The hills and cost locations are areas where

Fig. 3. Game camera image of Pampas fox (*Lycalopex gymnocercus*) preying on Magellanic penguin (*Spheniscus magellanicus*).

archaeological sites are commonly found, and carnivore transport must be considered an important formation process in the bone assemblage (Gutiérrez et al., 2016b).

5.1.3. Natural distribution of Magellanic penguin carcasses in a coastal locality of the Pampas region

As mentioned above, abundant Magellanic penguin (*Spheniscus magellanicus*) remains were identified in the costal environments, in particular in the locality Balneario San Cayetano. Given the large quantity of remains, we conducted a study to evaluate the natural distribution and taphonomic modifications of this bone assemblage, and discussed the potential for the natural incorporation of this species in the archaeological record. Additionally, the availability and quality of this resource for prehistoric hunter-gatherer populations was discussed.

No penguin breeding populations are present in the Pampas. However, individuals occasionally reach the shore. In general, their presence is the result of beaching during the non-breeding season (March to September), when penguins migrate north to feed along the coastal waters and continental shelf of central Argentina, Uruguay, and southern Brazil (Pütz et al., 2007; Stokes et al., 2014). The penguin bone assemblage was recovered in a survey conducted in December 2012. A total of 105 transects were surveyed, covering an area of 512,900 m^2 in different sub-environments of this locality, including the backshore, active dunes, stabilized dunes, and a freshwater shallow lake located behind the dune field. In this locality, penguin remains considerably outnumbered any terrestrial and aquatic bird.

A total of 213 Magellanic penguin remains were identified, all found along the backshore and active dunes. Most finds were disarticulated bones without soft tissue, with just a few occurrences of articulated bones, and carcasses. Most of the penguin remains belonged to adult individuals, with just a few subadults (Massigoge et al., 2015). The assemblage from this locality was attritional, as suggested by the presence of penguin remains in different stages of decay. Natural processes such as water transport, weathering, sedimentary abrasion, and predator action highly affected the distribution and preservation of specimens. The combined action of these processes promoted a fast decay of carcasses and bones. Variation in the time of disarticulation and in the structural bone properties of the distinct body parts resulted in a differential survivorship of skeletal elements. The resulting skeletal pattern was dominated by limbs (primarily humerus and femur) and pectoral girdle elements (mainly coracoids) (Massigoge et al., 2015).

Our taphonomic results indicated that the natural incorporation of penguin bones into surface archaeological sites can be expected along the backshore and deflated interdunes. However, the chances of long term burial and bone preservation are low; thus, the formation of a stratigraphic archaeological site containing intrusive penguin remains in these settings is unlikely. A higher probability of mixed archaeological and modern penguin bones is expected along the margins of interdune shallow lakes, where carnivores can introduce penguin bones and the sediment deposition can favor bone preservation. In relation to the availability and quality of this resource for prehistoric hunter-gatherer populations, ecological data of this species suggested that even though penguins could have been a potential prey, they were not an attractive food resource given their scarcity and poor nutritional condition when beached (García-Borboroglu et al., 2010; Massigoge et al., 2015).

5.2. Particular studies

Under this section we group those studies which are still naturalistic in scope and methodology but were oriented to understand a particular taphonomic agent. Specifically, they were pursued to study the modifications that such selected agents can leave on individual bones and bone assemblages; and to identify the archaeological implications.

5.2.1. Dens occupied by small carnivores

Between 2010 and 2013 a naturalistic study was carried out in a small carnivore den located on the banks of the Salado creek, General La Madrid County (Fig. 1). The studied bone assemblage was formed by non-ingested prey remains that were deposited in various events by Pampas fox (*Lycalopex gymnocercus*) and other small carnivores such as felids and mustelids (Kaufmann, 2016). Bone accumulation consisted of 1266 remains of various species, such as Southern long-nosed armadillo (*Dasypus hybridus*), Hairy armadillo (*Chaetophractus villosus*), hare, Plains vizcacha, Pampas fox, and cow (Fig. 4). The estimation of taxonomic abundance (NISP and MNI) shows that armadillos and hares are the most abundant prey in the bone assemblage. The skeletal representation of the hare is dominated by the postcranial skeleton, with underrepresentation of vertebrae and the anterior limb. With respect to the proximal elements, the zigopodium is slightly underrepresented. The most abundant skeletal elements in the armadillo sample are the dorsal scutes, caudal tubes, and vertebrae. The caudal tubes are associated with minimal soft tissue and would not be attractive to predators, an aspect that is manifested in high survival and a low frequency of damage (Kaufmann, 2016).

The percentage of specimens affected by carnivores was lower in armadillos (8%) than in hares (15.6%). The bones that presented the highest frequency of carnivore marks in hare are those that are associated with abundant meat like the pelvis, humerus, and femur. In the armadillos, the most affected element was the zigopodium, followed by the innominate, the axial skeleton, and a low frequency in the caudal vertebrae. Results suggested that the intensity of damage was influenced by the particular bone structure of the armadillos, in which the pelvis, lumbar vertebrae, and caudal vertebrae are less accessible to carnivore gnawing. Pits, punctures, and scores are the most abundant type of tooth marks. The bone elements analyzed in both taxa presented high percentages of completeness (Kaufmann, 2016).

5.2.2. Thermal alteration in a natural grassland fire

In September 2015, we collected a modern sample of bones from a low hill (locality La Vertiente, Olavarría County, Fig. 1) after the occurrence of a natural fire. The burnt area was approximately 1.75 km^2 and contained grass vegetation that was fully consumed by the combustion. The original characteristics of the fire are unknown (i.e., maximum temperature, residence and smoldering time, plant biomass). The survey was conducted through nine transects and covered an area of 45,000 m^2. The sample was classified in three taxon size categories: small (<1 kg), medium (1–20 kg), and large-sized vertebrates (>20 kg). According to the color of the cortical surface of the bones, three burning stages were determined: scorched, carbonized, and calcined. The burning profile was constructed by tallying specimens by their maximum burning stage. Also, the change in texture produced by the burning was recorded using the categories: glassy, cracking, and powdery. The percentage of the bones surface with thermal alteration was recorded considering intervals of 20% (Cain, 2005; Costamagno et al., 2005; David, 1990; Galeano and García-Lorenzo, 2014; Nicholson, 1993).

A total of 917 faunal remains were recovered, including 312 isolated dermal plates and 1 fragment of armadillo carapace

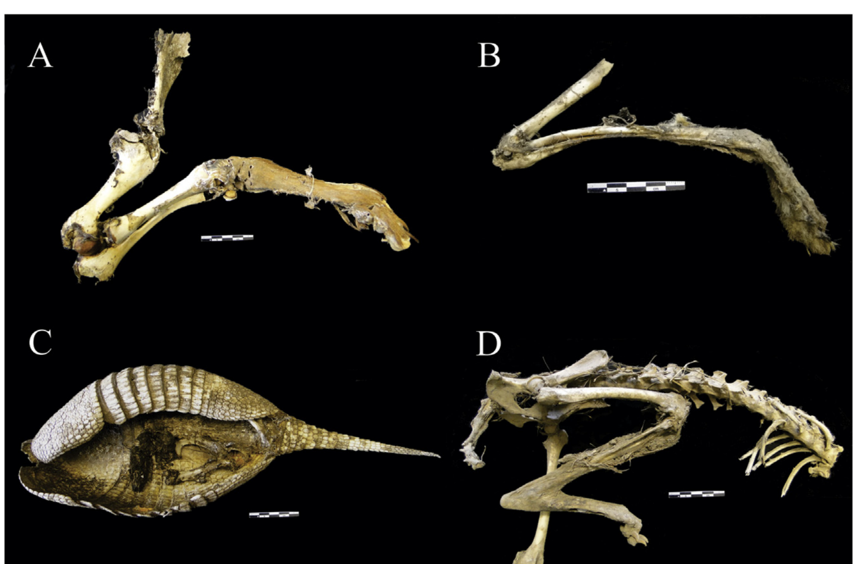

Fig. 4. Articulated portions recovered in carnivore den. (A) Forelimb of *Bos taurus*; (B) forelimb of *Lepus europaeus*; (C) carapace of *Dasypus hybridus* with feces; (D) hind limb, pelvis, vertebrae, and ribs of *Lycalopex gymnocercus*. Scale = 5 cm.

(Álvarez et al., 2017). In the bones and teeth sample (n = 604), 45.2% corresponded to small-sized animals, 30.8% to medium-sized animals, 18.4% to large-sized animals, and 5.6% to an undetermined category. A total of 403 specimens with thermal alteration were identified. The majority of the bones were calcined, and a small proportion was carbonized. A low percentage of bones from small and medium-sized animals were scorched. The extension of thermal alteration was higher for the small-sized category, where a significant proportion of the specimens were burnt in more than 80% of the surface. On the contrary, for large-sized animals, most of the remains were burnt in less than 20% of the surface. Changes in texture were similar for small and medium-sized animals, where glassy texture was the most common, followed by cracking. On the other hand, the frequency of cracking was higher in the large-sized animals.

This study of a natural fire indicated a high proportion of bones with thermal alteration, with calcined bones dominating the sample. These results were unexpected considering that in previous studies of grassland or brush fires, calcination was not frequently recorded (Buenger, 2003; David, 1990). Our study showed some differences in the burning damage in relation to the size classes. A higher extension of burning was recorded for the smaller taxa. Some of the factors that could have conditioned these differences were the percentage of the buried bone, and the state of the specimens before the fire (i.e., dry, fresh, de-fleshed, burial state, etc.) (Fig. 5).

5.2.3. Effects of burrowing activities by vizcacha

A naturalistic study was carried out in the archaeological locality Arroyo Seco, where an area inhabited by Plains vizcacha (*Lagostomus maximus*) was surveyed (Fig. 1). The Plains vizcacha is a large burrowing rodent (between 5 kg and 9 kg) that lives in communal burrow systems ("vizcacheras") and in social groups integrated by 10–30 individuals (Branch et al., 1994; Jackson et al., 1996). The consumption of plants, the burrowing of complex subterranean galleries and the gathering of materials to establish their territories (branches, bone, rocks, etc.) alter the local habitat. This rodent prefers habitats that were commonly occupied by hunter-gatherers (high and dry terrain), causing a potential mixture of natural and archaeological materials. The Plains vizcacha also constituted an important food resource throughout the Holocene (Martínez and Gutiérrez, 2004; Quintana and Mazzanti, 2011). Subsequently, when Plains vizcacha remains are recovered in archaeology sites, determining their origin can be problematic. In order to recognize the action of this rodent in the formation of archaeological sites, and to characterize their burial and accumulation habits, we analyzed 32 "vizcacheras" from this locality (Rafuse et al., 2017). The materials around the burrows were collected and taphonomic analyses were carried out on the bone remains (Fig. 6). The principal materials included branches, caliche, cow dung, plastics, rubber, metal, lithic artifacts, and bone. Among the faunal materials we identified 14 taxa, including mammals, birds, amphibians, fish, and reptiles. The majority of the bone remains corresponded to Plains vizcacha (NISP = 513; MNI = 34) (Rafuse et al., 2017). A differential representation of Plains vizcacha anatomical parts was observed; specifically a high frequency of pelvis, femur, and tibia; and a low frequency of tarsal and carpal bone, phalanges, vertebrae, ribs, and patella. The taphonomic analysis showed that weathering and trampling produced a differential destruction of the bones. The presence of carnivore marks, although in a low frequency, also suggested that carnivores may have altered the bone assemblage. Our data indicates that in locations where Plains vizcachas normally inhabit, their activities produce a strong impact on the local stratigraphy, mixing and accumulating a diversity of materials; including bones of animals that inhabited the burrows. Consequently, in archaeological assemblages where there is evidence of vizcacheras, determination of this rodent as a food resource for humans must be supported by anthropic modifications (Rafuse et al., 2017).

5.2.4. Bone modifications in guanaco killed by puma

The largest predator that we studied from a naturalistic approach is the puma (*Puma concolor*) (Kaufmann et al., 2016). This feline is particularly important from a taphonomic perspective because it is the main natural predator of the guanaco in southern South America (Borrero, 2013; Martínez and Gutiérrez, 2004). Between 2000 and 2006, fieldwork was carried out in the north of the Province of Río Negro (Argentina), where 158 guanaco carcasses were registered by various causes of death (e.g. poachers, puma, accidents with fences) (Kaufmann, 2009). One of the objectives of

Fig. 5. Example of a burnt *Bos taurus* carcass registered along the transects.

Fig. 6. Typical landscape modified by vizcacha (*Lagostomus maximus*). Note in the center left of the photo a local burrowing owl (*Athene cunicularia*).

this study was to provide new data on the bone modification patterns that the puma generates on the guanaco. Although this sample was obtained outside of the study area, we decided to include it in our research program since the interaction between these animals is very limited in the Province of Buenos Aires today.

The studied sample consisted of six guanaco of different ages killed by puma. Different lines of evidence, such as feces and tracks also suggested the scavenging by Pampas fox after the puma kill. Nevertheless, its action would have been limited to the displacement of some disjointed anatomical units and slight gnawing on bony portions (Kaufmann and Messineo, 2002). The puma generated a higher destruction of the rib cage, skull, and the first cervical vertebra in the unborn and young individuals. The sub-adult and adult individuals presented a greater integrity of skeletal elements. A high percentage of bones with tooth marks were recorded and only a few elements were fractured. The types of marks with greater frequency were scores, followed by punctures and pits. As observed in other studies (Martin and Borrero, 1997; Muñoz et al., 2008; Stiner et al., 2012), the punctures were commonly found on the body of the ilium and ischium, and around the femoral head. In general, our results agree with previous studies that observe that this feline produces a slight modification in medium prey (Borrero et al., 2005; Nasti, 2000; Stiner et al., 2012), with a greater intensity of modification in the younger individuals. However, under certain conditions the puma would have the ability to modify adult prey more intensively, including the breakage of the skull to access the brain tissue (Mondini and Muñoz, 2008; Muñoz et al., 2008).

6. Discussion: Research contributions and practical applications

Our results contribute significantly to understanding patterns of accumulation, preservation, and modification of the faunal record. Clearly, our actualistic data alerts us to the limitations of the applications of well-established frames of reference in the discipline, highlighting the importance of having our own set of actualistic data and results. We agree that each analyst cannot generate their own frames of reference they apply in their research; however, researchers need to be aware of the limitations so that they can make better choices when it comes to implementation of these methodological tools.

It is important to mention that in the case of experimental studies, natural variables are isolated or amplified in order to study their specific effects on bone elements. It is particularly important to consider these facts when applying the experimental results to the fossil assemblages. For example, captive animals can show clear differences compared to wild animals in terms of their feeding behavior (Gidna et al., 2013). Nevertheless, we are aware that in the archaeological record, taphonomic processes are interrelated and consequently their effects are also complex and variable. On the other hand, in the case of naturalistic studies, we are aware that the modern ecological conditions have varied over time, and the animal and plant populations have been highly affected by these changes (especially in the Pampas region). However, we still believe that applying a naturalistic approach can produce useful information for: 1) understanding how certain mechanisms of ecological interactions determine patterns of bone accumulation and destruction; and 2) generating expectations of how these modern processes can affect the integrity of archaeological sites. Considering the studies that we have carried out so far, we can highlight the following contributions of our taphonomic research program:

1) *Identifying the potential of mixture between natural faunal remains and archaeological materials in relation to the environment.* The development of taphonomic transects in a wide variety of environments allowed us to estimate the rate of natural deposited bones as well as the potential of contamination of archaeological sites located in different contexts. In this sense, the environments with the higher deposit of bone remains are the shallow lakes and hills. Moreover, observations of bone

accumulations allowed us to identify the places where a higher taxa diversity is expected (e.g., coast). We have also recorded biases in the representation of different anatomical units. Some of these trends depend on the bone properties and for this reason are extendable to other regions. This will allow making inferences in the future about the potential preservation of the bones of different sized animals, as shown by Cruz (2015) in Patagonia. The transect method allowed us to cover an extensive and diverse number of environments, and find bone remains from animals that we did not expect to find in great number in our study area (e.g., Magellanic penguin). This led us to study eto-ecological aspects of this species, and the modern distribution of their bones in the landscapes. Another interesting issue that derives from the transect method is the description and interpretation of the types of bone modifications recorded in each environment. This provides us with general predictions of the types of taphonomic agents and processes we would expect to find in the archaeological sites. Finally, while several animals that are not native to the Pampas (e.g., cattle, domestic dogs, European hare) were recorded; we have learned how to use this data for different purposes. In some cases, data obtained on foreign species (e.g., skeletal representation; differential burning damage) can be used as a comparable dataset for native species. For example, the European hare is a medium-sized mammal whose size is equivalent to some native rodents preyed on by hunter-gatherers (e.g., Plains vizcacha and coypu). Also, as mentioned by Western and Behrensmeyer (2009), these studies can be used to monitor ecological properties of fossil and contemporary communities, as well as evaluate the human impact in animal communities.

2) *To determine biases in bone preservation according to ontogenetic development.* When considering the weathering and fluvial action experiments, together with studies of bone mineral density in guanaco, it was possible to determine that there are significant differences in how different natural processes affect preservation according to age classes. In this sense, one of the trends recorded is that the elements of younger individuals with an incomplete fusion and low BMD, tend to weather faster and present a greater potential for water transport (González et al., 2012). However, our results also highlight the high inter- and intra-individual variability in BMD measurements and the bone response to these processes. To evaluate this variability, it is important to consider the incidence of these particular taphonomic processes in relation to other aspects. On the one hand, with the characteristics of the animal populations involved (e.g., nutritional and health status, lactation, genetics, sex and exercise) (Álvarez et al., 2010; Ioannidou, 2003; Lam and Pearson, 2004; Symmons, 2005), and on the other hand, with the micro-environment and the local context where different agents and processes, both natural and cultural, interact (Belardi et al., 2010; Gutiérrez et al., 2016a; Janjua and Rogers, 2008; Ross and Cunningham, 2011). Therefore, when applying actualistic taphonomic models to the archaeological record, the different contextual aspects and properties of the bone assemblage should be considered.

3) *To identify some of the natural agents of accumulation and alteration of bone remains at archaeological sites and characterize their taphonomic patterning.* During these years we have learned how native carnivores and rodents can potentially contribute to the formation of faunal assemblages in archaeological sites, either bringing in bones or removing or destroying bones discarded by humans. Our naturalistic observations in the Pampas region indicate that the Pampas fox and the Plains vizcacha transport and accumulate bones of different sized animals (e.g., chicken, penguin, hare, armadillos, sheep, cow) in particular places of the regional landscape, such as rock shelters, ravines, and low lying knolls. These places were frequently occupied by prehistoric hunter-gatherer groups and, as a consequence, mixing of archaeological materials and bones accumulated by these native animals should be expected. Additionally, the Plains vizcacha transports locally available objects to the context of their burrows and generates ecological niches, which facilitate the occupation by a high diversity of animals (small carnivores, anurans, and birds, among others). As already mentioned by other researchers (Arias et al., 2005), our naturalistic observations corroborate that the Plains vizcacha, like other species such as beaver (Nummi and Hahtola, 2008) and termites (Kaiser et al., 2017), are true ecosystemic engineers. During the construction of their complex galleries (Branch et al., 1999) the Plains vizcacha displaces a large volume of sediment, and disturbs the stratigraphy of a large portion of the landscape.

On the other hand, our experimental studies with Geoffroy's cat and Pampas fox indicate that these small carnivores produce important bone destruction when feeding on small preys, especially those elements from the axial skeleton. A similar pattern of anatomical representation was observed in the non-ingested bone samples from leporid carcasses consumed by other species of small canids and felids (Cohen and Kibii, 2015; Lloveras et al., 2016; Rodríguez-Hidalgo et al., 2013). Also, our feeding experiments showed that both carnivores produce the same types of tooth marks, predominating pits and scores. These patterns help to identify the role of small carnivores in the accumulation and/or scavenging of small vertebrates in archaeological sites.

4) *To generate diagnostic criteria in order to differentiate cultural from natural patterns.* An additional contribution made by our taphonomic project was the attempt to obtain criteria to differentiate cultural from natural patterns in faunal assemblages. We have focused on the representation of skeletal parts generated by carnivores and studied the patterns of thermal alteration produced by natural fires in different size vertebrates. According to our experiments, the underrepresentation of the axial skeleton in small mammal samples from archaeological sites should alert to the potential participation of small carnivores in the formation of the assemblages. The burnt pattern caused by a grassland fire shows some differences with the pattern produced by cooking. Nonetheless, the high frequency of uniformly burned bones -carbonized and calcined- resembles assemblages of bones used as fuel or directly disposed in hearths. In this sense, thermal alteration should not be used as evidence of human exploitation in the absence of discrete burning features or other cultural modifications such as cut marks. Both of these results highlight the complex mixtures of cultural and natural processes recorded in archaeological sites, and the difficulties in distinguishing them during analysis.

Our research has important implications to a variety of archaeological and paleontological studies, as well as forensic taphonomy, biology, and ecology. While our controlled experiments and naturalistic observations deal with native fauna, the results have some global implications. For example, considering the intrataxonomic variability in BMD has practical applications which helps archaeologists deal with the potential age-related taphonomic bias in the mortality profiles (Gutiérrez et al., 2010; Massigoge, 2012; Symmons, 2005). Still, to clarify the influence of age and other biological factors in BMD, some difficulties need to be addressed, including a larger sample size with other anatomical parts (Gutiérrez et al., 2010). Just as potential age related bias exists for measuring skeletal element survival, so does knowing the degree to which the taxonomic, anatomic, and age representation are biased by natural processes like fluvial transport and bone weathering (Gutiérrez et al., 2016a; Kaufmann et al., 2011). Fluvial transport is one of the most important processes that can affect bones in archaeological sites located close to bodies of water. The frame of reference proposed in Kaufmann et al. (2011), has been applied in various contexts and taxa, helping researchers estimate the role fluvial transport has had in bone accumulation (Jenkins et al., 2017; López et al., 2016; Massigoge et al., 2017; Organista et al., 2017; Tomassini et al., 2014; Zunino et al., 2012). Similarly, knowledge of intrataxonomic variability in bone weathering informs researchers of the potential bias in differential bone destruction (Saña et al., 2014). Developing standardized experiments of bone fluvial transport and bone weathering for different taxa is essential. However, experiments in bone weathering are long term; a single experiment may require more than 10 years of data recording. Weathering experiments are also destructive, which limits the number of skeletons that can be examined.

Naturalistic studies provide valuable information about taphonomic processes in different environments and contexts, such as the movement of bone (García-Viñas and Bernáldez-Sánchez, 2017) or carcass accumulation (Bochenski et al., 2017). Although all intervening factors cannot be controlled in nature, these studies permit to evaluate interactions or processes which cannot be produced in experiments. One major issue we faced in the construction of the taphonomic transect data is in field and lab recording methods. Uniform recording methods and standardized terminology is needed when dealing with these types of datasets, especially with multiple analysts. Digital recording devices in the field, such as tablets or handheld computers, can help reduce recording errors and allow for better data transfer and quantification in the laboratory (Smith and Levy, 2014).

The experimental data generated with small-sized terrestrial carnivores have provided practical applications for archaeological research at the local (Fernández et al., 2017; López et al., 2016; Mondini, 2017; Montalvo et al., 2015) and global scale (Armstrong, 2016; Arriaza et al., 2017a; Cohen and Kibii, 2015; Lloveras et al., 2016). Nonetheless, it is important to consider the variability which exists in the behavior of these different predators (captive vs wild, number of predators, different prey, etc.). Furthermore, methodological tools must be consistent; particularly anatomical representation indexes that measure the proportion of small-sized vertebrate elements (Andrews, 1990; Álvarez et al., 2012; Fernández et al., 2017; Fernández-Jalvo & Andrews, 1992; Lloveras et al., 2008). New methods for measuring and quantifying data must also be implemented; including computational methods for quantification such as 3D imaging to measure carnivore modifications (Aramendi et al., 2017; Arriaza et al., 2017b), as well as and standardized terminology of the marks generated by carnivores (James and Thompson, 2015).

As a final point, the taphonomic research developed here has practical applications for fields outside of archaeology. For example, in the field of forensic taphonomy; the transport and destruction of bones produced by carnivores is particularly relevant (Pokines, 2013). Data from wildfires also provides insights for this field (Symes et al., 2008). Naturalistic studies in specific environmental localities can also have practical applications in the field of conservation biology, ecology, and paleontology. In the case of beached penguin carcasses recorded along the coast of the Province of Buenos Aires; this information provides ecological information on modern distribution, migration patterns, and mortality of the Magellanic penguin (Massigoge et al., 2015). Research projects designed with an interdisciplinary approach, using standardized recording methods and terminology will help provide more useful applications across a number of disciplines.

7. Final remarks

The results of the taphonomic research program synthesized here are designed to form part of a larger corpus of actualistic data intended to be used in a variety of environmental and interdisciplinary contexts. Our research, which is strongly oriented towards the archaeological record, has broad results which can be applied to fields such as paleontology, biology, and forensics. This interdisciplinary research approach is progressively intergraded into our future agenda.

This paper shows the abundant information that our actualistic taphonomic program generated during the last 10 years, which positively impacted the advance of knowledge in Pampean archaeology. This actualistic program originated after several years of analyzing taphonomic effects in the zooarchaeological assemblages and as a natural consequence of understanding the contribution of modern environments for interpreting the formation of archaeological records. The development of a strong taphonomic perspective in our investigation responds to both the need for solid answers to several research problems in Pampean archaeology, and to the collaboration and participation of Eileen Johnson to our archaeological project. She taught us the benefits of taphonomy as a guiding discipline for archaeological interpretations.

The incorporation of the results of the actualistic taphonomy to the archaeological investigations of the Pampas region is gradual and its integration is still not complete. Clearly, our greatest contribution today is linked to the recognition that modern processes can provide us with valuable information to understand the past, even if the current environment is highly modified. New actualistic studies that consider environments, processes and agents not yet explored and, consequently, a greater diversity of interactions and contexts, will favor the construction of broader and more solid databases. It will be then when the incorporation of the results into archaeological research will be transformed substantially.

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