The Role of the Accipitriformes *Geranoaetus melanoleucus* and *Geranoaetus polyosoma* as Small Mammal Bones Accumulators in Modern and Archaeological Sites from Central Western Argentina

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Results of the taphonomic analysis of small mammal bone accumulations generated by the accipitriforms *Geranoaetus melanoleucus* and *Geranoaetus polyosoma* in several areas from Central Western Argentina (Mendoza Province) are presented here. In order to identify the role that these predators had in the formation of zooarchaeological assemblages, the anatomical representation, bone breakage patterns, and degrees of digestive corrosion were evaluated. According to these taphonomic variables, both *G. melanoleucus* and *G. polyosoma* may be placed in the Category 4 (heavy) of modification of prey bones. The results presented here were used as an analytical model for the interpretation of the micromammal fossil record from three archaeological sites in Mendoza Province. This comparison suggests that the skeletal remains recovered from one archaeological site are very close to those produced by *G. polyosoma*. However, accumulations from the other sites had intermediate values between those of *G. polyosoma* and *G. melanoleucus*.

Keywords: TAPHONOMY, ACTUALISTIC MODEL, ZOOARCHAEOLOGY, MICROMAMMALS, CENTRAL WESTERN ARGENTINA, RAPTORS

Introduction

Taphonomic studies of small mammal (≤1 kg) bone accumulations are essential for paleobiological and paleoecological interpretations, since many species included in this group have narrow ecological requirements (Fernández-Jalvo *et al*., 2011). These issues constitute a remarkable tool to understand and identify the processes and agents involved in the formation of bone assemblages, thus, revealing the biases of each type of accumulating agent. Predation plays an essential role in the structure and composition of small mammal assemblages. Its effects can be identified from the analysis of modifications in the surface of bones and teeth (mainly digestive corrosion), relative abundance of skeletal elements, and breakage patterns (Andrews, 1990; Fernández-Jalvo & Andrews, 1992; Fernández *et al*., 2017).

In Argentina, taphonomic studies based on accumulations generated by different species of Strigiformes have received special attention in the last years. The barn owl (*Tyto alba*) was the main species identified as small mammal bones accumulator in archaeological and paleontological sites (*e.g*., Pardiñas, 1999a, 1999b; Fernández *et al*., 2009, 2012; Fernández, 2012), followed by the Magellanic horned owl (*Bubo virginianus magellanicus*, Gómez, 2005; Montalvo *et al*., 2015), and the burrowing owl (*Athene cunicularia*, Montalvo *et al*., 2017). In South America, actualistic research has been carried out on small mammal remains predated by diurnal birds of prey including the Chimango caracara (*Milvago chimango*) (Gómez, 2007), southern caracara (*Caracara plancus*) (Gómez, 2007; Montalvo & Tallade, 2009, 2010), white-tailed kite (*Elanus leucurus*) (Montalvo *et al*., 2014) and variable hawk (*Geranoaetus polyosoma*) (Iglesias, 2009). However, archaeological and paleontological records with taphonomic evidences indicating the action of these birds as accumulating agents are still scarce (Fernández, 2012; Montalvo *et al*., 2014; Fernández *et al*., 2015; López *et al*., 2016).

The potential participation of the species of *Geranoaetus* (Accipitriformes) in the accumulation of small mammal remains has already been proposed for three archaeological sites of central west of Argentina, so-called

Rincón de Los Helados –RH– (López *et al.*, 2016), Arroyo Malo-3 –AMA-3– (Fernández, 2012; Fernández *et al.*, 2015), and Cueva Palulo –CP– (Fernández, 2012). These authors made comparisons with recent samples of diurnal raptors from different parts of the world, indicating preliminarily the action of the accipitriforms that inhabit Mendoza Province and feed mainly on small mammals, such as *G. melanoleucus* (black-chested buzzard-eagle) or *G. polyosoma*.

The species of *Geranoaetus* are widely distributed in South America; *G. melanoleucus* inhabits from the south of the Colombian Andes to southernmost Chile and Argentina, and *G. polyosoma* from the high Colombian Andes to sea level in Patagonia. *G. melanoleucus* is a common large-sized raptor (1670-3170 g) that builds its nests on rock shelters, cliffs, and trees (White *et al.*, 1994). It is a diurnal, opportunistic and generalist raptor, whose diet is mainly based on small mammals and secondarily on birds (Trejo *et al.*, 2006). *G. polyosoma* is a common medium-sized bird of prey (800-1800g) that builds its nests mainly on rock shelter, cliffs, trees, and scrubs (White *et al.*, 1994). It is diurnal and generalist, feeding mostly on small mammals (mainly sigmodontine rodents) and less on birds, reptiles, amphibians and invertebrates (White *et al.*, 1994). Therefore, both species could be considered potential small mammal accumulators in open-air and rock shelters archaeological and paleontological sites in a wide area of South America.

The results of a taphonomic analysis of the modifications produced by *G. melanoleucus* and *G. polyosoma* on small mammal prey bones and teeth recovered from modern pellets are here presented. These results are compared with data available from the literature concerning to modifications produced by other diurnal birds of prey. As well, new

data are provided for establishing criteria by which their role as fossil or archaeological bone accumulators or as agents involved in the formation of the deposit can be evaluated. Finally, the hypotheses proposed by Fernández (2012), Fernández *et al.* (2015), and López *et al.* (2016) for the origin of the small mammal assemblages from RH, AMA-3, and CP archaeological sites are here put to test.

Material and methods

Recent samples

Four recent pellet samples described below were studied; three produced by *G. melanoleucus* and one by *G. polyosoma*, recovered from different localities of Mendoza Province, Argentina. Unfortunately, in one sample of *G. melanoleucus* from Arroyo Malo, postcranial elements could not be studied because they were not collected (Fernández, 2012).

1) Villavicencio Natural Reserve (hereinafter Villavicencio; 32°35'S, 69°02'W, ~1650-1800 m asl, Figure 1). A total of 80 pellets were recovered from two nests of *G. melanoleucus* between August and December 2008. The environment is characterized by cold and dry climate, with temperature highly variable and scarce summer rainfall (~100-300 mm). This reserve includes an environmental mosaic composed by xeric grasslands and low bushes of Puna phytogeographic unit; columnar cacti, bromeliads of Cardonal phytogeographic unit, and xeric scrubland of Monte phytogeographic unit (Cabrera, 1976). Nests are located on rocky outcrops in the proximity of RH site.

2) Arroyo Malo locality (34°51'18''S, 69°53'00''W, ~2160 m asl, Figure 1). A total of 60 pellets of *G. melanoleucus* were

recovered from one nest located on rocky outcrops above AMA-3 site (see below) in March 2009. In this sample, neither the relative abundance of skeletal parts nor the taphonomic indexes could be studied. This area is located in the Patagonia phytogeographic unit, characterized by a semi-arid climate, shrub and grassy steppes (Cabrera, 1976).

3) Arroyo Panchino II locality (34° 56'37"S, 69°50'7"W, ~2330 m asl, Figure 1). A total of 50 pellets of *G. polyosoma* were recovered from two nests located on rocky

outcrops in the proximity of CP site (see below) in January 2007. Like Arroyo Malo, this area is located in the Patagonia phytogeographic Province.

4) Agua de La Mula (35º22' S; 68º15' W, ~900-1000 m asl, Figure1). A total of 22 pellets of *G. melanoleucus* were recovered from two nests located on rocky outcrops in October 2009. This site is near the northern boundary of the volcanic Payunia region, within the Monte phytogeographic unit (Cabrera, 1976), characterized by hot summer
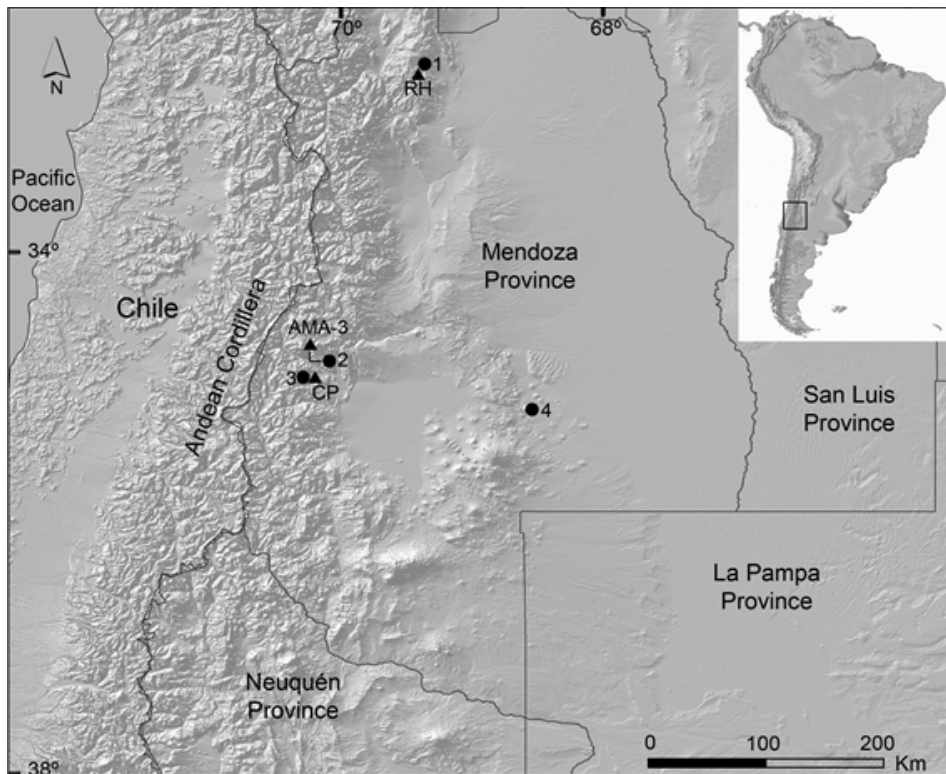

Figure 1. Map of the studied area including Rincón de los Helados (RH), Arroyo Malo-3 (AMA-3) and Cueva Palulo (CP) archaeological sites (triangles) and recent *Geranoaetus* samples (dots). *G. melanoleucus*: Villavicencio Natural Reserve (1); Arroyo Malo (2); Agua de La Mula (4); *G. polyosoma*: Arroyo Panchino II (3).

with low precipitations (~200 mm), xerophytic shrubs, and isolated stands of trees (Cabrera, 1976).

In this work, each sample was analysed considering together nestling and adult pellets, with the purpose of having a representative number of identifiable bone elements to obtain reliable data on the taphonomic variables. However, it is important to mention that nestlings usually produce more damage on the bones of their prey.

Archaeological samples

1) Villavicencio. A total of 220 small mammal remains were recovered from the archaeological excavation of the cave called Rincón de los Helados –RH– (32°37'36.65''S, 69°6''59.14''W, 2900 m asl, Figure 1) (López *et al.*, 2016). The chronology of this site ranges from ~1700 C^{14} BP to ~600 C^{14} BP (Chiavazza, 1995).

2) High valley of the Atuel River. A total of 7239 small mammal remains were recovered from the rock shelter AMA-3 (34º51'18''S, 69º53'00''W, 2160 m asl, Figure 1). The chronology ranges from ~8900 C^{14} BP to ~100 C^{14} BP (Fernández, 2012; Fernández *et al.*, 2015).

3) High valley of the Atuel River. A total of 667 small mammal remains were recovered from the cave CP, (34º56'40.40''S, 69º50'39.54''W; 2300 m asl, Figure 1). The chronology ranges from ~4000 C^{14} BP to ~130 C^{14} BP (Fernández, 2012).

The sediments of the archaeological sites were sieved through 2 mm-sized mesh. As mentioned before, the small mammals from archaeological samples were studied first. These taphonomic results (Fernández, 2012; Fernández *et al.*, 2015; López *et al.*, 2016) were compared with those from recent samples of *Geranoaetus* in order to evaluate the taphonomic hypotheses.

Methods

Fresh pellets were disaggregated manually, while moist, after a quick dip in warm water, and the anatomical elements were separated with surgical instruments. Remains were observed under a stereomicroscope, and some of them were photographed under the scanning electron microscopes: Jeol 35CF-8 kV of the *Unidad de Administración Territorial of CONICET* (Bahía Blanca, Argentina), and Jeol JSM6490LV-10 kV of *CONICET* (Mendoza, Argentina). Taxonomic determinations were made on the basis of cranial and teeth remains, using specimens of the mammal collections of *IADIZA-CONICET*, Mendoza, and *Museo de La Plata* (*UNLP,* La Plata, Argentina), and bibliographical sources for comparison (Fernández *et al.*, 2011). Samples are housed in the *Laboratory of Anatomía Comparada, Facultad de Ciencias Naturales y Museo* (UNLP), *Facultad de Filosofía y Letras* (IAyE, UNCuyo, Mendoza), and *IADIZA-CONICET*.

The taphonomic analysis followed the methodology proposed by Andrews (1990) and Fernández-Jalvo & Andrews (1992). They proposed five predator categories that broadly correspond, from low to high degree of modification by digestion, to Strigiformes (light to moderate), Falconiformes, Accipitriformes (moderate to heavy), and Carnivora (heavy to extreme). The analysis of digestive corrosion was performed on the diagnostic elements (incisors, molars, proximal femora, and distal humeri), for which exist a systematic taphonomic methodology (Andrews, 1990; Fernández-Jalvo & Andrews, 1992). These categories are based both on degree

of modification and frequencies of elements affected (Andrews, 1990). The categories of digestive corrosion on teeth of rodents and marsupials were also evaluated considering the contribution of Fernández *et al.* (2017), which distinguished digestive corrosion patterns on the different teeth morphologies of South American rodents Sigmodontinae, Caviinae, Ctenomyidae, and Abrocomidae; and the marsupials Monodelphini.

The minimum number of specimens (NISP), minimum number of skeletal elements (MNE), and minimum number of individuals (MNI) were calculated using mandibles and skulls discriminated by taxa.

The relative abundance of skeletal elements, considering the representation of each one of them in the context of the MNI [MNEi/(Ei×MNI)×100] was evaluated (Andrews, 1990).

The proportion of the different skeletal elements was calculated by means of different indexes: postcrania/crania (pc/c): [(femora+tibiae+humeri+radii+ulnae)×8/mandibles+maxillae+molars)×5]×100; f+h/md+mx: (femora+humeri/mandibles+maxillae)×100; t+u/f+h: (tibiae+ulnae/femora+humeri)×100; alv/m: (mandibular alveoli+maxillary alveoli/molars) ×100 and alv/i: (mandibular alveoli+premaxillary alveoli/incisors)×100.

The degree of the completeness of the skull, mandible, and postcranial bones was evaluated (Andrews, 1990).

Ordination (Principal Component Analysis, PCA) multivariate statistic was performed in order to explore the relationship between micromammal archaeological assemblages and recent samples produced by *G. melanoleucus*, *G. polyosoma*, and those generated by other raptors frequent in the study area (the Strigiformes *T. alba*, *A. cunicularia*, *B. v. magellanicus*). These statistics techniques were performed using the software PAlaeontological STatistics version 3.12 (PAST, Hammer *et al.*, 2001) which were based on a data matrix composed of the main taphonomic attributes considered.

Results

Taxonomic Composition

The abundances of the small mammals recovered at recent samples are detailed in Table 1.

Regarding *G. melanoleucus* samples, some differences in the taxonomic structure were observed. A total NISP of 429 and MNI of 56 were registered in the sample from Villavicencio. The main species were the caviomorph rodent *Galea leucoblephara* and the sigmodontine rodent *Phyllotis xanthopygus*. A total NISP of 128 and MNI of 42 were recorded in the sample from Arroyo Malo. This sample was dominated by the sigmodontines *Euneomys petersoni* and *Eligmodontia* sp. Agua de La Mula is the smallest sample (NISP=364, MNI=8) and was only represented by the sigmodontine *Graomys griseoflavus* and the caviomorph *G. leucoblephara*. Considering *G. polyosoma*, a total NISP of 2677 and MNI of 47 were registered in the sample of Arroyo Panchino II. The main species was the caviomorph *Ctenomys* sp., followed by the sigmodontines *E. petersoni* and *Abrothrix olivacea*.

Anatomical representation

Despite finding some differences, in the all samples the average relative abundance of the skeletal parts was low (Table 2). These low average values, added to the better

Table 1. Average weight (W), minimum number of individuals (MNI) and percentage of minimum number of individuals (MNI%) of the taxa consumed by Geranoaetus *in the modern samples.*

	W (in g)	G. melanoleucus						G. polyosoma	
		Arroyo Malo		Villavicencio		Agua de la Mula		El Sosneado	
		MNI	%	MNI	%	MNI	%	MNI	%
Didelphimorphia									
Thylamys pallidior	21.4	5	11.90	0	0	0	0	0	0
Rodentia									
Abrocomidae									
Abrocoma sp.	250.0	0	0	1	1.79	0	0	0	0
Caviidae									
Galea leucoblephara	190.0	0	0	36	64.29	3	37.50	0	0
Microcavia australis	223.2	1	2.38	2	3.57	0	0	0	0
Ctenomyidae									
Ctenomys sp.	127.9	2	4.76	0	0	0	0	23	48.94
Cricetidae									
Abrothrix hirta	30.1	1	2.38	0	0	0	0	1	2.13
Abrothrix olivacea	21.0	1	2.38	0	0	0	0	11	23.40
Akodon dolores	34.7	0	0	5	8.93	0	0	0	0
Paynomys macronyx	40.3	1	2.38	0	0	0	0	0	0
Eligmodontia sp.	21.1	13	30.95	0	0	0	0	0	0
Euneomys petersoni	85.0	13	30.95	0	0	0	0	11	23.40
Graomys griseoflavus	66.7	0	0	2	3.57	5	62.50	0	0
Phyllotis xanthopygus	57.5	5	11.90	10	17.86	0	0	1	2.13
Total MNI	0	42	0	56	0	8	0	47	0

Table 2. *Minimum number of elements (MNE) and values of the indexes calculated for small mammals from* Geranoaetus *modern samples: alv: alveolar; f=femur; t=tibia; h=humerus; r=radius; u=ulna; mx=maxilla; mb=mandible; m=molar; i: incisor.*

	G. melanoleucus				G. polyosoma	
	Villavicencio		Agua de La Mula		Arroyo Panchino II	
	MNE	%	MNE	%	MNE	%
mandible	29	25.9	10	62.5	41	43.6
maxilla	47	41.9	11	68.7	36	38.3
scapula	5	4.5	5	31.2	16	17
humerus	11	9.8	9	56.2	48	51.1
radii	15	13.4	6	37.5	19	20.2
ulna	16	14.3	8	50	32	34
pelvis	11	9.8	10	62.5	10	10.6
femur	12	10.7	9	56.2	28	29.8
tibia	25	22.3	12	50	18	19.1
vertebra	67	3.3	124	43.1	226	13.4
incisor	50	22.3	3	9.4	76	40.4
molar	50	7.4	2	2.1	204	36.2
metapodial	29	2.6	30	18.7	66	7
calcaneus	3	2.7	4	25	22	23.4
astragalus	2	1.8	1	6.2	12	12.8
phalange	30	1	25	5.6	186	7.1
rib	22	1.6	49	25.5	137	12.1
Average		11.5		35.9		24.5
Total MNE	424		318		1177	
bone splinters	191		126		1525	
f+t+h+r+u/md+mx+m	110.3		306.1		65.5	
f+h/md+mx	30.3		85.7		64.9	
t+u/f+h	178.3		111.1		66	
alv mx+alv md/m	80		300		618.2	
alv mx+alv md/i	12		33.3		422.2	

representation of certain elements compared with others, reflect a great loss of bones in accumulations generated by these two raptors.

For *G. melanoleucus*, in Villavicencio, a MNE of 424 was calculated (Table 2). In this sample, 191 bone splinters anatomically unidentifiable were recovered. All skeletal elements were identified, being the most abundant maxillae, followed by mandibles, isolated incisors, and tibiae. Astragali, phalanges, calcanii, metapodials, vertebrae and ribs were the less represented elements. In Agua de La Mula sample, a MNE of 318 was registered. In addition, 126 bone splinters were recovered. The relative abundance of tibiae, maxillae, mandibles, femora, humeri, ulnae, and pelves was higher than 50%. In Arroyo Malo sample, the values of MNE and NISP were the same (128).

G. polyosoma sample was composed by a MNE of 1177. Also, 1525 bone splinters were recovered. Humeri, maxillae, and mandibles were the most frequent elements (Table 2).

The two indexes evaluating the relationship between postcranial and cranial elements displayed marked differences (Table 2). In the sample of *G. polyosoma* cranial elements show better preservation. Similar results were obtained for f+h/md+mx index in the two samples of *G. melanoleucus* (Table 2). However, the pc/c index indicates a bias toward the postcranial elements related to the very scarce isolated molars recovered from Agua de La Mula sample. Villavicencio sample shows an equal proportion between both types of skeletal elements (Table 2). The t+u/f+h index indicated better preservation of distal elements for *G. melanoleucus*, while for *G. polyosoma* the proximal elements are the best represented. The calculated indexes to evaluate tooth loss, showed loss of maxillae and mandibles in the *G. melanoleucus* sample from Villavicencio; loss of molars and premaxillae in the sample from *G. melanoleucus* from Agua de La Mula, and loss of molars and incisors for the sample of *G. polyosoma*.

Breakage patterns

All the samples showed high proportions of unidentifiable remains. The proportion of breakage in cranial and postcranial elements was high, but not in the same frequency.

All skulls recovered from *G. melanoleucus* samples were fractured. Likewise, almost all skulls from *G. polyosoma* sample were broken (Table 3). Regarding mandibles, in *G. melanoleucus* from Villavicencio, more than 80% of them were broken, whereas in the other samples the proportion of breakage was minor. Breakage in teeth was high only in Agua de La Mula, while the broken elements were <40% in the other samples (Table 3). In all samples, isolated teeth were more frequently broken than those found *in situ*.

Complete postcranial elements were recovered in all samples (Table 3). The breakage was high in *G. melanoleucus* from Villavicencio and *G. polyosoma* from Arroyo Panchino II samples, in which complete long bones did not exceed 50% each one. In contrast, in *G. melanoleucus* sample from Agua de La Mula, the percentage of complete long bones was higher. The proximal segments were more abundant in femora, ulnae, and tibiae, whereas the distal ones were more numerous in humeri.

Digestion

In the sample of *G. polyosoma*, all elements had some degree of digestive corrosion (Table 4, Figure 2A-F). The most frequent

Table 3. Breakage in cranial and postcranial elements for small mammals from Geranoaetus modern samples.

| | *G. melanoleucus* | | | | | | *G. polyosoma* | |
| | Villavicencio | | Agua de La Mula | | Arroyo Malo | | A. Panchino II | |
	MNE	%	MNE	%	NME	%	MNE	%
Skull breakage								
Complete	0	0	0	0	0	0	1	2.8
With zigomathic arch	40	81.6	11	100	61	98.4	0	0
Without zigomatic arch	7	14.3	0	0	1	1.6	4	11.1
Fragments	2	4.1	0	0	0	0	31	86.1
Mandible breakage								
Complete	5	17.2	7	70	30	47.6	6	60
Without ascendent rami	24	82.8	3	30	33	52.4	4	40
Femur								
Complete	6	50	8	88.9			5	17.8
Proximal	5	41.7	1	11.1			14	50
Shaft	1	8.3	0	0			3	10.7
Distal	0	0	0	0			6	21.4
Humerus								
Complete	5	45.4	7	77.8			13	27.1
Proximal	1	9.1	0	0			11	22.9
Shaft	3	27.3	1	11.1			10	20.8
Distal	2	18.2	1	11.1			14	29.2
Tibia								
Complete	7	23.3	8	66.7			6	33.3
Proximal	10	33.3	2	16.7			4	22,2
Shaft	12	40	2	16.7			0	0
Distal	1	3.3	0	0			8	44.4
Ulna								
Complete	3	18.7	6	75			15	46.9
Proximal	10	62.5	2	25			17	53.1
Shaft	3	18.7	0	0			0	0
Distal	0	0	0	0			0	0

Table 4. Representation of categories of digestive corrosion for small mammals from Geranoaetus *samples.*

|	*Geranoaetus melanoleucus* Villavicencio									
Digestion of teeth	**Absent**	**%**	**Light**	**%**	**Moderate**	**%**	**Heavy**	**%**	**Extreme**	**%**
In situ incisors	11	44	3	12	8	32	3	12	0	0
Isolated incisors	3	6.2	7	14.6	22	45.8	14	29.2	2	4.2
In situ molars	133	50.9	50	19.1	47	18	29	11.1	2	0.8
Isolated molars	11	22.4	3	6.1	15	30.6	16	32.6	4	8.2
Digestion in postcrania										
Femur	3	27.3	3	27.3	3	27.3	2	18.2	0	0
Humerus	2	28.6	3	42.8	2	28.6	0	0	0	0
	Geranoaetus melanoleucus Agua de La Mula									
Digestion of teeth	**Absent**	**%**	**Light**	**%**	**Moderate**	**%**	**Heavy**	**%**	**5**	**%**
In situ incisors	11	73.3	4	26.7	0	0	0	0	0	0
Isolated incisors	0	0	2	66.7	1	33.3	0	0	0	0
In situ molars	28	50.9	23	41.8	4	7.3	0	0	0	0
Isolated molars	0	0	1	50	1	50	0	0	0	0
Digestion in postcrania										
Femur	3	33.3	3	33.3	1	11.1	2	22.2	0	0
Humerus	5	71.4	1	14.3	0	0	1	14.3	0	0
	Geranoaetus melanoleucus Arroyo Malo									
Digestion of teeth	**Absent**	**%**	**Light**	**%**	**Moderate**	**%**	**Heavy**	**%**	**Extreme**	**%**
In situ incisors	42	45.6	22	23.9	22	23.9	6	6.5	0	0
Isolated incisors	0	0	0	0	2	66.7	1	33.3	0	0
In situ molars	139	48.6	98	34.3	34	11.9	15	5.2	0	0
Isolated molars	0	0	0	0	0	0	0	0	0	0
	Geranoaetus polyosoma Arroyo Panchino II									
Digestion of teeth	**Absent**	**%**	**Light**	**%**	**Moderate**	**%**	**Heavy**	**%**	**Extreme**	**%**
In situ incisors	0	0	8	42.1	9	47.4	2	10.5	0	0
Isolated incisors	0	0	19	25	33	43.4	22	28.9	2	2.6
In situ molars	0	0	28	23.1	45	37.2	48	39.7	0	0
Isolated molars	0	0	68	33.3	73	35.8	47	23.4	16	7.8
Digestion in postcrania										
Femur	0	0	1	3.6	9	32.1	12	42.9	6	21.4
Humerus	0	0	5	10.4	8	16.7	21	43.7	14	29.2
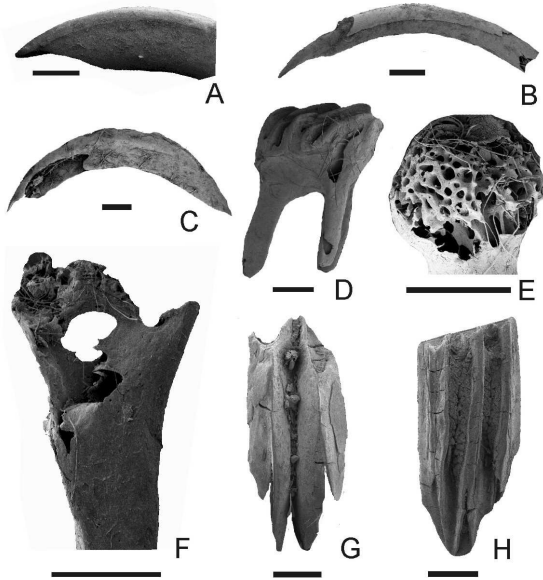
Figure 2. Examples of digestive corrosion in the studied samples. Cricetid bones from *Geranoaetus polyosoma* sample: A: light on incisor; B, moderate on incisor; C, extreme on incisor; D, heavy on molar; E, heavy on femur; F, extreme on humerus. Bones from *Geranoaestus melanoleucus* samples: G, heavy on Caviinae molar; H, heavy on Abrocomidae molar. Scale bar=1 mm. Photos G and H taken from Fernández *et al*. (2017), (Elsevier. All rights reserved).

modification category was moderate (35%), although light and heavy categories were also detected in high proportions.

In the sample of *G. melanoleucus* from Villavicencio, more than 50% of the teeth and 70% of postcranial bones showed corrosion (Figure 2G-H). Among teeth, the most frequent categories were moderate and heavy, whereas in femora and humeri were light and moderate. For the sample of *G. melanoleucus* from Agua de La Mula, 50% of teeth and 30% of postcranial bones evidenced traces of digestion, being light the most frequent category, although moderate and heavy degrees were also observed. In the sample of *G. melanoleucus* from Arroyo Malo, only teeth were evaluated. In this sample, no elements with extreme modifications were detected and the most frequent modification category was moderate. In all the samples, isolated teeth were more frequent and deeply altered by digestion than those found *in situ*.

Discussion

Taphonomic categorization of G. melanoleucus *and* G. polyosoma

Small rodents were the most abundant resources consumed by both species in all modern samples, with predominance of the largest species. By contrast, the other diurnal raptors (Accipitriformes and Falconiformes) that inhabit the study areas prey on insects, plants, and seeds, whereas small mammals constitute a smaller part of their diet (Fernández, 2012).

Despite the general patterns observed in all recent samples characterized by low relative abundances, indexes of anatomical representation, high breakage, and evidence of digestion in a high amount of diagnostic bones, the analysis of variables of samples from both species of *Geranoaetus* showed certain variability, even within the same species (Tables 2 and 5).

The major proportion of cranial elements in the sample of *G. polyosoma* was also observed in samples of *E. leucurus* (Montalvo *et al.*, 2014). Some values for *G. melanoleucus* showed better representation of cranial elements, others indicated equitable preservation between cranial and postcranial parts, while others showed the predominance of postcranial bones. Within diurnal raptors, only *C. plancus* yielded markedly better representation of postcranial elements; the loss of distal limbs found in the sample of *G. polyosoma* is coincident with accumulations produced by *C. plancus* and *E. leucurus* (Montalvo & Tallade, 2009; Montalvo *et al.*, 2014). By contrast, the samples of *G. melanoleucus* showed loss of proximal limb bones. The dominance of teeth *in situ* recorded in the sample of *G. polyosoma* also occurs in *C. plancus* (Montalvo & Tallade, 2009), but the general loss of teeth in some samples of *G. melanoleucus* is similar to that reported for *E. leucurus* (Montalvo *et al.*, 2014). Several researches have pointed out that the variability in the taphonomic features, even within the same species, may be associated with factors such as age, size of raptor and prey, prey availability, habitat type, among others (Gómez, 2005; Fernández *et al.*, 2017; López *et al.*, 2017). Thus, in all small-mammal bone accumulations, there is a taphonomic bias imposed by the predator itself and by the specific characteristics of the recovered samples. Although this variability difficult their general assessment, both raptors can be placed between categories 2 and 4.

Table 5. Categorization of Geranoaetus polyosoma *(black bar) and* Geranoaetus melanoleucus *(grey bar) effects on prey remains according to the different taphonomic variables (*sensu *Andrews 1990).*

Categories	1	2	3	4	5
Relative abundance				■ ▦	
pc/c			■		
Distal elemen tloss		▦	■		
Breakage of postcrania			▦	■	
Breakage of skulls				■	▦
Loss of zygomatic processes		▦		■	
Maxillary tooth loss		■ ▦			
Breakage of mandibles				■ ▦	
Mandibular tooth loss		■ ▦			
Proportions isolated teeth			▦	■	
Breakage of teeth				■ ▦	
Digestion of molars				■	
Digestion of incisors				▦	■
Digestion of postcrania				▦	■

The average of relative abundance of the skeletal elements was homogeneous in all samples with low values that range from 11.5% to 35.9% (category 4). The anatomical representation results in a typical "diurnal raptor" pattern, with bone loss and the five peaks showing higher proportions of mandible, humerus, ulna, femur-tibia, and isolated teeth (Figure 3) (Andrews, 1990).

The sample of *G. polyosoma* evidenced more fractured elements than those of *G. melanoleucus* (Table 5). This could be related to the larger size of *G. melanoleucus* suggesting they swallowed its prey whole.

The digestive corrosion on the bone surface was very high in remains of the sample of *G. polyosoma* and slightly lower in *G. melanoleucus* (Table 5). According to the taxa (Sigmodontinae, Caviinae, and Ctenomyidae) recovered from these samples, Fernández *et al.* (2017) observed that the

Sigmodontinae molars are the less modified by digestion, while molars of Caviinae and Ctenomyidae are more modified, even in extreme degree.

For the reasons mentioned above, *G. melanoleucus* and *G. polyosoma* were allocated in the category 4 of modification, typical of diurnal raptors (Andrews, 1990). Nevertheless, we found certain differences in the results of the taphonomic evaluation of the samples of *G. melanoleucus* (Table 6).

Comparison between archaeological and modern accumulations

Similarities and differences were detected between modern and archaeological samples. The relative abundances of skeletal elements were low in all samples (Figure 3). The pc/c index for *G. melanoleucus* samples from Villavicencio and Agua de la Mula
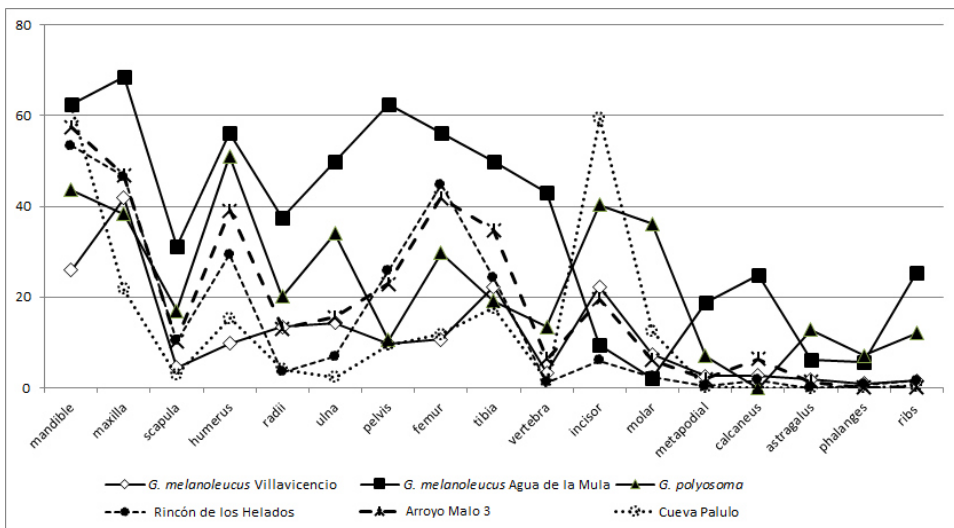

Figure 3. Relative abundance of skeletal elements identified in *Geranoaetus* samples compared with data from archaeological sites.

were similar to those obtained for RH and AMA-3 sites, with better representation of postcranial elements (Fernández *et al.*, 2015; López *et al.*, 2016). The pc/c index for *G. polyosoma* from Arroyo Panchino II was similar compared to the information of CP site, with higher proportion of cranial bones (Fernández, 2012). The f+h/md+mx index showed better preservation of cranial elements, both in modern and archaeological samples (Fernández, 2012; Fernández *et al.*, 2015; López *et al.*, 2016).

Despite the high breakage detected in recent samples, the broken bones exceeded 90% only for *G. melanoleucu*s from Villavicencio, whereas in the remaining modern samples they did not exceed 76%. In the archaeological samples the breakage of cranial and postcranial elements always exceeded at least 90%, probably by the influence of postdepositional processes (Table 6).

Modifications by digestion were high in CP and AMA-3 samples, like in the sample of *G. polyosoma*, where the affected diagnostic elements exceeded 90%. In RH, the percentages of affected elements varied between 34% for cranial bones and 58% for postcranial ones; these values were similar to those obtained for the samples of *G. melanoleucus*. The AMA-3 and CP samples also yielded remains with high degree of digestion, only identified for the modern sample of *G. polyosoma* (Table 6).

Principal Component Analysis (PCA) yielded coherent values grouping the archaeological samples with those of *Geranoaetus*, and separating them from samples of Strigiformes species, with known low values of modification (Figure 4). Specifically, CP site is very close to *G. polyosoma*; however, AMA-3 and RH sites had intermediate values between *G. polyosoma* and *G. melanoleucus* (Figure 4).

The prey items eaten by *G. melanoleucus* and *G. polyosoma*, occasionally may be the same as those consumed by other predators that inhabit the study areas such as *T. alba* (Abraham, 2012; López *et al.*, 2016) or carnivorous mammals (López *et al.*, 2017). This fact could cause problems when interpreting the accumulating agents of small mammal remains recovered in regional archaeological sites. However, the taphonomic results obtained in this study, provide with data to distinguish modifications produced by *Geranoaetus* from other predators that inhabit sympatrically the archaeological study areas.

The understanding of the taphonomic features produced by *G. melanoleucus* and *G. polyosoma* is very important in those places where these two raptors present sympatric distributions. This situation may emulate what happens at archaeological sites, where often more than one accumulating agent has been responsible for the small mammal bone accumulations (*e.g.*, Fernández *et al.*, 2009; Fernández, 2012; López *et al.*, 2017), as may be the case of *G. melanoleucus* and *G. polyosoma*.

Final remarks

According to the main taphonomic variables analysed, both *G. melanoleucus* and *G. polyosoma* may be placed in category 4 (heavy) of predator modification, based on the scheme proposed by Andrews (1990) (Table 6). The taphonomic features described for these assemblages deeply differ from those produced by Strigiformes, the most common accumulators of small mammals in archaeological and paleontological sites.

Table 6. Taphonomic variables in modern accumulations compared with archaeological samples; Rincón de los Helados (RH; López et al., *2016), Agua de la Mula 3 (AMA-3; Fernández, 2012; Fernández* et al., *2015) and Cueva Palulo (CP; Fernández, 2012); A=absent; L=light; M=moderate; H, heavy; E=extreme.*

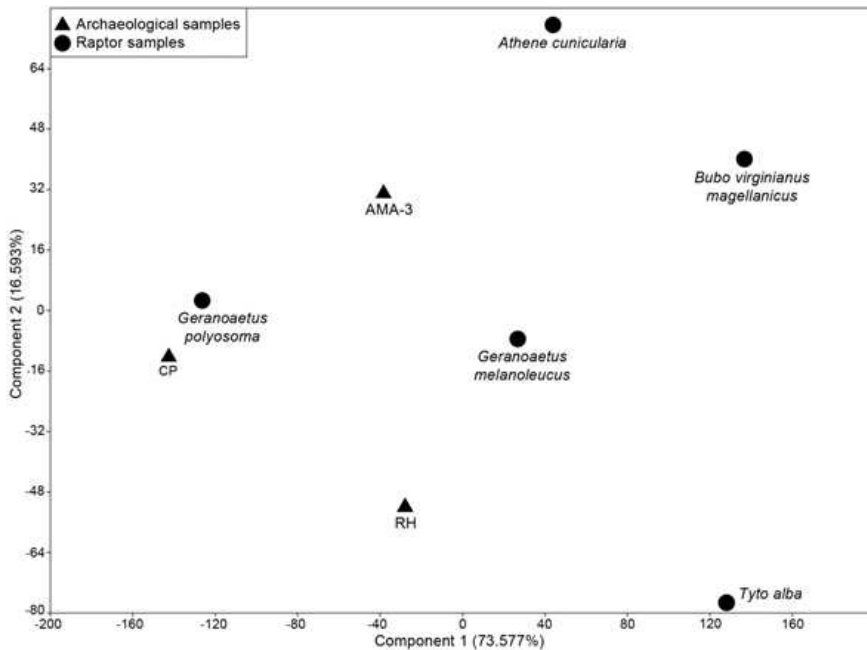|	*G. melanoleucus* samples			*G. polyosoma* sample	Archaeological bone assemblages		
	Villavicencio	ALM	Arroyo Malo	Arroyo Panchino II	RH	AMA-3	CP
Postcranial digestion (%)	72.2	50	-	100	57.6	91.4	100
Incisor digestión (%)	80.8	68.6	55.8	100	34.6	90.5	89.1
Molar digestión (%)	53.5	50.9	51.4	100	44.11	98	97.7
Main total digestion degrees	A-L-M	A-L-M	A-L-M	M-H	A-L-M	L-M-H	L-M-H
Breakage maxillae and mandible (%)	93.6	66.7	76	83	92.1	94.6	95.1
Breakage postcranial (%)	69.1	23.7	-	69	65	54.2	80

Figure 4. PCA of small mammal of archaeological samples (Rincón de los Helados -RH-, Arroyo Malo 3 -AMA 3-, Cueva Palulo -CP-; Fernández, 2012; Fernández *et al.*, 2015; López *et al.*, 2016) (Tables 2, 3, 4, 6), *Geranoaetus melanoleucus*, *G. polyosoma* (this work), averages of *Tyto alba* (Andrews, 1990), *Bubo virginianus magellanicus* (Montalvo *et al*., 2015) and *Athene cunicularia* (Montalvo & Tejerina, 2009).

Both species could yield small mammal accumulations on rock shelters, mainly composed by caviomorph and sigmodontine rodent skeletal elements with high representation of mandible, humerus, ulna, femur, tibia, and isolated teeth, and high values of breakage and digestive corrosion. The results presented here were used as an analytical model for the interpretation of the micromammal fossil record from three archaeological sites located in Mendoza Province, Argentina. This comparison suggests that the skeletal remains recovered from CP archaeological site are very close to those produced by *G. polyosoma*. However, accumulations from AMA-3 and RH archaeological sites had intermediate values between *G. polyosoma* and *G. melanoleucus*; thus, we preliminary maintain the assignation to the genus level.

Acknowledgments

References

Abraham, J. (2012). *Dieta del Águila Mora (*Geranoaetus melanoleucus*) durante tres períodos del ciclo reproductivo, en la Reserva Natural Villavicencio*. Degree Thesis, Facultad de Ciencias Sociales, Universidad Champagnat.

Andrews, P. (1990). *Owls, Caves and Fossils*. Natural History Museum Publications, London.

Cabrera, A.L. (1976). Regiones fitogeográficas argentinas. *Enciclopedia Argentina de Agricultura y Jardinería,* 1: 1-85.

Chiavazza, H. (1995). *Estudios Arqueológicos en el sitio "Rincón de Los Helados" ("RH"). Ocupación Multicomponente en Noreste de Pampa de Canota -Departamento de Las Heras, Provincia de Mendoza, República Argentina.* Degree Thesis, Facultad de Filosofía y Letras, Universidad Nacional de Cuyo.

Fernández, F.J. (2012). *Microvertebrados del Holoceno de sitios arqueológicos en el sur de Mendoza (República Argentina): aspectos tafonómicos y sus implicancias en la subsistencia humana*. Ph.D Thesis, Facultad de Ciencias Naturales y Museo, SEDICI Repositorio Institucional de la UNLP, La Plata.

Fernández, F.J., Moreira, G., Neme, G. & De Santis, L.J.M. (2009). Microvertebrados exhumados del sitio arqueológico "Cueva Arroyo Colorado" (Mendoza, Argentina): aspectos tafonómicos y significación paleoambiental. *Archaeofauna*, 18: 99-118.

Fernández, F.J., Ballejo, F., Moreira, G., Tonni, E.P. & De Santis, L.J.M. (2011). *Roedores cricétidos de la provincia de Mendoza. Guía cráneo-dentaria orientada para su aplicación en estudios zooarqueológicos*. Editorial SAA & Universidad de Sarmiento, Córdoba.

Fernández, F.J., Teta, P., Barberena, R. & Pardiñas, U. (2012). Small mammal remains from Cueva Huenul 1, Argentina. Taphonomy and paleoenvironments since the Late Pleistocene. *Quaternary International*, 278: 22-31.

Fernández, F.J., Neme, G. & De Santis, L. (2015). New small mammals record from Arroyo Malo-3 archaeological site of Central West Argentina. Taphonomy, paleoenvironments and Human occupations across the Holocene. *Archaeofauna*, 24: 27-52.

Fernández, F.J., Montalvo, C.I., Fernández-Jalvo, Y., Andrews, P. & López, J.M. (2017). A re-evaluation of the taphonomic methodology for the study of small mammal fossil assemblages of South America. *Quaternary Science Reviews*, 155: 37-49.

Fernández-Jalvo, Y. & Andrews, P. (1992). Small Mammal Taphonomy of Gran Dolina, Atapuerca (Burgos), Spain. *Journal of Archaeological Science*, 19: 407-428.

Fernández-Jalvo, Y., Scott, L., & Andrews, P. (2011). Taphonomy in palaeocological interpretations. *Quaternary Science Reviews*, 30: 1296-1302.

Gómez G.N. (2005). Analysis of bone modification of *Bubo virginianus* pellets from Argentina. *Journal of Taphonomy,* 3: 1-16.

Gómez, G.N. (2007). Predators categorizations based on taphonomic analysis of micromammals bones: a comparison to proposed models.In (Gutierrez, M.A., Miotti, L., Barrientos, G., Mengoni Goñalons, G. & Salamme, M. eds.) *Taphonomy and Zooarqueology in Argentina.* Oxford; BAR International Series 1601, pp. 89-103.

Hammer, O., Harper, D. & Ryan, P. (2001). PAST: Paleontological Statistics software package for education and data analysis. *Paleontologia Electronica*, 4: 1-9.

Iglesias, A.C. (2009). *Tafonomía de pequeños vertebrados depredados por* Buteo polyosoma *(Aves, Falconiformes)*. Degree Thesis, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de La Pampa, La Pampa.

López, J.M., Chiavazza, H. & Rosi, M.I. (2016). Small mammal remains recovered from two archaeological sites in northwestern Mendoza (late Holocene, Argentina): Taxonomic composition, taphonomic issues, and paleoenvironmental implications. *Quaternary International*, 391: 26-37.

López, J.M., Rosi, M.I., Tabeni, S., Bender, B. & Chiavazza, H. (2017). Taphonomic analysis of small mammal bone remains preyed upon by wildcats (Carnivora: Felidae) from the central Monte Desert (Mendoza, Argentina). *Boreas*, 46 (2): 282-293.

Montalvo, C.I. & Tallade, P. (2009). Taphonomy of the accumulations produced by *Caracara plancus* (Falconidae). Analysis of prey remains and pellets. *Journal of Taphonomy*, 7: 235-248.

Montalvo, C.I. & Tejerina, P. (2009). Análisis tafonómico de los huesos de anfibios y roedores depredados por *Athene cunicularia* (Strigiformes, Strigidae) en La Pampa, Argentina. In (Berón, M., Luna, L., Bonomo, M., Montalvo, C.I., Aranda, C., & Carrera Aizpitarte, M. eds.) *Mamül Mapu: pasado y presente desde la arqueología pampeana.* Buenos Aires: Editorial Libros del Espinillo, pp. 323-334.

Montalvo, C.I. & Tallade, P. (2010). Análisis tafonómico de restos no ingeridos de roedores presa de *Caracara plancus* (Aves, Falconidae). In (De Nigris, M., Fernández, P.M., Giardina, M., Gil, A.F., Gutiérrez, M.A., Izeta, A., Neme, G. & Yacobaccio, H.D. eds.) *Zooarqueología a principios del siglo XXI: aportes teóricos, metodológicos y casos de estudio.* Buenos Aires: Ediciones del Espinillo, pp. 419-428.

Montalvo, C.I., Fernández, F.J., Liébana, M.S., Santillán, M. & Sarasola, J.H. (2014). Taphonomic analysis of rodent bone accumulations produced by the White-tailed Kite (*Elanus leucurus*, Accipitriformes) in Central Argentina. *Journal of Archaeological Science*, 52: 354-362.

Montalvo, C.I., Fernández, F.J. & Tallade, P. (2015). The role of *Bubo virginianus magellanicus* as rodent bone accumulator in archaeological sites. A case study for the Atuel River (Mendoza, Argentina). *International Journal of Osteoarchaeology*, 26 (6): 974-986.

Montalvo, C.I., Fernández, F.J., Bargo, M.S., Tomassini, R.L. & Mehl, A. (2017). First record of a Late Holocene fauna associated with an ephemeral fluvial sequence in La Pampa Province, Argentina. Taphonomy and paleoenvironment. *Journal of South American Earth Sciences*, 76: 225-237.

Pardiñas, U.F.J. (1999a). Los roedores muroideos del Pleistoceno Tardío-Holoceno en la Región Pampeana (sector este) y Patagonia (República Argentina): aspectos taxonómicos, importancia bioestratigráficas y significación paleoambiental. Ph.D. Thesis, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata, La Plata.

Pardiñas, U.F.J. (1999b). Tafonomía de microvertebrados en yacimientos arqueológicos de Patagonia (Argentina). *Arqueología*, 9: 265-340.

Trejo, A., Kun, M. & Seijas, S. (2006). Dieta del águila mora (*Geranoaetus melanoleucus*) en una transecta oeste-este en el ecotono Norpatagónico. *Hornero*, 21: 31-36.

White, C.M. Olsen, P.D. & Kiff, L.F. (1994). Falcons. In (del Hoyo, J., Elliott, A. & Sartagal, J. eds.), *Handbook of the birds of the world. Volume 2: New World vultures to Guinea Fowl*. Barcelona: Lynx Editions, pp. 216-275.