



# Amidst wind, sand and raptors. Small mammal bone remains recovered in open-air archaeological sites from the Monte Desert in Central Western Argentina: taphonomic and palaeoenvironmental implications

José Manuel López<sup>1,2</sup>  · Horacio Chiavazza<sup>3,4</sup>

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## Abstract

The distinctive characteristic of the Monte Desert, the most arid rangeland of Argentina, is reflected in the varied composition of its small mammal fauna. The present study analyses the taphonomic features and the palaeoenvironmental implications of small mammal bone and tooth accumulations recovered in open-air archaeological sites from the Monte Desert plains of northern Mendoza (Central Western Argentina) in the South American arid diagonal. In order to identify the agents responsible for such accumulations relative abundance trends, bone breakage patterns and digestive corrosion were evaluated. The action of postdepositional processes, like weathering and trampling, also were analysed. Taphonomic results allowed the detection of avian raptors—owls in particular—as the principal accumulating agents of small mammal bone and tooth accumulations of open-air archaeological sites from the Monte Desert. In order to make palaeoenvironmental inferences, the taxonomic structure of archaeological and modern small mammal assemblages was analysed and compared, added to the evaluation of taphonomic dynamics in the archaeological sites. The taxonomic composition of archaeological assemblages differed from that of the current assemblages from the study area. Thus, an extinct species (*Holochilus lagigliai*) and a little-known species highly adapted to desert environments (*Tympanoctomys barrerae*) were detected in the archaeological record. Recent pellet samples showed major proportions of opportunistic and generalist species as well as the presence of an exotic species (*Mus musculus*). The general impoverishment of current small mammal assemblages in comparison with past ones (e.g. richness, diversity and evenness) could be attributed to the deep impact of the anthropic perturbations generated by economic activities since the arrival of European conquerors ca. 500 years BP. Small mammal archaeological assemblages could indicate a scenario of greater environmental heterogeneity during the Late Holocene than in the present, and thus, greater availability of patch resources in the landscape.

**Keywords** Zooarchaeology · Taphonomy · Deserts · Microvertebrates · Sandy soils · Palaeoecology · Extinctions · Biological invasions

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✉ José Manuel López  
mlopez@mendoza-conicet.gov.ar; manuelv82@hotmail.com

Horacio Chiavazza  
hchiavazza@gmail.com

<sup>1</sup> Instituto Argentino de Investigaciones de las Zonas Áridas (IADIZA-CONICET), CCT-Mendoza, Av. Ruiz Leal s/n, Parque General San Martín, 5500 Mendoza, Argentina

<sup>2</sup> Instituto de Arqueología y Etnología, Facultad de Filosofía y Letras, Universidad Nacional de Cuyo, 5500 Mendoza, Argentina

<sup>3</sup> Laboratorio de Arqueología Histórica y Etnohistoria, Instituto de Arqueología y Etnología, Facultad de Filosofía y Letras, Universidad Nacional de Cuyo, 5500 Mendoza, Argentina

<sup>4</sup> Museo del Área Fundacional de Mendoza, 5500 Mendoza, Argentina

## Introduction

Small mammal ( $\leq 1$  kg) bone and tooth remains recovered from archaeological sites have been overlooked in South American archaeological studies for various reasons. Among them are the difficulties associated with taxonomic determinations, deficiencies present in sample recovery and preservation in fieldwork and the lack of a coherent theoretical-methodological model applied to the study of such zooarchaeological remains (Stahl 1996; Pardiñas 1999; Fernández et al. 2017a). Small mammals, in general, have narrow ecological requirements, and the remains recovered in archaeological contexts offer the possibility of performing ecological inferences over past environments and their evolution over time, taking into account the current distribution of each taxon (Andrews 1995; Fernández-Jalvo et al. 2011).

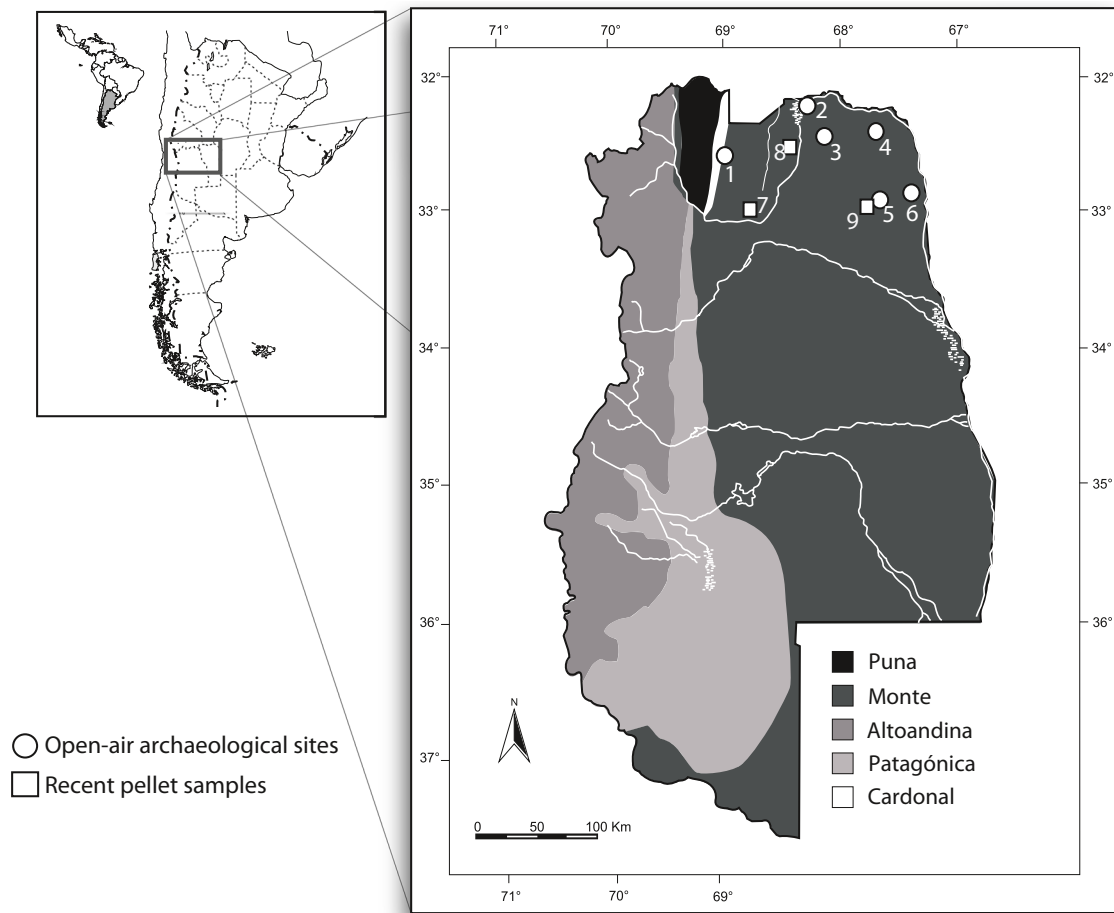
In South America, mainly in Argentina, most research on archaeological small mammal bone assemblages has focused on the Pampean, Patagonian and Northwestern regions, mainly corresponding to Pampa, Patagonian steppe and Puna phytogeographic provinces. Most of them showed the potential of such remains to improve our comprehension of human-environmental systems in the past (e.g. Pardiñas 1999; Fernández et al. 2009, 2011a, 2015a, b; Fernández 2012; Ortiz et al. 2012; Scheifler et al. 2012; Teta et al. 2013; Quintana 2016). Palaeoenvironmental studies on historical contexts from the Monte Desert based on documentary evidence point out major environmental perturbations during the last 500 years. Such alterations are related with the economic activities developed since the arrival of European conquerors, such as mining, land clearing, intensive livestock and agriculture, felling and manipulation of watercourses, among others (e.g. Abraham and Prieto 1981; Prieto et al. 2003, 2008, 2012; Prieto and Chiavazza 2006; Prieto and Rojas 2012). At the same time, some regional ecological studies have pointed out the deep impact that recent economic and commercial activities have had on animal and plant communities, also strongly modifying the landscape (Ojeda and Mares 1982; Roig 1991; Tabeni and Ojeda 2003, 2005). However, there are still few studies that evaluate environmental fluctuations during Prehistoric times, particularly the Late Holocene, probably associated with the establishment of current climatic conditions in the region around 4000 years ago (Navarro et al. 2012 and references therein). The scarcity of environmental information for the Late Holocene in Monte Desert contexts precludes a systematic approach to human-environment relationships during Pre-Hispanic times.

Some studies conducted in Central Western Argentina in the phytogeographic units of Puna, Monte and Patagonia have utilised archaeological small mammal assemblages not only to make palaeoenvironmental inferences but also to interpret human behaviour in the past (e.g. Fernández et al. 2009; Fernández 2012; López et al. 2016; Fernández and Pardiñas

2018). However, these works have generally been conducted in rockshelters or caves sites, possibly due to the sedimentary composition of the hundreds of sites located in the plains of the Monte Desert, mainly on sandy and unconsolidated soils, often without defined stratigraphies in aeolian environments (e.g. Chiavazza 2009, 2012, 2014). Despite these characteristics, archaeological studies from the central Monte Desert sites demonstrated the potential of these sites to understand both human occupations in the past and the environmental fluctuations of the last two millennia when human occupation of the central Monte Desert plains was recorded (e.g. Chiavazza 2007, 2012, 2014, 2016; García Llorca and Cahiza 2007; Cahiza and Ots 2014; Ots et al. 2016). A recent study argued that regional archaeological preferences by researchers towards cave or rockshelter sites and stratified contexts shows an incomplete picture of prehistoric occupation and landscape use in Central Western Argentina. Thus, that study highlights the importance of sites located in the plains of the Monte Desert—which covers more than 50% of the territory of Central Western Argentina—has been underestimated due to aeolian action and fragmentation of the archaeological record (Garvey and Bettinger 2018).

The Monte phytogeographic province, the most arid rangeland of Argentina, is located in western Argentina ( $24^{\circ} 35'$ ,  $44^{\circ} 20'$  S;  $62^{\circ} 54'$ ,  $69^{\circ} 5'$  W). It is an arid-semiarid zone, where the ratio between annual rainfall and evapotranspiration is lower than 0.5 (between 0.05 and 0.5) (Abraham et al. 2009; Labraga and Villalba 2009). Physiognomically, the central Monte Desert is a mosaic of two vegetation types: shrubby steppes dominated by *Larrea cuneifolia*, *Larrea divaricata*, *Larrea nitida*, *Acantholippia* spp. and *Junellia* spp. and open mesquite forests of *Prosopis*—mainly between  $29^{\circ}$  and  $33^{\circ}$  S—in addition to large proportions of bare sandy soils (Rundel et al. 2007). The distinctive feature of the Monte is reflected in the varied composition of its mammal fauna, particularly small mammals including rodents and marsupials (Ojeda et al. 2002). Therefore, taphonomic and palaeoenvironmental studies based on small mammal bone accumulations recovered in archaeological sites from the central Monte Desert constitute a valuable tool to interpret human-environment relationships and past landscape features.

The present study analyses the taphonomic features of small mammal bone and tooth accumulations recovered in six open-air archaeological sites from the central Monte Desert (Central Western Argentina) in an area crossed by the South American arid diagonal (Bruniard 1982). In order to identify possible accumulating agents of such bone sets, relative abundances, breakage patterns, digestive corrosion, thermal alterations and cut marks were evaluated, as well as signals produced by postdepositional processes (e.g. weathering and trampling). Taphonomic results were interpreted and compared with those reported in regional archaeological research



**Fig. 1** Archaeological and recent small mammal bone accumulations recovered in the Monte Desert in a phytogeographic context. Open-air archaeological sites: 1, Agua de los Pajaritos; 2, Punto Arqueológico 14.7 (PA14.7); 3, Punto Arqueológico 52 (PA52); 4, Punto Arqueológico 24.2

(PA24.2); 5, Punto Arqueológico 46.4 (PA46.4); 6, Punto Arqueológico 68.1 (PA68.1). Recent accumulations from owl pellets: 7, *Athene cunicularia* from Lunlunta (Maipú); 8, *Tyto alba* from San José (Lavalle); 9, *Tyto alba* from Paleocauce central (PA46.4)

performed at Monte Desert sites and with information provided by actualistic studies of different predators that inhabit the study area. With the aim of making palaeoenvironmental inferences, the taxonomic compositions of archaeological assemblages and current regional ones were analysed and compared.

## Materials and methods

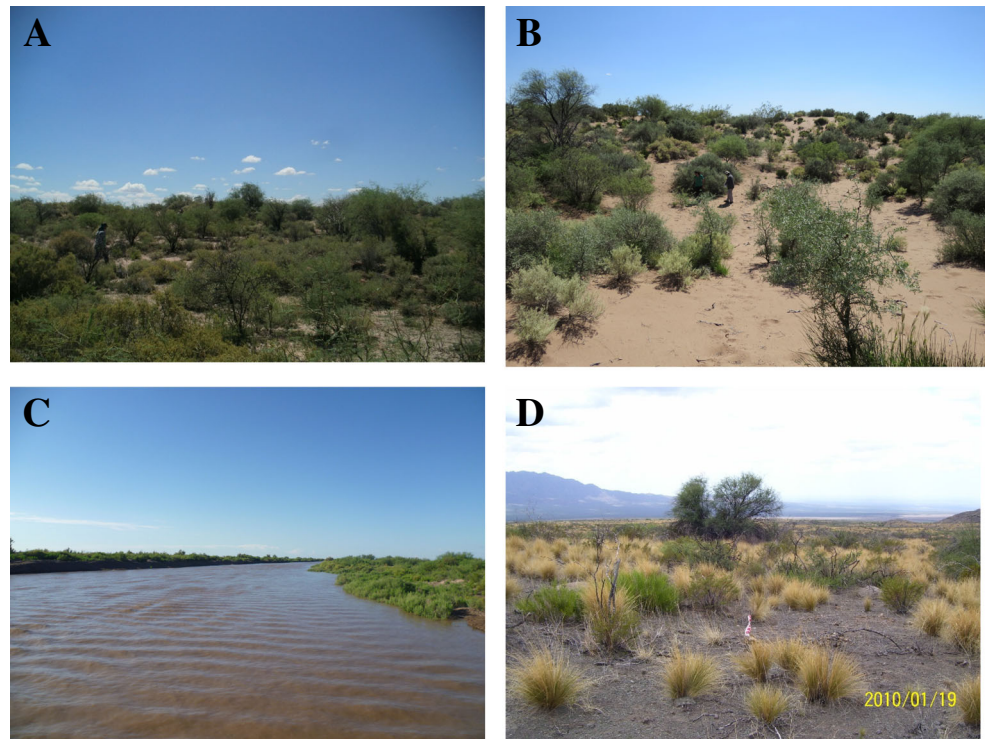
The study was carried out in a large area of northeastern Mendoza Province, Argentina, (Figs. 1 and 2) including different areas of the Monte phytogeographic province in open-air archaeological sites from aeolian sedimentary contexts between 900 and 500 masl.

The small mammal bone remains analysed in this study were recovered in archaeological excavations conducted between 1998 and 2014. Open-air archaeological samples were generally obtained from sandy contexts associated with different kinds of watercourses. Thus, three of them were recovered

in paleoriverbeds corresponding to Mendoza river (PA24.2, PA46.4, PA52); one sample belongs to current lagoon contexts (Lagunas de Guanacache; PA14.7); one sample was obtained from the current riverbed of Desaguadero river (PA68.1); whereas, the last sample comes from the lower piedmont of the Andean precordillera (Agua de los Pajaritos). As determined through radiocarbon and relative dates, all sites correspond to human occupation contexts during the last 2000 years (Table 1). The general features of each archaeological site can be seen in the [Electronic supplementary material \(S1\)](#).

Considering the general lack of stratified contexts on sandy soils in these archaeological sites, the material was obtained through surface and subsurface (0–5 cm) excavations. However, an open-air stratified site from the piedmont (Agua de los Pajaritos) was also included in the present study. Although PA68.1 is a stratified site, all small mammal bone remains were recovered in surface and subsurface sectors (0–5 cm). A 2-mm screen mesh was used for the recovery of the remains.

**Fig. 2** Some representative environments from the Monte Desert of northern Mendoza and some open-air archaeological sites of the present study. **a, b** Punto Arqueológico 68 archaeological site in a scrubland (*Larrea* spp. mainly) with some proportions of bare sandy soils. **c** Mendoza river in the lowlands; **d** Agua de los Pajaritos archaeological site in the piedmont



Bone and tooth remains were examined using a stereomicroscope (variable magnification of  $\times 8$  to  $\times 50$ ). Taxonomic determinations were made at species level, whenever possible, based on cranial and dental elements, through comparison with current specimens from the Vertebrate Collection of IADIZA (CCT-Mendoza) as well as with specialised literature (e.g. De Santis et al. 1991; Fernández et al. 2011b). Some species are indistinguishable from cranial and dental remains, which in certain cases the determinations were made to genus level (e.g. *Abrocoma* sp., *Ctenomys* sp., *Eligmodontia* sp.).

The number of identified specimens by taxon (NISP), minimal number of individuals (MNI) and minimal number of elements (MNE) was calculated (Lyman 2008). Shannon diversity index ( $H'$ ) was calculated on the basis of MNI, taking into account the logarithm of richness as the highest value (greatest diversity) that each sample could reach. An evenness index also was calculated based on  $H'$  ( $J = H'/H_{max}$ ), where  $H_{max}$  is the logarithm of specific richness. Values vary from 0 to 1. The closer to number 1, the more heterogeneous and/or equally the species are represented, respectively (Krebs 1989).

To increase the information on modern small mammal assemblages from the study region, and thus, strengthen the potential of our palaeoenvironmental inferences, owl pellet samples were recovered both near archaeological sites (e.g. PA46.4), whenever possible, and in other meaningful areas associated with intensive wine and olive agriculture (Lunlunta). Only cranial and dental elements were analysed from the current samples with the aim to assess the taxonomic composition of these communities. Data previously reported on modern small mammal assemblages were

also considered (e.g. Rodríguez and Ojeda 2013; Castillo et al. 2018; López et al. 2018).

The taphonomic analysis followed the methodology proposed by Andrews (1990), Fernández-Jalvo and Andrews (1992) and Fernández et al. (2017b). This methodology also examines the possible natural predators of small mammals from the study area. Modification categories consider alteration, frequency and intensity degrees of affected elements based on three main variables: relative abundances, breakage and digestion. Relative abundances of skeletal elements were evaluated taking into account the representation of each element in the whole sample (MNE $_i$ ) on the basis of the expected number of each element in one individual ( $E_i$ ) and on the basis of MNI by using the following formula:  $MNE_i / (E_i \times MNI) \times 100$ . To evaluate the relationships between cranial and postcranial elements, two indexes were calculated: postcrania/crania (pc/c) = ((femora + tibiae + humeri + radii + ulnae)  $\times$  (8) / (mandibles + maxillae + molars)  $\times$  (5)) and  $f + h/md + mx = ((femora + humeri / mandibles + maxillae))$ . To evaluate the relationship between the representation of distal and proximal elements of the skeleton, one index was used:  $t + ul/f + h = ((tibiae + ulnae / femora + humeri))$ , whereas two calculations were used for measuring tooth loss:  $alv/m = ((empty\ mandibular\ molar\ alveoli + empty\ maxillary\ molar\ alveoli / molars))$  and  $alv/i = ((empty\ mandibular\ incisor\ alveoli + empty\ premaxillary\ incisor\ alveoli / incisors))$ . Didelphid mammals were not included in the last two calculations, as their dental formula was considerably different from that of rodents.

**Table 1** Taphonomic values of the analysed variables of small mammal bone and teeth accumulations recovered in open-air archaeological sites from the Monte Desert

Archaeological site	Open-air sites from the present study located in the Monte Desert					Some rockshelter sites from the Monte Desert and Puna				
	PA14.7	PA24.2	PA46.4	PA52	PA68.1	Agua de los Pajaritos	VQGI I	VQGI II	VQGI III	RH
Chronology <sup>14</sup> C (BP; min-max)	1600–200	1600–600	2000–200	1600–200	1200–300	1900	200–500	500–2000	2000–3100	1800–300
M <sup>2</sup> excavated	16	16	22	16	4	7	8	8	8	6
NISP	48	227	284	47	45	80	2323	3748	3209	251
ARA %	11.14	22.29	27.15	9.35	6.05	9.92	18.34	31.46	24.65	15.23
pc/c index	2.08	5.46	0.61	4.16	0.29	0.64	0.99	2.39	1.79	1.48
f + h/md + mx index	1.12	3.12	0.78	7.00	0.14	0.26	0.41	0.63	0.71	0.74
t + u (or t + r) / f + h index	0.44	0.64	2.00	0.85	4	0.83	0.66	0.69	0.70	0.41
Alv i index	0.66	0	0.03	0	0.40	1.66	0.63	0.81	0.86	3.00
Alv m index	6.50	5.00	0.45	0	3.00	6.00	7.49	8.84	9.63	9.40
Postcranial digestion %	11	16.66	70	42.88	0	80	14.5	29.5	26	68.4
Incisor digestion %	20	100	30	20	0	0	13.5	19	16	56
Incisors digested in situ %	50	0	100	0	0	0	8.09	8.89	8.25	50
Isolated incisors digested %	0	100	28.58	20	0	0	16.66	22.61	17.88	71.43
Molar digestion %	7.14	0	34	20	12.5	18.51	11.6	14.4	14	56
Molars digested in situ %	0	0	0	0	25	17.03	10.13	11.87	12.02	52.5
Isolated molars digested %	50	0	36.74	25	10	28.58	13.64	27.64	26.32	97
Main total digestion degrees	A-L-M	A-L-M	A-L-M	A-L	A	A-L	A-L-M	A-L-M	A-L-M	A-L-M-H
Main digestion degrees on teeth	A-M	A-L-M	A-L	A-L	A	A-L	A-L	A-L	A-L	L-M
Main digestion degrees on postcranial	A-L	A	A-L-M	A-L	A	A-L	A-L	A-L	A-L	L-M
Breakage maxillae and mandibles %	100	100	100	100	100	92.30	89.6	87.8	89	92.07
Breakage postcranials %	92.30	100	100	100	100	66.66	42.4	24	22.1	65.8
Weathering %	45	99.5	93.30	88	97.91	78.75	1.4	0.99	0.90	2
Thermal alterations %	20	10.2	3.9	2.1	11.1	0	0.99	2	1.5	0.90

Comparison with taphonomic values reported for small mammal bone accumulations recovered in rock shelter sites from the study area. Sources of the chronologies of archaeological sites of the present study: PA14.7, PA46.4 and PA52 (Chiavazza 2014); PA24.2 (Chiavazza 2016); PA68.1 (Prieto Olavarría et al. 2016); Agua de los Pajaritos (Chiavazza et al. 2010)

Abbreviations: NISP, number of specimens identified by taxon; ARA, average relative abundance of skeletal elements; pc, postcranial; c, cranial; md, mandible; mx, maxillae; f, femur; h, humerus; t, tibiae; u, ulnae; i, incisors; m, molars; A, absent; L, light; M, moderate; H, Heavy; VQGI I, Vaquería Gruita I (component 1); VQGI II, Vaquería Gruita I (component 2); VQGI III, Vaquería Gruita I (component 3) (López et al. 2016, López 2018); RH, Rincón de los Helados (López et al. 2017b)

Breakage patterns on cranial (skull, mandible, teeth) and postcranial bones (femora, humeri, tibiae, ulnae) were analysed taking into account the degree of completeness of each element, considering complete and fractured elements separately and calculating the percentage of breakage. Four categories were used for skull breakage: complete, maxillary with zygomatic, maxillary without zygomatic and minor fragments; four degrees were used for mandible breakage: complete, ascendant ramus broken, without ascendant ramus and without ascendant ramus and inferior edge broken. Breakage of diagnostic long bones (femora, humeri, tibiae and ulnae) was recorded as complete, shaft, proximal and distal parts.

Modifications by digestion were evaluated on diagnostic elements (molars, incisors, femora and humeri) distinguishing four degrees of digestive corrosion (light, moderate, heavy and extreme), except when digestion was absent. Digestion is the most reliable taphonomic variable to identify the possible accumulating agent of small mammal bone remains from archaeological and palaeontological sites, owing to its clear taphonomic signals, which can be differentiated from other taphonomic alterations, and whose traces are not modified by postdepositional processes (Andrews 1990; Fernández-Jalvo et al. 2014; Fernández et al. 2017b).

In order to strengthen the interpretation of possible accumulating agents, size and predictability indexes were calculated (Pardiñas 1999). The first one allows distinguishing small mammal bone accumulations generated by nocturnal raptors (mainly strigiforms) from those accumulated by other predators, and is calculated using the following formula: (MNI small sized  $\leq 50$  g- + MNI medium sized  $-50$  to  $150$  g-) / (MNI large sized  $\geq 150$  g-). The index considers that strigiforms feed on smaller species than accipitriforms, carnivorous mammals and humans. The second is calculated to evaluate relationships between grouped and non-grouped species of small mammals, using the following formula: (MNI colonials + MNI gregarious + MNI grouped) / (MNI cryptic + MNI solitaires). Nocturnal raptors generally prey on cryptic and solitaires small mammal species, whereas the proportions of grouped species in assemblages generated by accipitriforms and humans are higher than that observed for strigiforms.

The action of postdepositional processes was also analysed, including weathering, trampling, root etching and abrasion (Andrews 1990; Fernández-Jalvo et al. 2014). Principal component analysis (PCA) was conducted against previously reported archaeological and modern samples (López et al. 2016; López 2018; Andrews 1990; Gómez 2005; Montalvo and Tejerina 2009; Montalvo et al. 2016; López et al. 2017a, b, 2018, respectively) in order to explore sample ordination in a multivariate space. PCA worked over a data matrix composed by percentage of digestion on incisors, molars and postcranial elements; percentage of breakage on cranial and postcranial elements; calculated indexes of relative abundances; and average of relative abundance of skeletal

elements. PCA was performed using the software Paleontological Statistics (PAST) version 3.12 (Hammer et al. 2001).

## Results

### Taphonomic analysis

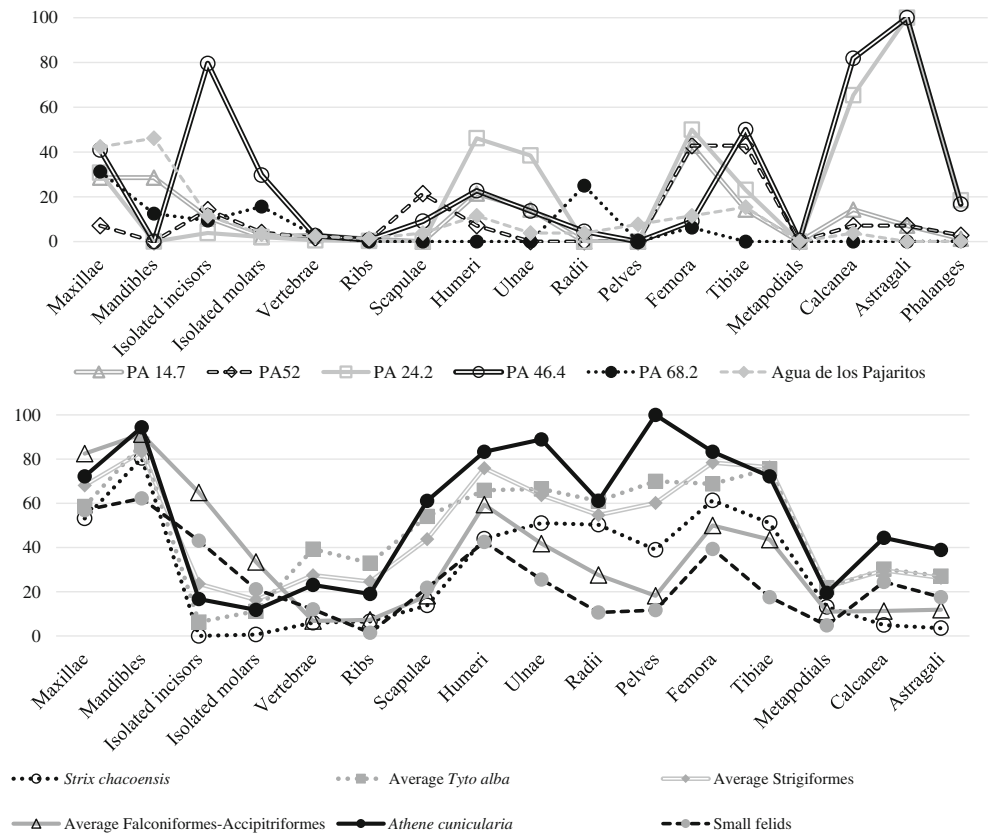
A total of 734 specimens was recovered and analysed. With the exception of isolated incisors, tibiae, calcanea and astragali in one site (PA46.4) and femora, astragalus and calcaneus in another site (PA24.2), the relative abundance of each skeletal element was low (Fig. 3). Thus, except in the aforementioned cases, the relative abundance of each skeletal element did not exceed 50%. Most elements had relative abundances of less than 20%. Relative abundance averages ranged between 6.05% (Agua de los Pajaritos) and 27.15% (PA46.4).

The results of the indices used to evaluate relationships between cranial and postcranial elements (pc/c and  $f+h/md+mx$ ) revealed three accumulations that indicated a better representation of postcranial elements (PA14.7, PA24.2, PA52), whereas in all others, cranial bones were better represented than postcranial bones (Tables 1 and 2). In the three sites with higher postcranial representation, proximal elements were better represented than distal ones, whereas distal elements were better represented in the remaining sites. The relationship between the number of preserved alveolar spaces and incisors showed a loss of maxillae and mandibles in all subsurface sites, whereas in the stratified site, a loss of molars and incisors was detected. Regarding the  $alv\ md + alv\ mx / m$  index, in four sites tooth loss was observed (PA14.7, PA24.2, PA68.1 and Agua de los Pajaritos), whereas in PA46.4 and PA52, a loss of mandibles and maxillae was identified (Table 1).

Breakage of cranial and postcranial bones was considerably high (Tables 1 and 3). In the subsurface open-air sites, all cranial bones were recovered broken, whereas in four out of five sites, all postcranial bones were fractured. Although in the stratified site, breakage was lower than in the subsurface sites, the proportion of broken bones continued to be high. The great majority of broken bones ( $\geq 90\%$ ) showed rough and/or angled broken edges.

Digestive corrosion (almost always light and exceptionally moderate in PA14.7, PA24.2, PA46.4 and Agua de los Pajaritos— $\leq 5\%$  by site or heavy in Agua de los Pajaritos— $\leq 5\%$ ) was detected in the diagnostic elements in all sites, although in different proportions (Tables 1 and 4; Fig. 4). Regarding incisors, proportions of digestion ranged from 0% in Agua de los Pajaritos and PA68.1 to 50% in PA24.2 ( $n = 1$ ). The proportions of molars modified by digestion ranged from 0% in PA24.2 to 34% in PA46.4 ( $n = 18$ ). Postcranial elements were affected by digestion from 0% in PA68.1 to 80% in Agua de los Pajaritos ( $n = 4$ ).

**Fig. 3** Top, relative abundances of skeletal elements of small mammal bone accumulations recovered in open-air archaeological sites from the Monte Desert. Down, relative abundance of skeletal elements in modern small mammal bone accumulations: *Strix chacoensis* (López et al. 2018), average *Tyto alba*, average of Strigiformes (after Andrews 1990); Average Falconiformes-Accipitriformes (after Andrews 1990); *Athene cunicularia* (Montalvo and Tejerina 2009); small felids (López et al. 2017a)



A high proportion of elements, primarily identified as category 1, were weathered. In most sites, more than 75% of the elements were affected by this postdepositional process,

except PA14.7 with 45% of weathered elements. No significant amounts of skeletal elements were detected with thermal alterations ( $\leq 11\%$  with the exception of PA14.7–20%—in

**Table 2** Relative abundances of skeletal elements of small mammal assemblages recovered in open-air archaeological sites from the Monte Desert in Central Western Argentina

	PA14.7		PA24.2		PA46.4		PA52		PA68.1		Agua de los Pajaritos	
	MNE	%	MNE	%	MNE	%	MNE	%	MNE	%	MNE	%
Maxillae	4	28.57	8	30.76	9	40.90	1	7.14	5	31.25	11	42.30
Mandibles	4	28.57	0	0.00	0	0.00	0	0.00	2	12.50	12	46.15
Isolated incisors	3	10.71	2	3.84	35	79.54	4	14.28	3	9.37	6	11.53
Isolated molars	2	2.04	4	2.05	49	29.69	4	4.08	20	15.62	7	3.36
Vertebrae	11	2.85	4	0.55	16	2.64	6	1.55	12	2.72	17	2.37
Ribs	2	1.09	1	0.29	2	0.69	1	0.54	0	0.00	5	1.37
Scapulae	0	0.00	0	0.00	2	9.09	3	21.42	0	0.00	1	3.84
Humeri	3	21.42	12	46.15	5	22.72	1	7.14	0	0.00	3	11.53
Ulnae	2	14.28	10	38.46	3	13.63	0	0.00	0	0.00	1	3.84
Radii	0	0.00	0	0.00	1	4.54	0	0.00	4	25.00	1	3.84
Pelves	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	7.69
Femora	6	42.85	13	50.00	2	9.09	6	42.85	1	6.25	3	11.53
Tibiae	2	14.28	6	23.07	11	50.00	6	42.85	0	0.00	4	15.38
Metapodials	0	0.00	0	0.00	1	0.45	0	0.00	0	0.00	0	0.00
Calcanea	2	14.28	17	65.38	18	81.81	1	7.14	0	0.00	1	3.84
Astragali	1	7.14	26	100.00	22	100.00	1	7.14	0	0.00	0	0.00
Phalanges	5	1.27	124	18.45	103	16.72	11	2.80	1	0.22	1	0.13

Minimum number of skeletal elements (MNE) and representation of each element based on the minimal number of individuals (MNI) (%)

PA14.7, Punto Arqueológico 14.7; PA24.2, Punto Arqueológico 24.2; PA46.4, Punto Arqueológico 46.4; PA52, Punto Arqueológico 52; PA68.1, Punto Arqueológico 68.1

**Table 3** Amount and percentages of breakage of cranial and postcranial elements recovered in open-air archaeological sites from the Monte Desert in northern Mendoza

	Punto Arqueológico 14.7		Punto Arqueológico 24.2		Punto Arqueológico 46.4		Punto Arqueológico 52		Punto Arqueológico 68.1		Agua de los Pajaritos	
	N	%	N	%	N	%	N	%	N	%	N	%
Mandible												
Complete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	15.38
Ascendant ramus broken	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	8	61.53
Without ascendant ramus	4	80.00	0	0.00	0	0.00	0	0.00	1	50.00	2	15.38
Without ascendant ramus and inferior edge broken	1	20.00	0	0.00	0	0.00	0	0.00	1	50.00	1	7.69
Maxilla												
Complete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
With zygomatic	3	75.00	8	100.00	9	81.81	1	100.00	1	20.00	10	76.92
Without zygomatic	1	25.00	0	0.00	0	0.00	0	0.00	4	80.00	1	7.69
Minor fragments	0	0.00	0	0.00	2	18.19	0	0.00	0	0.00	2	15.38
Femur												
Complete	1	16.67	0	0.00	0	0.00	0	0.00	0	0.00	2	66.66
Proximal	5	83.33	13	100.00	2	100.00	6	100.00	0	0.00	1	33.33
Shaft	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Distal	0	0.00	0	0.00	0	0.00	0	0.00	1	100.00	0	0.00
Humerus												
Complete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	33.33
Proximal	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Shaft	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	33.33
Distal	3	100.00	12	100.00	5	100.00	1	100.00	0	0.00	1	33.33
Tibia												
Complete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	25.00
Proximal	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	25.00
Shaft	1	50.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Distal	1	50.00	6	100.00	11	100.00	6	100.00	0	0.00	2	50.00
Ulna												
Complete	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Proximal	2	100.00	10	100.00	3	100.00	0	0.00	0	0.00	1	100.00
Shaft	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Distal	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00



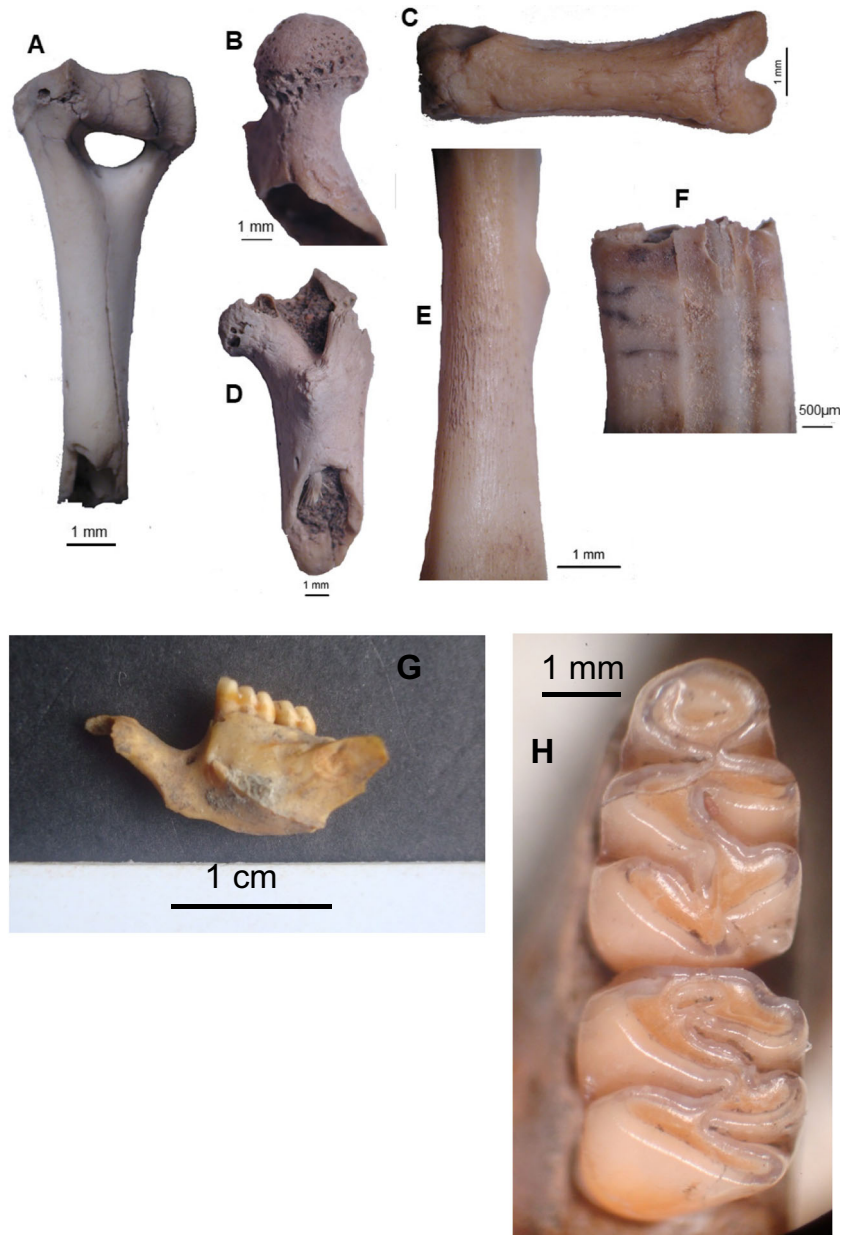
**Table 4** Amount of isolated and in situ incisors, isolated and in situ molars and postcranial diagnostic elements recovered in open-air archaeological sites from the Monte Desert in northern Mendoza

	Incisors in situ	Isolated incisors	Molars in situ	Isolated molars	Postcranial diagnostic elements
Punto Arqueológico 14.7	2	3	12	2	9
Punto Arqueológico 24.2	0	2	2	4	24
Punto Arqueológico 46.4	1	35	3	49	7
Punto Arqueológico 52	0	5	1	4	7
Punto Arqueológico 68.1	0	3	4	20	0
Agua de los Pajaritos	10	6	47	7	5

each set, Table 5). Generally, these elements were calcined or burned completely (in reference to the amount of surface area

of the bone modified) not showing thermal alterations associated with anthropic activity, such as partial, differential or

**Fig. 4** Examples of weathering and digestion in open-air archaeological sites from the Monte Desert of Mendoza (a–f). *Holochilus lagigliai* (g–h). **a** Humerus with category 1 of weathering and breakage with rough and angled edges, **b** slight cracking and light digestion on femur, **c** phalanx with two modification category of weathering, **d** weathering (category 2) on femur, **e** light weathering (category 1) on humerus shaft, **f** weathering (category 1) and digestion (light) on Caviidae molar, **g** left hemimandible of *H. lagigliai* recovered in Punto Arqueológico 14.7 (Lagunas de Guanacache, Mendoza) in labial view, **h** left lower molar series of such hemimandible of *H. lagigliai* in occlusal view, with m1 and m2



**Table 5** Amount and percentages of thermoaltered bones recovered in open-air archaeological sites from the Monte Desert of northern Mendoza

	<i>N</i> burnt bones	% burnt bones	<i>N</i> calcined bones	% calcined bones
Punto Arqueológico 14.7	1	2	9	18.75
Punto Arqueológico 24.2	22	9.69	2	0.88
Punto Arqueológico 46.4	10	3.52	1	0.35
Punto Arqueológico 52	1	2.12	0	0
Punto Arqueológico 68.1	1	2.22	4	8.88
Agua de los Pajaritos	0	0	0	0

heterogeneously burned bones (e.g. Medina et al. 2012; Fernández et al. 2017a). Cut marks were not detected. Root traces were detected at very low frequencies ( $\leq 2.4\%$  in each set), and abrasion from fluvial transport was not observed.

### Taxonomic composition of archaeological small mammal bone assemblages

Small mammal assemblages recovered in open-air archaeological sites of the present study are mainly composed by typical species from the Monte Desert (Table 6). Large-sized small mammals ( $\geq 150$  g) dominated in all sites. The detected species were the didelphid *Thylamys pallidior* (pallid fat-tailed opossum) (PA14.7 and Agua de los Pajaritos) and the caviomorph rodents *Abrocoma* sp. (chinchilla rat) (Agua de los Pajaritos), *Galea leucoblephara* (lowland yellow-toothed cavy) (PA24.2, PA46.4, PA68.1 and Agua de los Pajaritos), *Microcavia australis* (southern mountain cavy) (PA14.7, 24.2, PA46.4, PA68.1 and Agua de los Pajaritos), *Ctenomys* sp. (tuco-tuco) (PA14.7, PA46.4, PA52, PA68.1 and Agua de los Pajaritos) and *Tympanoctomys barrerae* (viscacha rat) (PA14.7, PA46.4, PA52); and the cricetid rodents *Eligmodontia* sp. (gerbil mouse) (PA24.2, PA46.4), *Graomys griseoflavus* (gray leaf-eared mouse) (PA24.2) and *Holochilus lagigliai* (marsh rat) (PA14.7) (Fig. 3).

Shannon diversity index ( $H'$ ) showed values between 0.50 and 0.70 in all subsurface open-air sites, whereas in the stratified site,  $H'$  reached 0.54. The evenness index was high in all subsurface open-air sites ( $\geq 0.89$ ), whereas in the stratified site the value was moderate, close to 0.5. The predictability index showed values higher than 1 in all sites, whereas the size index resulted in values lower than 1, except in PA52. Frequency and index values can be observed in Table 6.

### Taxonomic composition of modern small mammal bone assemblages

Small mammal assemblages recovered from modern pellet samples are composed by the didelphid *T. pallidior* (San José), the caviomorph rodents *M. australis* (Paleocauce central) and *Ctenomys* sp. (San José and Paleocauce central); the cricetid rodents *Akodon dolores* (dolorous grass mouse)

(Paleocauce central), *Calomys musculus* (drylands vesper mouse) (San José, Paleocauce central and Lunlunta), *Eligmodontia* sp. (San José and Paleocauce central), *G. griseoflavus* (San José and Paleocauce central); and the exotic muridae *Mus musculus* (house mouse) (Paleocauce central and Lunlunta). Species frequency and index values at each site can be observed in Table 7.

The  $H'$  index resulted in values between 0.18 (Lunlunta) and 0.74 (Paleocauce central), whereas the evenness index indicated values between 0.61 (Lunlunta) and 0.88 (Paleocauce central). The predictability index was considerably lower than 1 in all current pellet samples, whereas the size index was higher than 1 in all samples.

## Discussion

### Accumulating agents and taphonomic issues

The results obtained from the taphonomic analysis of small mammal bone and tooth accumulations from open-air archaeological sites in the Monte Desert suggest the action of avian raptors, particularly owls. The absence of anthropic activity signals (e.g. kind and frequency of thermal alterations or cut marks) discards the participation of human beings in the generation of the aforementioned small mammal bone and tooth accumulations. The high level of breakage and the low relative abundance of skeletal elements (even total averages) suggest a considerable loss of bones.

Digestion is the most reliable variable to infer agents responsible for small mammal bone accumulations recovered in archaeological and palaeontological sites. This is due to the fact that digestive damage has a unique morphology and therefore can be clearly distinguished from any other modification on bone and tooth surfaces (Andrews 1990; Fernández-Jalvo et al. 2014). On the contrary, other taphonomic variables (e.g. breakage, relative abundances and proportions of a kind of species) can be influenced both by predator behaviours and by postdepositional processes. This accounts for the difficulty in differentiating both processes on bone surface, thus generating equifinality problems (Andrews 1990; Pardiñas 1999).

**Table 6** Taxonomic composition of small mammal bone accumulations recovered in open-air archaeological sites from the Monte Desert

	Archaeological sites from the present study						Average body mass (g)
	PA14.7	PA24.2	PA46.4	PA52	PA68.1	Agua de los Pajaritos	
MNI	7	13	11	7	8	13	
	MNI %	MNI %	MNI %	MNI %	MNI %	MNI %	
Didelphimorphia							
<i>Thylamys pallidior</i>	14.28				12.5		21.4
Rodentia							
Abrocomidae							
<i>Abrocoma</i> sp.						23.07	157.3
Caviidae							
Caviidae indet	14.28	46.15	9.09	28.57	25		
<i>Galea leucoblephara</i>		15.38	27.27		12.5	7.69	190
<i>Microcavia australis</i>	14.28	15.38	18.18		37.5	38.46	223.2
Ctenomyidae							
<i>Ctenomys</i> sp.	14.28		9.09	14.28	12.5	30.76	161.1
Octodontidae							
<i>Tympanoctomys barrerae</i>	14.28		18.18	14.28			84.4
Cricetidae							
Sigmodontinae indet	14.28	7.69	9.09	42.85			
<i>Eligmodontia</i> sp.		7.69	9.09				21.1
<i>Graomys griseoflavus</i>		7.69					66.7
<i>Holochilus lagigliai</i>	14.28						307.5
Diversity <i>H'</i>	0.69	0.57	0.66	0.55	0.53	0.54	
Evenness <i>J'</i>	1	0.95	0.94	0.92	0.89	0.49	
Log richness	0.69	0.60	0.69	0.60	0.60	1.11	
Predictability index	1.33	3.33	4.5	1.33	7	13	
Size index	0.75	0.25	0.22	1.33	0.14	0	

Percentages (%) of each species

*MNI*, minimal number of individuals; *H'*, Shannon diversity index; *J'*, evenness index; *Log S*, logarithm of richness; *PI*, predictability index; *SI*, size index

Digestive corrosion, mainly light, was detected in all small mammal bone accumulations analysed in the present study. Although in some cases proportions of this effect were high, this could be the consequence of small sample size or of the high loss of skeletal elements. These features, added to the action of weathering and trampling on sandy soils, could bias the representation of each sample. Thus, high proportions of all types of diagnostic elements in only one assemblage were never detected. For example, where a high frequency of incisors digested was found (PA24.2), neither molars nor postcranial elements were strongly modified by digestion. These “contradictory” values (even in the stratified site) could also be influenced both by site characteristics (subsurface and/or open-air sites) and by the effect of postdepositional processes, like trampling and weathering. These processes are strong modifiers of “original” bone accumulations, altering site integrity and resolution as well as presence, abundance, completeness and proportion of skeletal elements (Andrews

1990). For example, calculated indexes to evaluate relationships between skeletal parts, however, did not show incoherencies inside each archaeological sample. On the other hand, such contradictory values could also be the effect of mixing accumulations from different predator groups or the selective transport of particular elements (e.g. digested incisors) in the sites (open-air sites in particular). However, the presence of only one type of digestion (almost always light) in all archaeological sites, the considerable loss of bones, the high level of breakage by trampling, the intense action of weathering, the absence of signals of fluvial transport, added to the sandy and surface features of the studied open-air sites, allow thinking about the strong influence of postdepositional processes in the generation of these confusing and scarcely coherent values. Thus, the material was accumulated by owls and later trampled and moved postdepositionally (through wind and weathering) occurring bone loss. Small molars may also have been lost as they move through screens easier

**Table 7** Taxonomic composition of small mammal bone accumulations recovered from recent owl pellet samples at the Monte Desert

Predator	MNI% <i>Athene cunicularia</i> Laguna de Soria Castillo et al. (2018)	MNI% <i>Tyto alba</i> San José Present study	MNI% <i>Strix chacoensis</i> Telteca López et al. (2018)	MNI% <i>Tyto alba</i> Paleocauce central Present study	MNI% <i>Athene cunicularia</i> Lunlunta Present study
<i>N</i> pellets	56	36	147	29	93
MNE (cranial and dental)	198	60	414	70	253
MNI total	69	26	141	30	85
Didelphimorphia					
<i>Thylamys pallidior</i>		7.69	26.95		
Rodentia					
Caviidae					
<i>Microcavia australis</i>			3.55	10.00	
Ctenomyidae					
<i>Ctenomys</i> sp.		7.69		6.66	
Cricetidae					
Sigmodontinae indet			5.67		
<i>Akodon dolores</i>	1.44		2.12	20.00	
<i>Calomys musculus</i>	46.37	19.23		36.66	15.29
<i>Eligmodontia</i> sp.	14.50	7.69	28.36	10.00	
<i>Graomys griseoflavus</i>		57.70	33.33	13.33	
<i>Oligoryzomys flavescens</i>	18.84				
Muridae					
<i>Mus musculus</i>	18.84			3.34	84.71
Diversity <i>H'</i>	0.57	0.53	0.56	0.74	0.18
Evenness <i>J'</i>	0.82	0.76	0.80	0.88	0.61
Log richness	0.69	0.69	0.69	0.84	0.30
Predictability index	0	0.08	0.03	0.20	0
Size index	69	5.5	27.2	5.00	0

MNE, minimal number of elements; MNI, minimal number of individuals proportion (%) of each species; *H'*, Shannon diversity index; *J'*, evenness index; *Log S*, logarithm of richness; *PI*, predictability index; *SI*, size index

than longer incisors. At this point, the role of digestion is reinforced as a proxy to approach the possible accumulating agents of small mammal bone and tooth accumulations recovered in open-air archaeological sites from the Monte Desert. Without stratigraphy, we can be sure these are not intrusive species burrowing taking into account the lack of complete articulated specimens, the discoloring of the bones, which does not look modern, and the type and frequencies of modifications by digestion.

Trampling has been pointed out as one of the main causes of bone loss (cranial bones and teeth mainly) (Andrews 1990) observed in the analysed archaeological samples. The great abundance of large species could be the consequence of these destructive processes, and it should not be attributed to the dietary preferences of certain predators. Thus, differential preservation has been found to be strongly linked with structural bone density in vertebrates of all sizes (e.g. Denys et al. 1997; Andrews and Armour-Chelu 1998). Atmospheric processes, like weathering, can considerably affect bone

accumulations. For this reason, small mammal bones corresponding to larger species could be better preserved than bones from smaller species (Denys et al. 1997), although also small species could preserve better due to faster sediment cover speeds. The high abundance of autopodium bones (more dense than other skeletal elements) can also reflect differential preservation and destruction by postdepositional processes. Even small mammal bone accumulation from the stratified site showed high proportions of weathered bones and breakage by trampling.

Small mammal bone and tooth accumulations recovered in open-air archaeological sites from the Monte Desert showed some differences with those accumulations reported for rockshelter sites from the same study area located in highlands (refer to Table 1 for examples). Thus, loss of skeletal elements, breakage and weathering were higher in open-air sites than in rockshelter sites. In general, small mammal bone accumulations recovered in rockshelter sites, including regional ones, show better preservation conditions than those small mammal

bone accumulations recovered in open-air sites (Andrews 1990; Fernández 2012; López 2018).

When taphonomic values were incorporated in a data matrix to explore ordination in a multivariate space through PCA, the distribution of open-air archaeological samples was much more similar among them than with any of the current predator samples from the Monte Desert (Fig. 5 top; components 1 and 2 account for 82.89% of the variation; eigenvalues PC1 = 3460.32, PC2 = 1923.46). This is interesting, considering that archaeological bone samples were “modern” bone samples in the past. The grouping of open-air archaeological samples and the discrimination of current small mammal bone samples generated by several predators reflects that the common features detected in small mammal bone samples from open-air archaeological sites are even stronger than the taphonomic trends generated by each predator. These common features are probably related with the sedimentary characteristics of open-air sites—all of them on sandy soils and almost always from surface and subsurface record—with the strong action of weathering and trampling, and with the participation of the same type of predators in all small mammal bone and tooth accumulations.

When small mammal bone samples from rockshelter archaeological sites were included in another PCA analysis, bone accumulations from open-air archaeological sites of the Monte Desert were also grouped and discriminated both from current predator bone samples and from small mammal bone accumulations recovered in rockshelter archaeological sites (Fig. 5 down; components 1 and 2 account for 83.04% of the variation; eigenvalues PC1 = 3048.98, PC2 = 1594.99). In addition, archaeological samples recovered for the present study on sandy soils were probably never incorporated into the sedimentary context of each site or did so very slowly.

Despite the high level of destruction by sedimentary features and by postdepositional processes, degrees and frequencies of digestion allowed to infer avian raptors (particularly owls) as accumulating agents of small mammal bone and teeth accumulations from open-air archaeological sites of the Monte Desert.

If the evaluation of digestion traces had not been considered, the high level of destruction and bone loss could lead to misinterpretations. Thus, these highly modified bone assemblages could be erroneously associated with carnivorous mammals, diurnal raptors or humans, which strongly modify their prey remains, both in frequency and intensity, and produce assemblages of primarily large-sized small mammal prey (e.g. López et al. 2017a, b; Fernández et al. 2017a, respectively).

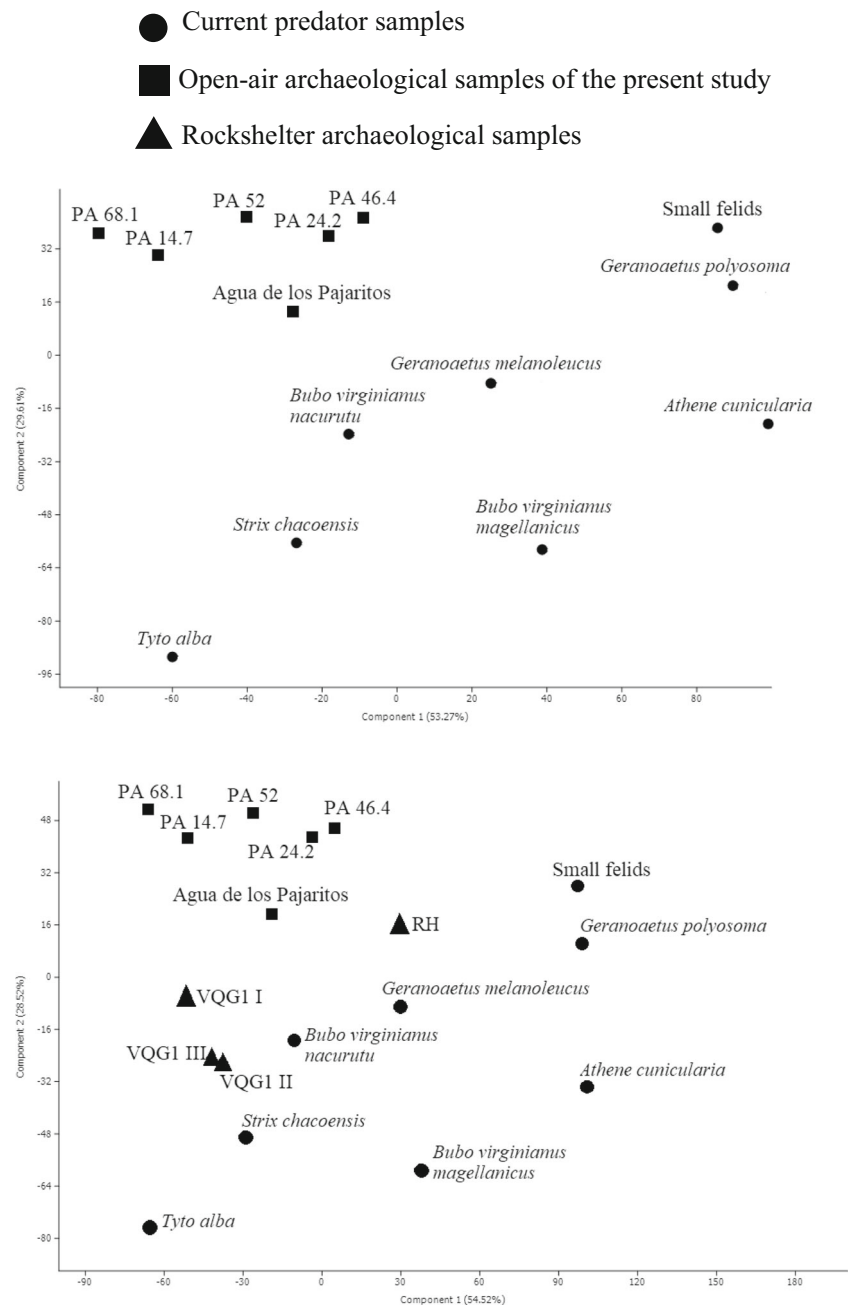
### Palaeoenvironmental considerations

Small mammal assemblages recovered in open-air archaeological sites for the present study are mainly composed by

typical species connected to xeric environments from the Monte Desert. They differ among them, however, in their habitat use patterns, ecological preferences and the sites in which each species appears (Gonnet and Ojeda 1998; Braun and Mares 2002; Tabeni and Ojeda 2003; Corbalán 2004, 2006; Corbalán and Debandi 2005; Creighton and Gardner 2007; Ojeda et al. 2007; Albanese 2010; Díaz et al. 2015; Dunnun 2015; Patton et al. 2015). The didelphid *T. pallidior* is mostly present in open, low-complexity areas, although they can also be found both in shrubby areas and in more humid sites with dense vegetation along watercourses. Gerbil mouse *Eligmodontia* sp. frequents open areas with stripped sandy soils and disperse shrubs. Gray leaf-eared mouse *G. griseoflavus* prefers closed and complex habitats with trees and high shrub cover. Marsh rat *H. lagigliai* is only known for the type locality (El Nihuil, Mendoza) from one specimen collected in the 1950s (Fernández et al. 2017b). Taking into account that the species of genus *Holochilus* is adapted to a semiaquatic life, in riparian and swampy environments of the tropical lowlands (Gonçalves et al. 2015), the presence of *H. lagigliai* in arid and semi-arid lands could correspond to apparently sub-optimal areas related with the existence of permanent watercourses. The wetland where *H. lagigliai* was found (PA14.7; Lagunas de Guanacache) could serve during the late Holocene like a refuge to relictual populations of some subtropical mammals adapted to mesic conditions within the arid context of the Monte Desert (Roig 1991). This has also been suggested for other mammalian species, such as *Chrysocyon brachyurus* (Roig 1991; Fernández et al. 2017c).

Systematic trap works and an extensive analysis of recent owl pellets, both in the present study and in other ecological works, suggest the extinction of *H. lagigliai* in recent times (Contreras and Rosi 1980; Rodríguez and Ojeda 2013; Fernández et al. 2017c; Castillo et al. 2018). Viscacha rat *T. barrerae* is an endemic octodontid rodent from Central Western Argentina, distributed in the phytogeographic provinces of Monte and Patagonia, between 300 and 1400 masl. It presents a patchy distribution associated with salty (Ojeda et al. 2007), sandy and open shrubland environments and has been described as one of the rodent species best adapted to desert environments (Verzi et al. 2002; Díaz et al. 2015). Southern mountain cavy *M. australis* prefers shrubby and forested environments from the plains and piedmont, mainly (Sassi et al. 2011; Taraborelli et al. 2011). Lowland yellow-toothed cavy *G. leucoblephara* inhabits grasslands and shrubby environments with good vegetation cover (Ojeda 2006; Dunnun 2015). The genus *Abrocoma* is endemic from South America. Species of this genus inhabit mountain slopes from the piedmont and plains connected with rocky outcrops, scattered low shrubs and hard grasses with low cover and cacti (Braun and Mares 2002; Taraborelli et al. 2011). The *Ctenomys* species presents a wide distribution

**Fig. 5** Principal component analysis based on taphonomic variables obtained from small mammal bone assemblages from de Monte Desert. Top, comparison between taphonomic values of open-air samples of the present study and taphonomic values reported for bone accumulations generated by several predators. Down, comparison between taphonomic values of open-air samples of the present study; taphonomic values reported for bone accumulations recovered in rockshelter sites from the study area (López et al. 2016; López 2018); and taphonomic values reported for bone accumulations generated by several predators: Small felids (López et al. 2017a); *Geranoaetus melanoleucus* and *Geranoaetus polyosoma* (López et al. 2017b); *Strix chacoensis* (López et al. 2018); *Tyto alba* (Andrews 1990); *Bubo virginianus nacurutu* (Gómez 2005); *Bubo virginianus magellanicus* (Montalvo et al. 2016); *Athene cunicularia* (Montalvo and Tejerina 2009)

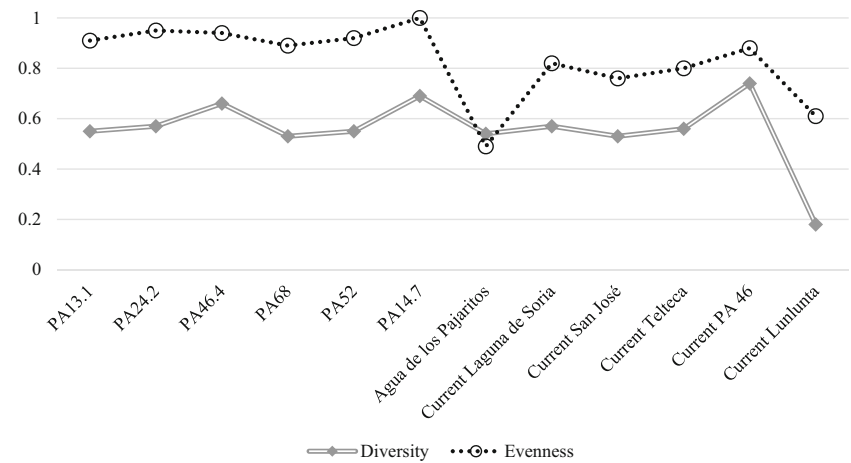


in all vegetation patches of the phytogeographic units from the study area (Rosi et al. 2002, 2005).

On the other hand, some species were not detected in the archaeological record, although they were identified in recent pellet samples. Dolorous grass mouse *A. dolores* is associated with shrubby steppes and thick grasslands (Corbalán 2004, 2006). Drylands verper mouse *C. musculus* is connected with grasslands and scrublands of high cover, both in piedmont and plains. It is a widely distributed opportunistic species also abundant in areas strongly affected by intensive agriculture (e.g. Contreras and Rosi 1980; Fernández 2012, 2014; Teta et al. 2014). House mouse *M. musculus* is an exotic

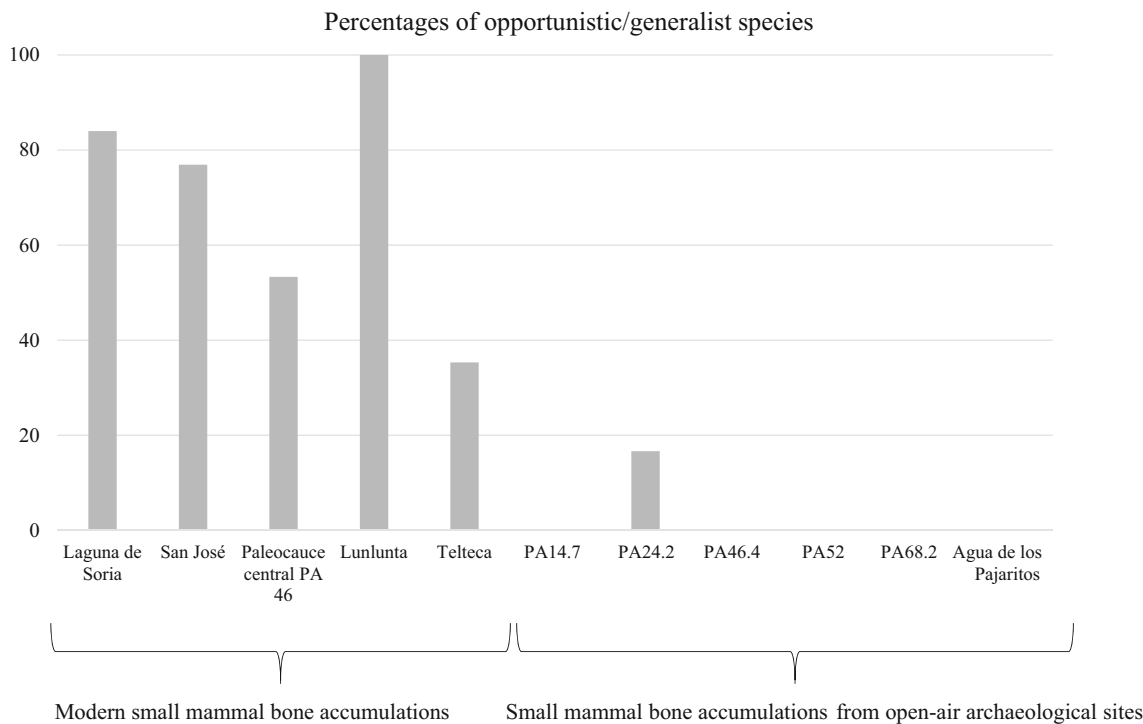
species distributed worldwide, accidentally introduced in America after the arrival of the European conquistadors. In South America, *M. musculus* has been reported since the middle of the sixteenth century (Novillo and Ojeda 2008). This species adapts quickly to new and varied environments, competing with native rodents (Novillo and Ojeda 2008; Ballari et al. 2016). It is a commensal species, which prefers habitats related with human activities mainly in urban and suburban areas, although it has also been detected in areas strongly affected by intensive agriculture from the Monte Desert of Mendoza (e.g. Contreras and Rosi 1980; Lunlunta and Paleocauce central in the present study).

**Fig. 6** Comparison of trends of diversity  $H'$  and evenness between small mammal bone accumulations from open-air archaeological sites and from current pellet samples generated by several predators. Laguna de Soria—*Athene cucularia* (Castillo et al. 2018; López 2018); San José—*Tyto alba*, Paleocauce central PA 46—*Tyto alba* and Lunlunta—*Athene cucularia* (present study); Telteca—*Strix chacoensis* (López et al. 2018)



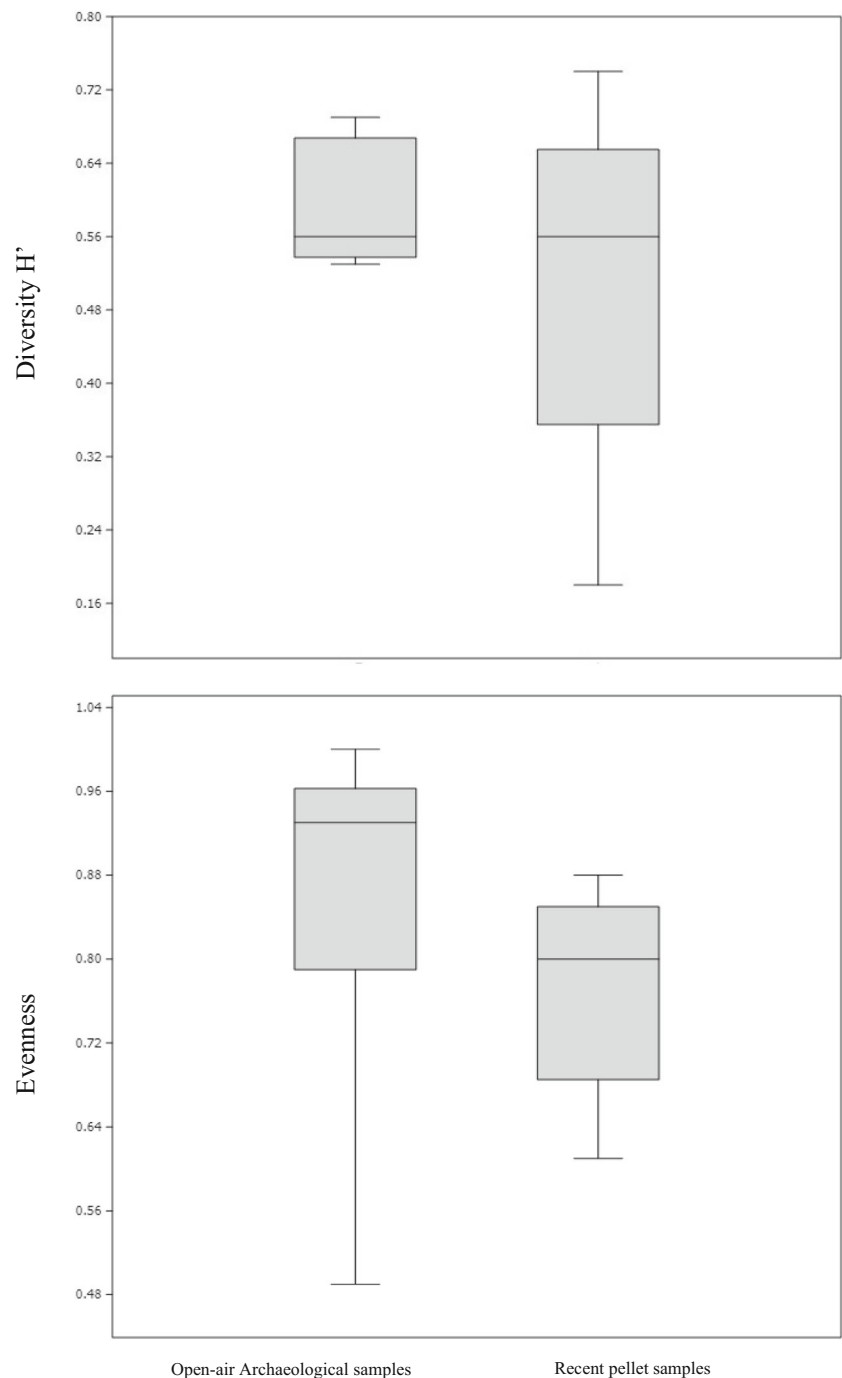
In a recent study conducted in the study area, *Oligoryzomys flavescens* (yellow pygmy rice rat) was detected from pellets generated by *Athene cucularia* in a lagoon context (Castillo et al. 2018; López 2018). That rodent species, of which neither archaeological nor current samples were detected in the present study, prefers open areas with grasslands near water bodies. It also inhabits the edges of cultivated lands (Weksler and Bonvicino 2015) being a typical component of Pampean agroecosystems (Cirignoli et al. 2006). In Mendoza, it has been detected in the central northern plains of Monte Desert, with a preference for herbaceous and shrubby vegetation associated with relatively humid sites or close to water bodies (Contreras and Rosi 1980; Fernández 2012).

The greater richness, evenness and diversity detected in small mammal archaeological assemblages compared with present-day communities reflect environmental conditions during the late Holocene different than during modern times (Figs. 6, 7 and 8). At the same time, the co-occurrence of species in the archaeological record with current allopatric distributions (non-analogue communities) also supports this idea. These changes in the taxonomic structure of archaeological small mammal assemblages might reflect minor or moderate environmental fluctuations capable of producing modifications in vegetation structure, water availability and the consequent availability of optimal habitats and microhabitats for each species.



**Fig. 7** Percentages of opportunistic/generalist species in archaeological and recent small mammal bone accumulations from the Monte Desert. Laguna de Soria—*Athene cucularia* (Castillo et al. 2018); Telteca—*Strix chacoensis* (López et al. 2018)

**Fig. 8** Boxplot of taxonomic composition of archaeological and recent small mammal bone accumulations from the Monte Desert. Top, diversity  $H'$ ; down, evenness



Some palaeoenvironmental studies have highlighted the deep impact of human activities (mainly land clearing, overgrazing, intensive agriculture, urban development and trading) on the native landscape in the last 500 years with the arrival of European conquistadors to the study region. The economic activities mentioned above, were intensified during the last 150 years, generating drastic reductions, the disappearance and/or de-structuring of the vegetation communities (e.g. Prieto and Abraham 2000; Prieto et al. 2003; Villagra et al. 2009; Mafferra 2017;

Castillo et al. 2018), strongly affecting soils and water availability. Such strong alterations in the landscape also negatively affected the existence and distribution of native mammals from the arid lands of South America and the Monte Desert in particular (Roig 1991; Tabeni and Ojeda 2003, 2005; Fernández 2014; Teta et al. 2014; López et al. 2016; Fernández et al. 2017b). In several cases, those impacts even influenced biological invasions of exotic species (Contreras and Rosi 1980; Castillo et al. 2018) such as *M. musculus*.



The effect of overgrazing and the consequent desertification in the Patagonian region, which would have strongly compacted the soils, have been identified as causes of the current extirpation or retraction of some subterranean species, like the *Tympanoctomys* genus, that would have had a wider and more continuous distribution in the past (Fernández 2014; Teta et al. 2014). The current patchy distribution of *T. barrerae*—not detected in current samples of the present study—could be generated by the impact of human activities and not by the original distribution of this species. Although *C. musculus* is a native species connected with thick scrublands and grasslands, it has also been detected in areas strongly modified by intensive agriculture (Fernández 2014; Teta et al. 2014; Castillo et al. 2018; López 2018). The absence of this rodent in the archaeological record, and its presence and abundance in the recent small mammal assemblages, could also be related to the deep impact on native landscapes generated by intensive anthropic activities (e.g. intensive agriculture), added to the presence of the exotic *M. musculus*. *Eligmodontia* sp. increased its frequencies in recent pellet samples in comparison with those frequencies detected in the archaeological record. The increase of this species in the current samples has been associated with the impact on soils and vegetation generated by overgrazing and land clearing (Fernández 2014; Teta et al. 2014). The previously mentioned extinction of *H. lagigliai* has been associated with the intentional disappearance or the deep retraction of water bodies and wetlands due to the development of cities and the implementation of an intensive agriculture economic system after the arrival of the European conquerors since the middle of the sixteenth century. The handling of watercourses for purely productive and agricultural purposes (in a semi-arid area) negatively impacted the landscape and the availability of water (Fernández et al. 2017c; López 2018) also generating a major habitat uniformity and a simplified landscape.

The differences between past and present small mammal assemblages from the Monte Desert support the idea of a scenario of greater environmental heterogeneity during the late Holocene than in the present (López et al. 2016). This scenario may imply greater vegetation density and more availability of patch resources than in the present. Habitats with greater resource availability and diversity can sustain more species and higher diversities, whereas more available microhabitats offer more refuge against predators and provide more richness and diversity of food resources. Thus, as the number of microhabitats that can be occupied by small mammal species with different environmental requirements increases, this greater habitat complexity (vertical variation of vegetation) and heterogeneity (horizontal variation of vegetation) increase the coexistence of small mammal species (Cramer and Willig 2002; Corbalán 2004; Novillo et al. 2017).

The taxonomic trends detected in small mammal bone accumulations recovered in open-air archaeological sites in the

present study are consistent with tendencies reported for small mammal bone accumulations in regional archaeological research at Central Western Argentina, for sets recovered in other types of sites, such as rockshelter sites (Fernández 2012; López et al. 2016; López 2018). Thus, the general impoverishment of current small mammal assemblages (lower richness, evenness and diversity than in the past; an increase in the representation of exotic and/or invasive species) in relation with past ones, has been detected both in open-air and rockshelter sites from Central Western Argentina. Despite the strong modifications generated by postdepositional processes and low site integrity and resolution, archaeological small mammal bone accumulation reflects original native Monte Desert environments during the late Holocene.

## Conclusions

The results of the analysis of taphonomic variables of anatomical representation, breakage and digestion on small mammal bone and teeth remains recovered in open-air archaeological sites from the central Monte Desert (northeastern Mendoza) include identification of the accumulating agents as belonging to Andrews' (1990) modification categories 1 and 2 (light and intermediate modifiers), such as owls. Despite the high abundance of medium- and large-sized small mammals, anthropic signals in such bone accumulations were not detected. The better preservation of the large-sized small mammals could be attributed to the differential preservation of bones and not to the hunting habits of predators. Small mammal bone and tooth accumulations recovered in open-air archaeological sites from the central Monte Desert showed high levels of destruction and bone loss. Thus, considerable proportions of elements affected by trampling and weathering were detected. Although these postdepositional processes modified the original features of bone assemblages, taphonomic traces (mainly digestion) were detected, providing the opportunity to infer the possible accumulating agents. Is it possible that another predator is responsible, someone we would not consider in cave contexts but which may be active in accumulating open-air assemblages? There are several predators in the study area, including strigiforms, which feed on small mammals and commonly accumulate small mammal bones in open-air contexts (e.g. López et al. 2017a, b, 2018). However, we need more actualistic taphonomic research to strengthen and systematise the knowledge on taphonomic signals generated by each predator on its prey.

The taxonomic structure of small mammal assemblages from archaeological contexts differed from the modern small mammal assemblages present in the area. Thus, richness, diversity and evenness were generally higher in the archaeological sets than in the current ones. Frequencies of the

integrating species of archaeological assemblages were also different in comparison with the modern ones.

An extinct species, *H. lagigliai*, was detected in an archaeological site in a lagoon context. A little-known species highly adapted to desert environments was also detected in several archaeological sites (*T. barrerae*). Both the reported extinct species and the taxonomic composition of archaeological assemblages in comparison with the current ones suggest a scenario of greater environmental heterogeneity during the late Holocene than in the present. This situation may have allowed the coexistence of species with current allopatric distributions and the presence of *H. lagigliai*. The general impoverishment of modern small mammal assemblages in comparison with past ones could be related to the deep impact caused by the anthropic perturbations developed by economic activities on soils, vegetation and water availability since the arrival of European conquerors ca. 500 years BP and intensified during the last 150 years. The taxonomic and palaeoenvironmental implications of these processes has also been identified and discussed by research from other regions of southern South America, like Pampa and Patagonia (e.g. Fernández 2014; Teta et al. 2014). At the same time, Pardiñas and Teta (2013) have pointed a stability (despite minor variations) in the taxonomic structure of Holocenic small mammal assemblages from Patagonia, pointing out the strong changes when modern communities (last 150 years) are compared with past ones. This could be due both to Holocenic climate fluctuations that were not strong enough to produce deep changes in the taxonomic structure of small mammal communities and to the resilience of small mammal species to minor or moderate environmental fluctuations. This fact gives an idea of the impact generated by recent urban and economic activities on native landscapes, and particularly on small mammals (e.g. Tabeni and Ojeda 2003, 2005). As evidence of the effect of these changes, this study documents the difference between past and present small mammal assemblages.

More heterogeneous environments in the past could have supported greater diversity and resource availability around the landscape than in the present. This must be a factor to consider in regional archaeological research, considering the broader diet breadth detected for human populations after ca. 2000 BP in the region. For this reason, new analytic variables are required to distinguish human and environmental factors to explain, discuss and understand the variability of the archaeological record and the cultural variability and evolution of the region. Despite differences from a taphonomic and palaeoenvironmental perspective, in general terms, small mammal bone accumulations from open-air archaeological sites have similar explanatory potentials to those reported for small mammal bone accumulations recovered in rockshelter sites. The former, however, are in worse conservation conditions and have lower integrity and resolution than the latter. Integrating small mammal bone accumulations from different

site types in Central Western Argentina will certainly contribute to fuller, more detailed interpretations of past environments and the evolution of the human systems through time. At the same time, we expect that the taphonomic trends detected in open-air archaeological sites from the Monte Desert in Central Western Argentina contribute to the discussion of the generation, accumulation, recovery, potential and importance of small mammal bone and tooth accumulations recovered in open-air archaeological sites around the world.

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## Compliance with ethical standards

**Conflict of interests** The authors declare that they have no conflict of interest.

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