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Modern and archaeological owl pellets as paleoenvironmental and taphonomic markers in human occupation contexts in the Ongamira Valley, Córdoba, Argentina

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ABSTRACT

The presence of microvertebrates in archaeological sites can be attributed to a variety of causes, including natural ones, such as the regurgitation of microvertebrates consumed by various predators. Determining the origin of these remains is therefore of great importance to our understanding of site formation processes. In addition, the detailed study of these remains can provide complementary data on such topics as the composition of biocenoses, palaeoenvironments and the seasonality of deposits. In this study, we analyzed modern sets of regurgitated pellets of the barn owl (*Tyto alba*) from the Alero Deodoro Roca site (ADR), Ongamira, Córdoba, Argentina. We compared the results with those from archaeological microvertebrates from excavations at ADR, dating to the Late Holocene (ca. 1900–3600 years BP). Most of the archaeological assemblages show the same composition as those of the modern pellets produced by Strigiformes. However, we observed variation in the representation of taxa, reflecting environmental changes over time. Using current temperature and humidity data to compare the assemblages, we observed that some results could be related to Holocenic climatic variations, already described by other studies. Furthermore, this research suggests that Strigiformes may occupy the rockshelters in Autumn-Winter, at which time the site (ADR) would not have been occupied so intensely by human populations.

1. Introduction

The study of hunter-gatherer societies that inhabited caves and rockshelters in the province of Córdoba (Argentina) allows us to analyze the relationship between humans and other inhabitants of those spaces, namely the barn owl (*Tyto alba*). Like other Strigiformes birds, the barn owl is one of the main predators of small mammals, birds and arthropods. The actualistic study of their feeding habits by examination of their regurgitated pellets can be used for multiple lines of research. Firstly, by studying these predators' preferred environments, their hunting behaviors, how they eat and digest their prey, and how they modify their diet today, we can gain a better understanding about these same processes in the past. That is, examination of the preferential environments of modern predators will help us to make more precise paleo-ecological interpretations.

Secondly, analyzing the taphonomic condition of microvertebrates recovered in archaeological contexts helps us understand the origin of their deposition (anthropic, bird regurgitation, or death in caves and/or burrows), and also contributes to an understanding of archaeological site formation processes.

Thirdly, in prehistoric assemblages, studying the taxonomic variability represented in the *Tyto alba* diet will provide us with information and new interpretations on the seasonality of human occupation. Furthermore, a better understanding of the variation of the barn owl diet complements other environmental fine grain data, facilitating development of more precise paleoenvironmental models.

In particular, *Tyto alba* trophic habits and feeding behaviors have been studied throughout the Southern Cone of South America (e.g., Bellocq, 2000; Pardiñas and Cirginoli, 2002). In Argentina, for example, research productivity in paleontology and biology is greater in the central and southern regions of the country (Pardiñas and Cirginoli, 2002 and references there mentioned), and to a lesser degree, in the northwest and northeast (Pardiñas and Cirginoli, 2002; Bó et al., 2007; Nanni et al., 2012). Although the present-day provincial territory of

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Córdoba, which is part of Argentina's central region, was an area of active research until the late 1990s, a decrease in such work over the past two decades indicates a necessity to deepen and update these studies in our region (e.g., Kravetz, 1978; Massoia et al., 1987; Nores and Gutiérrez, 1990; Diéguez and Corbella, 1997).

Moreover, there is a dearth of research on archaeological sites in Argentina in which microvertebrate skeletal remains of taphonomic origin have been identified in owl pellets (e.g., Fernández et al., 2011a, 2011b, 2012; Fernández and De Santis, 2013; Mignino, 2017).

From an archaeological and taphonomic perspective, owl pellets have been considered good estimates of the current taxonomic composition of small vertebrates and invertebrates in a region, offering the possibility of obtaining parameters for comparative actualistic frameworks and for paleoenvironmental studies (e.g., Teta et al., 2005; Ortiz and Jayat, 2007; Fernández et al., 2011a, 2011b; Santiago, 2012; López et al., 2016; Mignino, 2017). This implies that, given certain stenoic features, such as high sensitivity to environmental changes, the small vertebrates have been configured as (bio)indirect indicators of environmental contexts, allowing one to generate climate reconstruction models and articulation with other proxy data of this nature (e.g., Andrews, 1990, 1995; Betancourt et al., 1990; Crivelli-Montero et al., 1996; Fernández-Jalvo, 1996; Pardiñas, 1998; Ortiz and Jayat, 2007; Fernández et al., 2011a, 2011b, 2012; Santiago, 2012; López et al., 2016; Mignino, 2017).

Owl pellets, or regurgitation balls, are hair, bones, teeth, feathers, and insect cuticle accumulations (i.e., those parts not processed) that birds of prey expel through the mouth after digestion of softer parts. Pellets can be found in abandoned buildings, warehouses, at the foot of light poles, in creek gully caves, or in any space occupied by owls or diurnal raptors. Their study represents a minimum-intervention, non-invasive methodology, without environmental impacts (Pardiñas and Teta, 2012). The systematic collection of pellets produced by modern birds of prey provides a good understanding of the seasonal variation in the diet of these animals. At the same time, and from a taphonomic point of view, it allows us to reduce an implicit bias related to the presence of small animals in archaeological sites associated with the trophic habits of this type of bird (e.g., Andrews, 1990, Montalvo et al., 2014, Lloveras et al., 2012).

Both qualitative and quantitative variations represented by the regurgitated pellets are subject to a number of exogenous and endogenous factors. The former involves the main modeling forces of numerical variations in small vertebrate populations in different geographical contexts (e.g. Gutiérrez et al., 2010), such as climate and availability of resources.

On the other hand, some endogenous or intrinsic factors (e.g., prey plasticity, reproduction) also show not only quantitative and qualitative variation in the diet of these birds, but also changes in the frequency of regurgitations in sectors where there is continuous sampling (Nores and Gutiérrez, 1990; Bellocq, 2010).

However, when making inferences about paleoenvironmental contexts, we must be careful to consider ethological habits such as hunting behaviors or stages of reproduction linked to climatic factors, that may significantly impact the dynamics of bird population, small mammals and insects, among others (e.g., Leirs et al., 1997; Forchhammer et al., 1998; Grenfell et al., 1998; Loeville and Ghil, 2004; Bellocq, 2010).

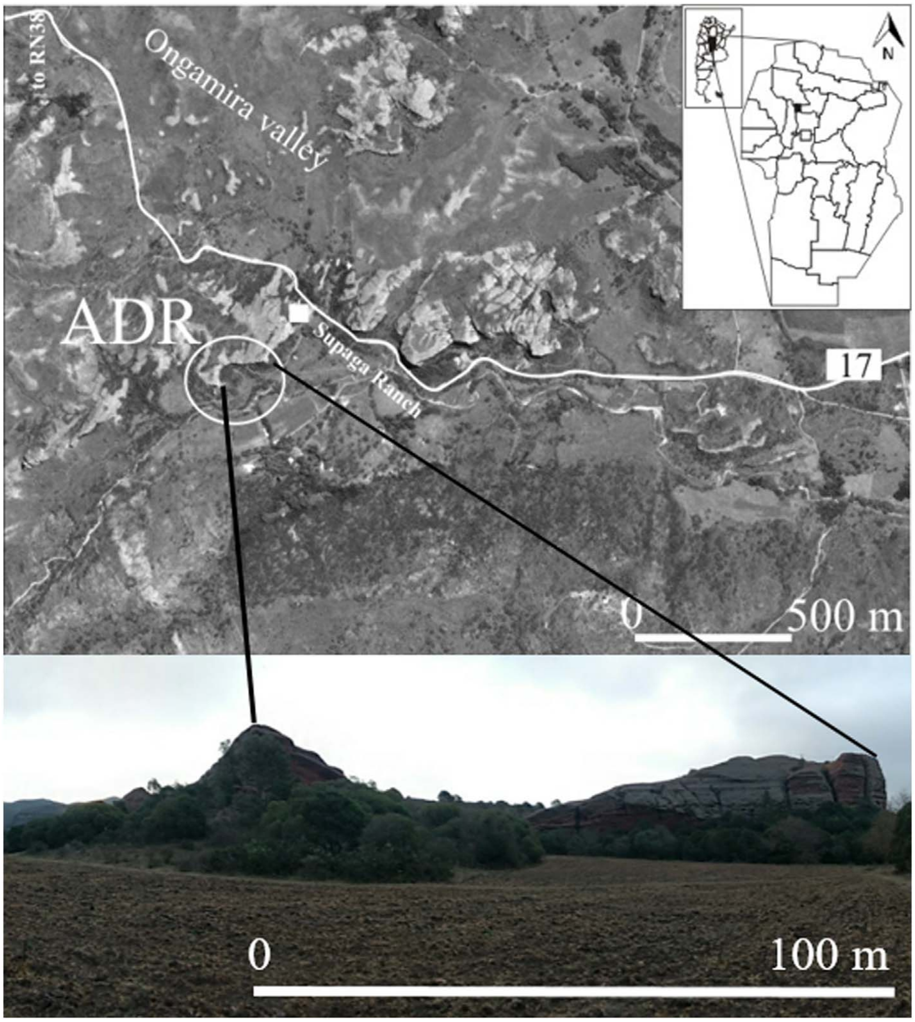


Fig. 1. Location of the archaeological and actualistic sample area and general view of the Rockshelter.

Finally, although barn owls are present in many regions of the world (Bó et al., 2007), they depend on particular features of the landscape, such as open areas (crop fields, steppes, rocky areas, etc.) or scattered woodland zones for hunting and feeding. They are also sedentary, which allows us, by observing the microvertebrate variation of their regurgitated pellets, to explore the potential and limitations on our understanding of paleoclimatic variations in the archaeological site studied. It also allows us to clarify when microvertebrate remains have been incorporated into the archaeological record as a result of death in caves in these contexts.

1.1. *Area of study*

The Ongamira Valley is located in the department of Ischilín, northwest of the province of Cordoba, in central Argentina (Fig. 1). This valley is located to the northwest of the Uritorco Hill, one of the most important peaks of the region, in the northern limits of the Sierras Chicas. The same area includes a Cretaceous formation that includes rockshelters with evidence for human occupation at various times. These rock formations are of variable sizes, forming concave spaces or enclosures with a roof, floor, and interior wall, opened to the outside and exposed to the elements, i.e.,: rocky projections that can provide shelter (Goldberg & Mandel, 2008, in Zárate, 2016) (Fig. 2A–D).

The valley is in the phytogeographic ecoregion called "Bosque Chaco Serrano" (Chaco Serrano woodland), a xeric deciduous forest domain with woody plants such as the Horco-quebracho (*Schinopsis haenkeana*), molle (*Lithraea ternifolia*), and coco (*Zanthoxylum fagara*). Lower areas include trees such as tala (*Celtis tala*), white quebracho (*Aspidosperma* quebracho-blanco), and other woody species of the genus *Prosopis* and *Acacia* (Cabrera, 1976; Cabido et al., 1991; Cagnolo et al., 2006).

According to data released by the National Institute of Agricultural Technology (http://climayagua.inta.gob.ar/), at present, the climate of the area is classified as continental temperate with hot summers and cold, dry winters. It snows over 1000 m above sea level occasionally between June and July. Temperatures range from 9 °C in June and July to 25 °C in January and February (Yanes et al., 2014) (Fig. 3a).

Precipitation registers mark a seasonal pattern, probably replicating seasonal fluctuations from the South Pacific and Atlantic anticyclones, showing an average rainfall of 10 mm in dry seasons (winter), 150 mm in warm seasons, and 850 mm during rainy seasons (summer) (Yanes et al., 2014) (Fig. 3b). The relative air humidity can be high: according to Yanes et al. (2014), the year 2011 had a monthly average ranging from 64% in September to 93% in June, generating an annual average of 85% relative humidity (Fig. 3c).

Some of these climatic observations can be associated with larger-scale phenomena. From this perspective, the so-called "Arid Diagonal" marks the physiognomy of the general climatic scenario in the central Argentina region (Bruniard, 1982; Garleff et al., 1991; Pennington et al., 2000). This sector receives Atlantic moisture with maximum rainfall during the austral summer, while in other Diagonal sectors (e.g., Patagonia) there is influence from the Pacific, characterized by maximum precipitation values during the winter (e.g. Piovano et al., 2009). An understanding the paleoclimate and dynamics produced by the Arid Diagonal movement over time - and its ties to variation in faunal compositions - is essential to informing our interpretation of the adaptations of past populations, including microvertebrates, owls, and humans, throughout the different chronological contexts addressed here.

2. Materials and methods

In this study, we analyzed a set of cranial and post-cranial microvertebrate skeletal remains from archaeological contexts at the site of Alero Deodoro Roca (herein referred to as ADR). We then compared our results to a modern collection of barn owl pellets and their microvertebrate contents. The latter are present in modern systematic and seasonal collections at ADR, where barn owls roost.

The archaeological material (NISP = 472) comes from 25 stratigraphic units (Harris, 1991) identified through systematic excavation at ADR. They were recovered during fieldwork using fine sieves with a mesh s of ~2 mm (Cattáneo et al., 2013; Cattáneo and Izeta, 2016a,

Fig. 2. A. Alero Deodoro Roca rockshelter north wall. B. View of cavities in the wall where the barn owl nests. C. Barn owl pellets in situ D. Owl pellet close up.

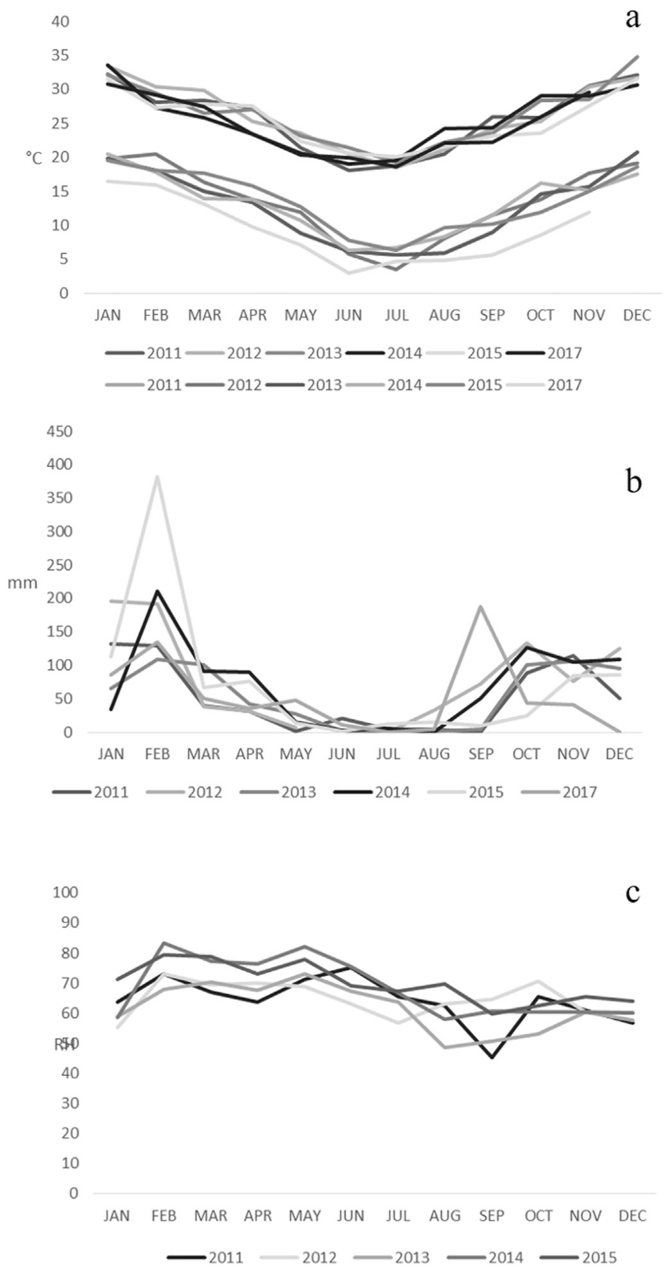


Fig. 3. a. Maximum and minimum mean temperatures. Series 2011–2015 and 2017. b. Rain measurement. Series 2011–2015 and 2017. c. Relative humidity. Series 2011–2015.

2016b). Sediment was sampled and sieved with finer meshes (< 1 mm) from the stratigraphic units allowing recovering isolated teeth in some cases. Those remains comes either from the units described and the units associated with temporary occupations of mobile hunter-gatherer societies, which left archaeological traces of structured fire pits, as well as lithic and bone remains. These occupations were dated between ca. 3600 and 1900 BP (Table 1; Izeta et al., 2016). In three cases, stratigraphic units were interpreted as old rodent cave systems and nests filled with sediment (Cattáneo and Izeta, 2016b). The 25 stratigraphic units were grouped for study according to associated radiocarbon dates, resulting into six chronological blocks (Table 1).

Modern barn owl diet was studied from 206 pellets. The sampling corresponds to systematic and seasonal collections over the years 2013, 2014, 2015 and 2017 in ADR Sector B (Cattáneo et al., 2017). The samples were weighed, measured and cleaned at the Instituto de Antropología de Córdoba (IDACOR-CONICET) facilities.

Table 1
Small vertebrate zooarchaeological samples from Alero Deodoro Roca Sector B. Radiocarbon dates from Izeta et al., 2016; Cattáneo et al., 2017.

Chronological groups	Chronology	Stratigraphic unit	NSP	Total
1		1	1	8
		2	2	
		9	4	
		13	1	
2	1915 ± 45[a]	32-36-37-38-39	45	45
	~1900 (cave)	58	1	1
3	~1915–2900 (cave)	64	2	4
	~1915–2900 (cave)	69	2	
4	~2900–3600	59	11	64
		60	27	
		61	26	
5	2942 ± 25[b]	50	2	92
	2944 ± 44[c]	7	85	
	2952 ± 21[d]	34	5	
	~3000	6	27	80
		11	13	
		14	7	
		22	2	
		35	31	
6	~3600	43	174	178
		45	4	
		Total	472	

[a] MTC15148; calibrated age (calBP) 1 sigma: 1872-1850; 1841-1745; calibrated age (calBP) 2 sigma: 1915-1710; $\delta^{13}C_{PDB}$ (‰): − 17.02 ± 0.03; $\delta^{15}N_{air}$ (‰): 4.32 ± 0.69; C/N: 3.4; Purification method: bone ultrafiltered gelatin. Camelid bone.

[b] YU-2293; calibrated age (calBP) 1 sigma: 3201-3191; 3162-3068; calibrated age (calBP) 2 sigma: 3210-3002; $\delta^{13}C_{PDB}$ (‰): − 26.77 ± 0.5; charcoal.

[c] YU-2291; calibrated age (calBP) 1 sigma: 3075-2967; calibrated age (calBP) 2 sigma: 3159-2950; $\delta^{13}C_{PDB}$ (‰): − 26.09 ± 0.43; charcoal.

[d] YU-2290; calibrated age (calBP) 1 sigma: 3138-3130; 3107-3095; 3078-2991; calibrated age (calBP) 2 sigma: 3158-2959; $\delta^{13}C_{PDB}$ (‰):25.72 ± 0.3; charcoal.

The owl pellets were unbundled manually, using surgical instruments, recovering bone and tooth material as well as insect cuticles. The prey were identified at the highest level of taxonomic identification possible, using dental and skull reference collections, as well as identification guides of small vertebrates (e.g., Quintana, 1996; Fernández et al., 2011a, 2011b; Patton et al., 2015). The evaluations were made on the basis of identification from cranio-mandibular remains using occlusal morphology as a specific indicator.

Our taphonomic studies were based on the systematic-descriptive method defined by Andrews (1990), applied to various fossil associations, and to the identification of alterations produced on the cortical bone surface subsequent to its accumulation. Following this approach, we evaluated possible marks caused by digestive acids, weathering trace levels, root action, and alterations by manganese oxide and calcium carbonate. In addition, we used analogies between the degrees of alteration produced by known predators and the archaeological sites analyzed (e.g. Andrews, 1990, Ballejo et al., 2012, Fernández et al., 2017, Fernández-Jalvo and Andrews, 2016, Montalvo et al., 2014).

This approach is based on two general premises. The first centers on the idea that accumulation of small mammals is attributed to the action of predators and that through research and taxonomic and taphonomic identification of ingested prey, it is possible to identify the predator that caused the accumulation. The second premise is that through the observation of current behavior of small vertebrate and invertebrate predators (ethology), we can draw analogies between the changes we observe in fossil assemblages and the identified predator pellets. In addition, the physical-chemical alterations involved not only inform us about the condition of the specimen sets but also help in our reconstruction of microenvironmental sequences.

Having established the characteristics of actualistic assemblages, we proceeded to evaluate the barn owl dietary variation by comparing these data with those related to environmental temperature, relative humidity, and precipitation as provided by the National Meteorological

Table 2
Types and states of fractures identified in the archaeological samples (NISP).

Chronological group	Fracture/state	Complete	Fresh (green)	Intermediate	Dry	Indeterminate	Total
1	Complete	3	–	–	–	–	3
	Transverse	–	–	–	3	1	4
	Longitudinal	–	–	–	–	–	–
	Indeterminate	–	–	–	–	1	1
	Staggered	–	–	–	–	–	–
	Oblique	–	–	–	–	–	–
2	Complete	–	–	–	–	–	–
	Transverse	–	–	–	6	–	6
	Longitudinal	–	–	–	–	–	–
	Indeterminate	–	–	–	1	4	5
	Staggered	–	–	–	1	–	1
	Oblique	–	–	–	1	33	34
3	Complete	–	–	–	–	–	–
	Transverse	–	–	–	–	–	–
	Longitudinal	–	–	–	–	–	–
	Indeterminate	–	–	–	–	2	2
	Staggered	–	–	–	–	–	–
	Oblique	–	–	–	–	–	–
4	Complete	23	–	–	–	–	23
	Transverse	–	2	–	2	6	10
	Longitudinal	–	–	–	–	–	–
	Indeterminate	–	6	–	–	25	31
	Staggered	–	–	–	–	–	–
	Oblique	–	–	–	–	–	–
5	Complete	59	–	–	–	–	59
	Transverse	–	4	–	4	21	29
	Longitudinal	–	–	–	–	–	–
	Indeterminate	–	–	–	–	84	84
	Staggered	–	–	–	–	–	–
	Oblique	–	–	–	–	–	–
6	Complete	73	–	–	–	–	73
	Transverse	–	2	1	11	11	25
	Longitudinal	–	1	–	2	–	3
	Indeterminate	–	2	–	–	73	75
	Staggered	–	1	–	–	–	1
	Oblique	–	1	–	–	2	3

Service of the Argentine Republic for the years 2011, 2012, 2013, 2014, 2015 and 2017 in their Weather Centers from the cities of Córdoba and Villa Maria del Río Seco in the province of Córdoba. The first is located about 100 km southeast of Ongamira Valley, and the second about 100 km northeast. These two stations are the nearest to each other in the area under study, and present very similar data. Thus, we can observe climate trends from time-series of weather records during those periods. For both stations, the climatic series include data on daily temperature, relative humidity and precipitation. To find trends, daily data were grouped according to month (Fig. 3a, b, and c).

2.1. *The archaeological sample*

The observations made in the archaeological sample indicate that, in general, the assemblage exhibits good preservation conditions for its study. A quantitative approach informs us that 40% of the sample exhibits no modification or degree of alteration at all.

Fractures types were analyzed following Villa and Mahieu's (1991) morphology of breakage patterns. This kind of bone modification it is highly present in the collection (> 66% of the bones shows breakage patterns). The most frequent fracture is the transverse type (NISP = 74), while less represented is the oblique type (NISP = 37), followed by the longitudinal (3) and the staggered (NISP = 2) types. In addition, 198 specimens were assigned to the undetermined category, while the rest (158 specimens) show no fractures (Table 2).

If we consider the conditions in which fracturing occurred, dry fractures are more common than fresh. In the latter type, fractures usually have a helical shape, producing acute and obtuse angles in the fractured surface, and exhibiting softness to the touch (Fernández-Jalvo and Andrews, 2016). Breakage in the dry state was distinguished by the extent to which the item had lost collagen and developed division lines on the surface, while at the same time losing organic matter (Fig. 4; Table 2).

Chronological grouping allows us to determine that groups 1, 4, 5 and 6 all show a fragmentation rate of about 60%. In contrast, groups 2 and 3 show 100% fragmentation, where all of the elements are damaged. Group 3, a small sample with only two fractured specimens, must be interpreted with caution.

Evidence for weathering, when present, is relatively moderate, following Andrews' (1990) model. Small cracks parallel to the fibrous structure of the bone, along with some chipped teeth, are interpreted as Andrews' (1990) Stage 1. The best preservation conditions are observed in the most recent chronological groups (1, 2, and 3) where little to no weathering is observed. Groups 4, 5, and 6 present a higher frequency of weathering Stage 1. Group 5 shows approximately 50% of the sample with some alteration and groups 4 and 6 around 70% (Table 3).

The marks left by digestive acids were observed on many specimens (Fig. 4A–D). It is important to note that several factors are involved in predator digestion, and each is associated with a type of predator. Their biological and ethological characteristics lead us to interpret digestion as a diagnostic element of the agent causing the accumulation (Andrews, 1990). In the entire assemblage analyzed we observed that 49.5% of the sample exhibits damage caused by predator gastric juices. The degrees of digestion observed are dominated by the "light" category for chronological groups 1, 2, 4, 5, and 6, with more or less homogeneous loss of tooth enamel and mild truncations in enamel and occlusal cusp surfaces, in addition to a slight corrosion of postcranial skeleton elements (Table 3).

Along with light gastric corrosion, we observed on some molars a relatively more pronounced alteration, which wore down the occlusal surface. This kind of modification can be described as a "moderate"

Fig. 4. A. Sigmodontine rodent Tibia with oblique fracture in fresh condition (136-ADR). B. Caviomorph rodent Tibia with transverse fracture in intermediate condition (295-ADR). C. Bird long bone with oblique fracture in intermediate condition (921-ADR). D. *Ctenomys* sp. Metapodia with longitudinal fracture in fresh condition (2867-ADR). E. Caviomorph rodent Femur of with oblique fracture in fresh condition (1430-ADR). F. microvertebrate Rib combining fractures (oblique of longitudinal type) in dry condition (1433-ADR).

Table 3
Taphonomic agents and processes identified in ADR Sector B small vertebrate archaeological samples. Frequencies expressed as NISP.

Taphonomic attributes	Chronological groups					
	1	2	3	4	5	6
Weathering						
Stage 0	8	31	2	20	79	48
Stage 1		15	–	44	93	132
Stage 2	–	–	–	–	–	–
Stage 3–4	–	–	–	–	–	–
Gastric corrosion						
Unmodified	7	26	2	28	65	37
Light	1	9	–	19	60	73
Moderate	–	–	–	–	–	–
Strong	–	–	–	–	–	–
Extreme	–	–	–	–	–	–
Root etching	–	–	–	–	–	2
Thermo-alteration						
Unmodified	7	45	2	58	149	148
Charred	2	1	–	6	21	30
Calcined	–	–	–	–	–	1
Charred-calcined	–	–	–	–	2	1
Corrosion[a]	–	11	–	18	46	70

[a] Specimens showing alterations due to sedimentary corrosion, which can hide the gastric corrosion of raptors, are included under this category.

stage in terms of Andrews' (1990) scale. Generally, we do not expect barn owl alterations on bone and teeth to show such kind of damage. Therefore, several alternatives can be considered as the agents or processes responsible for this modification. On the one hand, raptors other than the barn owl are present in the region (Fernández et al., 2017; Giraudo et al., 2006) and may be the origin of this kind of modification. However, because of their ethology several predators can be dismissed as the causes of bone accumulations. Here we can name FALCONIFORMES (falcons, "*chimangos*" and "*caranchos*"), CATHARTIFORMES (American or new world vultures), ACCIPITRIFORMES (hawks and "*caracoleros*"), didelphids (weasels and "*marmosas*"), and some medium size and large carnivores, among others. All these taxa have distinctive digestive processes that produce bone accumulations different than those of the barn owl and other Strigiformes (e.g. Gutiérrez & Gómez, 2007; Montalvo et al., 2016; Rafuse et al., 2014). On the other hand, this kind of corrosion can also be related to soil acidity rather than the effects of strigiform bird deposition. Soil composition in the rockshelter tends to be slightly acidic because of the high component of silica in the soil. This has been confirmed by PH tests in the stratigraphic units, and over time this acidity can affect the surfaces of bones and teeth (see Table 4). In addition, some specimens show traces of root action, and the presence of roots can make the surrounding environment even more acid (Fig. 5f). Thus, both soil corrosion and root activity can veil the action of gastric acids in some samples. A NISP of 145 (30% of the archaeological sample) presents some kind of surface modification that cannot be certainly assigned to any single type of corrosion (gastric acids, root etches or soil corrosion).

Thermal alteration on the sample is low, with only four elements showing color changes (Nicholson, 1993) that indicate carbonization and calcination. These four occur in groups 5 and 6. A total of 60 elements show charcoal traces and part of the cortical surface partially affected by carbonization, and these are primarily from groups 5 and 6. The vast majority of the sample (over 80%) shows no alterations that could be attributed to hearths or exposure to temperatures that would damage their structural conditions.

In contrast to the high level of taxonomic identification of the archaeological sample (Table 5), the more modern chronological groups (1 to 3) did not allow specific taxonomic assignment because they included only elements of the post-cranial skeleton. The stratigraphic units of group 4 contained only two rodent species: *Ctenomys aff. C. osvaldoreigi* and *Microcavia australis*. In groups 5 and 6, there are three species of sigmodontine rodents (*Akodon* sp., *Reithrodon auritus* and *Phyllotis xanthopygus*), a Ctenomyidae (*Ctenomys aff. C. osvaldoreigi*), and a Caviidae (*Microcavia australis*). A Passeriformes was also found in chronological group 6.

2.2. The actualistic sample

In terms of taphonomic attributes, and in accordance with the

Table 4
Stratigraphic units soil pH values.

Chronological group	Sample	pH	Square	Stratigraphic unit	Interpretation	Description*
1	1	6	XIX-B	UE2	Sediment layer	Compact surface, color 5 YR 6/4. Predominates gravel, grit, silt, clay. Presence of compacted guano.
1	2	6	XVII-B	UE9	Combustion area	The unit is compact. 5 YR 4/3. Predominant gravel, grit, silt, clay. Snails abound and there are traces of charcoal, also bone material.
2	15	6	XVIII-B	UE38	Sediment layer	A matrix of fine loose sand of 5 YR 4/4 color along with gravel, clay and reddish silt.
2	13	7	XVIII-B	UE58	Crotovina	Cave filling.
3	8	7	XVIII-B	UE64	Crotovina	Cave filling.
3	9	7	XVIII-B	UE69	Crotovina	Cave filling with the presence of rodent bone remains.
4	4	7	XIV-C	UE60	Combustion area	Combustion area with a sub-circular rock enclosure.
5	10	6	XV-C	UE22	Combustion area	Carbonaceous stain associated with remains of snails Its color was defined as 5 YR 3/2.
5	14	6	XIV-C	UE34	Hearth	Set of small combustion areas joined together by material composed of ash and snails. Color 2.5/5 YR/1.
5	6	6	XV-C	UE59	Hearth	Lime-sandy sediment with ashes, shell fragments and whole shells. Bone material in poor condition was found.
5	5	6	XIV-C	UE7	Sediment layer	Sediment of black coloration, and composed mainly of silts and clays together with gravel-like material from the eaves. Color 3/10 YR/2.
5	3	7	XV-C	UE35	Hearth	Color 5 YR 4/5K, composed of sandy silt, ash, fragmented snails, bone remains and carbon fragments.
5	11	7	XIV-C	UE50	Hearth	Hearth with remains of ash and shells. Enclosed by a set of rocks and some thermo-altered bone remains.
6	7	6	XVI-C	UE43	Sediment layer	It is composed of gravel and silt and presents base rock. A large quantity of bones and lithic remains are found along with ash patches. The general tonality is 5 YR/2.5/2.
6	12	6	XV-C	UE45	Hearth	Reused hearth. Sediment is found between the ash and coal layers.

*Based on Cattáneo and Izeta, 2016a, b. All colors based on the Munsell Soil Color Chart.

methodology proposed by Andrews (1990), the modern assemblages analyzed show tooth enamel loss caused by the corrosive effects of digestive acids assigned to the “light” category on a seasonal basis.

Among the actualistic group of 206 owl pellets, we identified eight different prey taxa, which comprised at least 632 individuals. The taxa correspond to two groups of vertebrates (mammals and birds) and a group of arthropods (carabid insects) (Table 7).

Seasonal distribution of the 206 modern owl pellets indicates a greater number of samples produced in warm seasons. In contrast, we observed an abrupt drop in the accumulation of pellets in the colder seasons (autumn/winter) of the years 2013 to 2015. Indeed, during that span, just four pellets were recovered (Table 7). However, during the cold season of 2017, 33 new pellets were recovered. It seems the lack of samples between 2016 and 2017 is related to the abandonment of the rockshelter by the barn owl as a result of hunting pressure by local peoples.

The taxonomic identifications indicate a predominance of mammals at 96%, while the contribution of birds (Emberizidae) and insects it is low (1% and 3%, respectively). Among the mammals, the majority identified are sigmodontine rodents (89%), while hystricognath rodents (4%) and Didelphimorphia (7%) occur less frequently.

Within the group associated with sigmodontine rodents, the majority represent *Phyllotis xanthopygus* (61%), followed by *Calomys musculinus* (30%) and *Akodon polopi* (9%). The presence of caviomorph rodents is attested by *Microcavia australis* (60%) and *Ctenomys aff. C. osvaldoreigi* (40%). The individuals assigned to marsupials correspond to a single South American species, *Thylamys pallidior* (Table 7).

3. Discussion

3.1. Actualistic assemblages and climate data

Diet studies of current *Tyto alba* regurgitation pellets indicate that it is possible to identify certain patterns and correlations that are repeated throughout the periods analyzed. In general, there is a widespread consumption of prey items during warm seasons, with the presence of small mammals, birds and arthropods, indicating a broad spectrum diet (Table 7).

In contrast, we see a decline in the breadth and diversity of the trophic niche in cold seasons (showing only the consumption of sigmodontine rodents and marsupials in very low numbers), as well as a sharp decrease in the frequency of owl pellets in the areas sampled (Table 7).

The comparison of these observations with climate data for these periods (Fig. 3) indicates that, while temperature and relative humidity values have remained constant over the years, there is a positive correlation between the amount of rainfall and an increase in regurgitation pellets (i.e.,: in 2013, with 625 mm average rainfall, we recovered 56 pellets in spring/summer; in 2015, with 885 mm average rainfall, we recovered 78 pellets during the spring alone). Beyond the fact that in 2015 we only recovered pellets during one season, variability in prey items increased. In 2017, the dry and cold season have exceptional rainfall and high temperatures. During this period, we collected a greater number of pellets and observed an increase in the variability of prey present in the pellets.

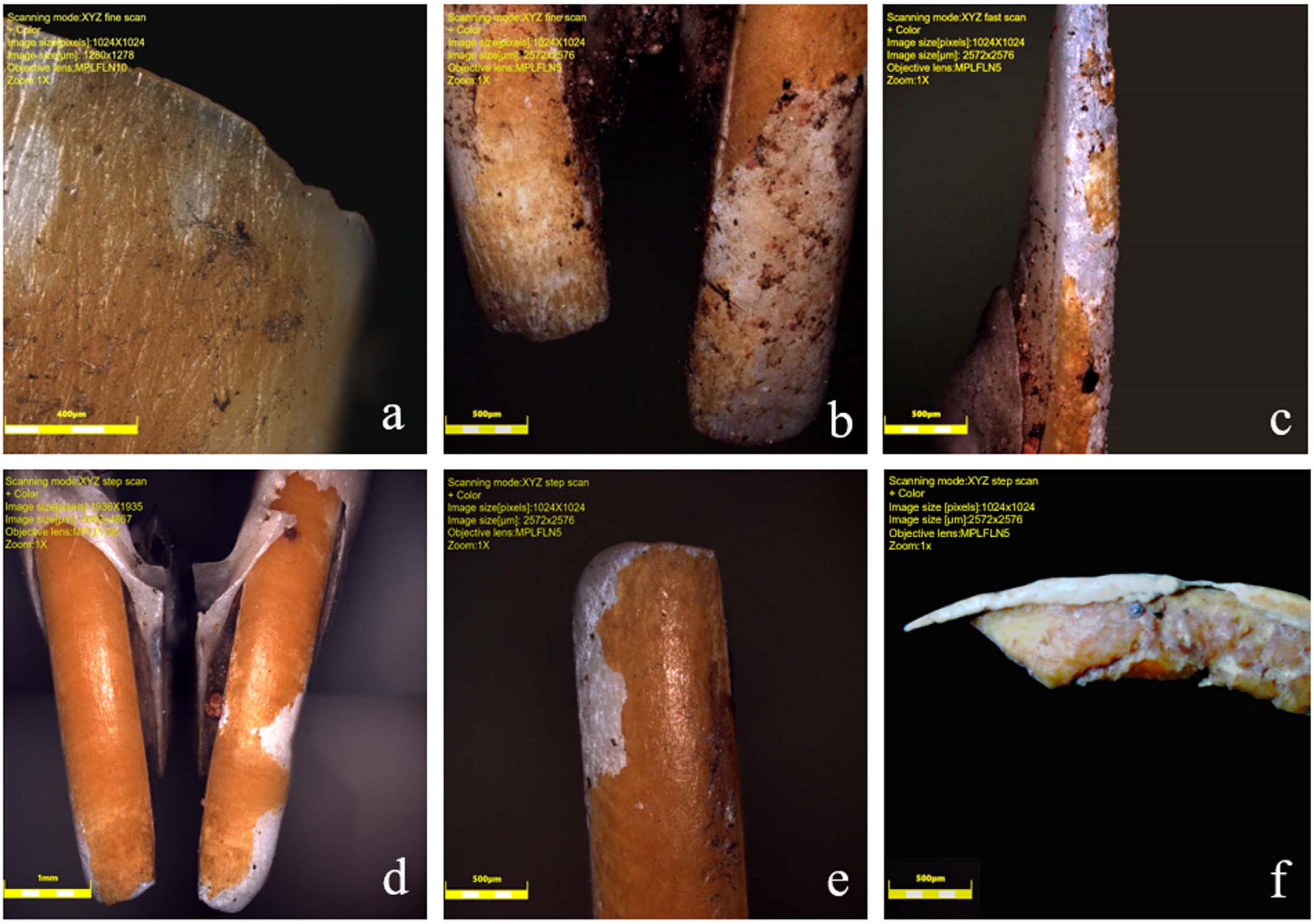


Fig. 5. Archaeological and actualistic samples showing the effects of gastric and root/soil acids on small vertebrate incisors. a. ADR A2 2, (108x,) archaeological (gastric). b. ADR A 2 4, (108x), archaeological (gastric). c. ADR A 2 4, (216x,) archaeological (gastric). d. ADR Corral 5, actualistic (gastric). e. ADR Corral 6, actualistic (gastric). f. ADR 529 (108x) archaeological (soil/root).

An increase in rainfall during any season allows higher food availability (e.g., arthropods and plant cover for *Thylamys pallidior*), resulting in an exponential broadening of the dietary breadth of *Tyto alba*. In turn, it is possible to observe in 2015 the warm season effects caused by ENSO (El Niño Southern oscillation) as one of the factors in the increase of mammals in different areas of South America's Southern Cone, and as one of the key climatic forces that help us to understand the population dynamics of these animals and diet variations (e.g., Meserve et al., 1995, 2003; Barryman, 1999). Indeed, the abundance of sigmodontine rodents suggests that ENSO climatic events may have an effect on population patterns.

Faced with this, during rainy periods (mostly the warm and rainy season and especially when heavy rains occur), *Tyto alba* chooses a more general consumption of prey, expanding its trophic activity. In dry seasons, with an abrupt decrease in precipitation levels, it behaves as a

Table 5
Small vertebrate taxa identified in the chronological groups 4 to 6 (~2900 to 3600 BP). ADR Sector B. Expressed as MNI (Minimal Number of Individuals).

	Chronological group		
	4	5	6
RODENTIA	1	1	2
SIGMODONTINAE	–	–	–
Akodon sp.	–	3	–
Reithrodon auritus	–	2	4
Phyllotis xanthopygus	–	3	–
CTENOMYIDAE	–	–	–
Ctenomys aff. C. osvaldoreigi	1	5	6
CAVIIDAE	–	–	
Microcavia australis	3	2	4
Passeriforme	–	–	1
Total	5	16	17
Ntaxa	2	5	4

Table 6
Alero Deodoro Roca site modern Owl pellets sample grouped by season. Two categories are shown; one hand the complete pellets collected either fresh or dry; on the other hand modern sets of micro vertebrates and microfauna resulting from pellets disaggregation in situ. (X): Presence; (–): absence.

		Complete pellets	Naturally disaggregated pellets
2013	Winter	0	X
	Spring	53	X
2014	Summer	3	X
	Autumn	4	X
	Winter	0	X
	Spring	35	–
2015	Summer	0	X
	Autumn	0	–
	Winter	0	–
	Spring	78	X
2017	Autumn	7	–
	Winter	26	–
	Total	206	

Table 7
Taxa identified in actualistic Barn Owl pellets. Expressed as MNI.

	2013		2014				2015				2017			Total
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	
RODENTIA	–	4	4	–	–	–	1	–	–	1	–	–	–	**10**
SIGMODONTINAE	3	–	2	2	7	5	8	–	–	10	–	4	**5**	**46**
Akodon polopi	5	15	1	–	–	–	5	–	–	13	–	9	8	**56**
Calomys musculinus	11	47	23	13	1	11	12	–	–	11	–	11	8	**148**
Phyllotis xanthopygus	13	91	44	2	20	29	20	–	–	42	–	5	16	**282**
CTENOMYIDAE	–	–	–	–	–	–	2	–	–	–	–	–	–	**2**
Ctenomys aff. C. osvaldoreigi	–	1	–	–	–	–	4	–	–	3	–	–	–	**8**
CAVIIDAE	–	–	–	–	–	–	2	–	–	–	–	–	–	**2**
Microcavia australis	–	5	–	–	2	1	4	–	–	–	–	–	–	**12**
Thylamys pallidior	–	25	–	2	1	7	3	–	–	–	–	2	1	**41**
PASSERIFORMES	–	4	–	–	1	2	1	–	–	–	–	–	–	**8**
INSECTA	–	6	–	–	–	11	–	–	–	–	–	–	–	**17**
Total	**32**	**198**	**74**	**19**	**32**	**66**	**62**	**–**	**–**	**80**	**–**	**31**	**38**	**632**
Ntaxa	3	6	3	3	4	4	6	–	–	4	–	4	4	

specialist predator, incorporating only its preferred prey (sigmodontine rodents). In fact, according to Gómez et al. (2012), during their work gathering seasonal regurgitation pellets in other areas of the western sector of this ecoregion (with altitudes under 800 m.a.s.l., continental warm climate in the summer, and warm to cold in winter, average annual temperature of 21.5 °C, and average annual rainfall between 500 and 950 mm), they identified a total of 16 mammals species, mainly those belonging to the Cricetidae family (*Calomys* sp., *Akodon dolores*, *Oligoryzomys* cf. *O. flavescens*, *Akodon caenosus*, *Akodon simulator*, *Graomys centralis*, *Holochilus chacarius*, *and Necromys lasiurus*). They also identified murid rodents (*Rattus* sp.), Ctenomyidae (*Ctenomys* sp.), Caviidae (*Galea leucoblephara*, *Microcavia australis*), and Didelphimorphia (*Thylamys* sp.). Similar trends were observed (Nanni et al., 2012) in other areas, where temperatures drop to an annual average of 20 °C and an average rainfall of 617 mm is recorded. The pellets of these assemblages are dominated by mammals (86%), followed by birds (7%) and insects (7%). Cricetidae rodents dominate the mammal portion of the assemblages (*Calomys musculinus*, *Necromys lasiurus*, *Akodon dolores*), and caviomorph rodents (*Galea leucoblephara*, *Ctenomys* sp.) are also present (Nanni et al., 2012).

However, beyond these exogenous factors we understand that there are certain factors (especially ethological) that affect the frequency of regurgitation pellets. As shown in Tables 6 and 7, dry seasons generally have low abundance and taxonomic richness in comparison to the warm-wet season. There is also a sharp drop in the number of collected regurgitation pellets in this sector. Namely, a decline in diet and trophic niche amplitude values (as a result of falling precipitation values), in addition to a marked decrease in the accumulation of regurgitation pellets as a product of *Tyto alba* nesting habits, impacts the qualitative and quantitative composition of the sets.

Fraga (1984) and Nores and Gutiérrez (1986) have demonstrated that in the province of Córdoba during owl reproductive stages (dry season) and brood care (≤ 30 days), the nestlings incorporate regurgitation pellets into their nests. This is likely one of the causes of low frequency of regurgitation pellets in ADR during the dry seasons.

In light of actualistic data in Ongamira and in nearby regions, we must compare the behavior of archaeological findings from micromammals at ADR, which are dominated by two groups of vertebrates (rodents and birds). As seen from the results of taphonomic studies, assemblage analysis, size of the species recorded, frequency of skeletal elements, their preservation conditions, and marks resulting from digestion, the data clearly indicate that the remains from chronological groups 1, 4, 5 and 6 may have accumulated as a result of the predatory activity of strigiform birds, rather than carnivorous, falconiforms and accipitriforms (Bochenski et al., 1998; Montalvo et al., 2012, 2014, 2016). In Table 8 and Fig. 6 we can see how the local *Tyto alba* and *Bubo virginianus magellanicus* share some similarities on different indexes (abundance and elements representation). In contrast, other predators produce pellets with very different attributes, allowing us to segregate them confidently. According to Fernández et al. (2017) local Southern Cone predators share characteristics different from those known for other continents such as Europe, Africa or even North America. Moreover, prey such as small vertebrates also show differences in skeletal composition, tissues and tooth hardness, which in some cases contrast with the international bibliography.

Instead, *Bubo virginianus magellanicus* shows similar patterns, which

Table 8
Different indexes from South American predators. *Tyto alba* from Andrews (1990) it is used to show the differences in feeding habits related with specific small vertebrates preys available in European and south American ecosystems.

Taxa	Average relative abundance	pc/c	(f + h)/(md + mx)	(t + r)/(f + h)	References
Bubo virginianus magellanicus	47,8	310,60	95,00	94,74	Montalvo et al. (2016)
Tyto alba (Ongamira)	61,13	294,51	111,92	98,22	This paper
Bubo virginianus nacurutu	58,3	214,3	103,4	109,8	Montalvo et al. (2016)
Tyto alba	43,8	251	93	105	Andrews (1990)
Caracara plancus	9,59	124,71	164,61	53,57	Montalvo and Tallade (2009)
Leopardus geoffroyi	40,2	93,5	82,6	100	Rafuse et al. (2014)
Lycalopex gymnocercus	50,2	192	70	128,6	Rafuse et al. (2014)
Tyto alba	59,99	195	100	93	Gutiérrez & Gómez (2007)
Asio flammeus	22,6	328	90	333	Gutiérrez & Gómez (2007)
Bubo virginianus	40,9	193	124	106	Gutiérrez & Gómez (2007)
Athene cunicularia	35,45	188	115	102	Gutiérrez & Gómez (2007)
Circus buffoni	18,8	21	17	57	Gutiérrez & Gómez (2007)
Didelphis albiventris	40,1	146	158	79	Gutiérrez & Gómez (2007)
Conepatus chinga	38,3	302	288	157	Gutiérrez & Gómez (2007)

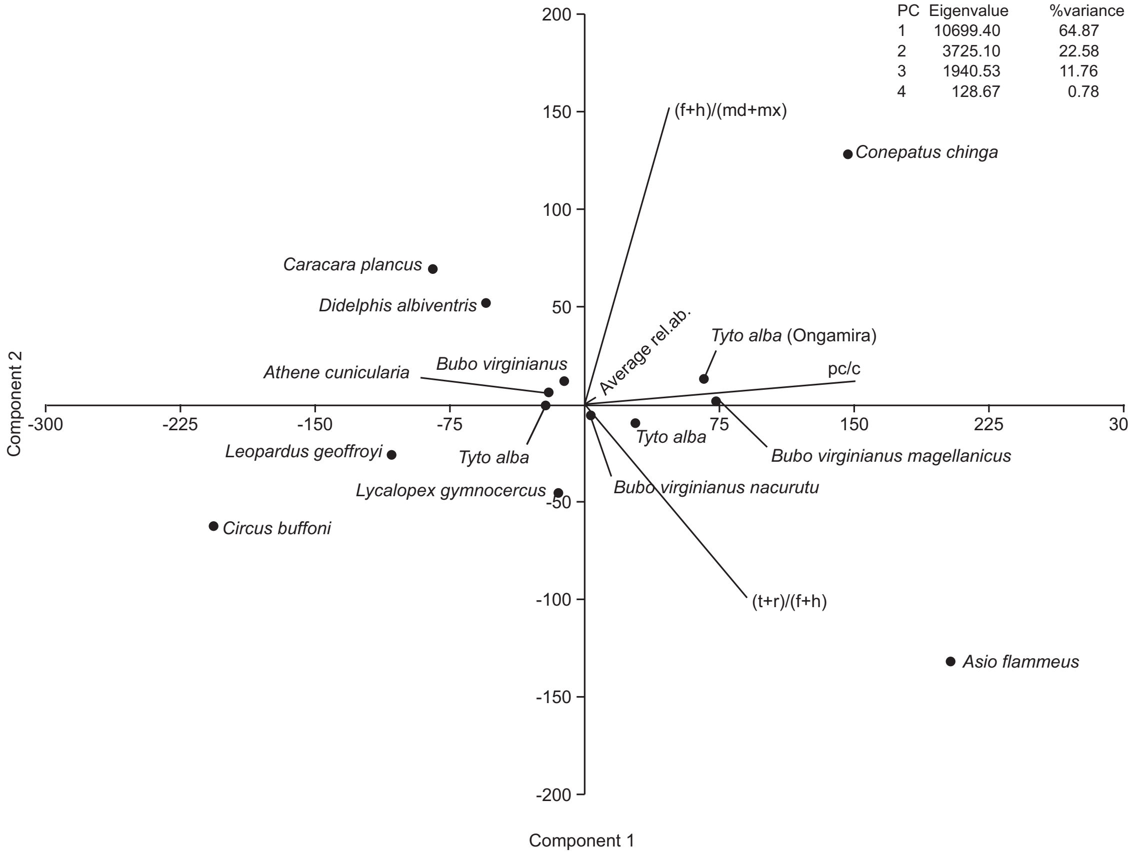


Fig. 6. Principal Component Analysis showing modern assemblages indexes from different predators on the assessment of average relative abundance and the relationship between cranial and postcranial elements. Software: PAST 3.15 (Hammer et al., 2001).

may suggest the chance of some kind of co-occurrences. Though this species is not present in the Ongamira valley today (Trejo and Bó, 2017), and though it is more prone to occupy lowlands, it may have inhabited the rockshelter some millennia ago. Similar co-occurrences have been noted in Europe between *Tyto alba* and *Bubo bubo* (a taxon not represented in the South American record) (e.g. Milchev, 2016).

The comparison of marks on the cortical surfaces of long bones and enamel suggests that the specimens were taphonomically added into each of the archaeological chronological components. The possible death and subsequent deposition of individuals in situ inside caves and burrows should also be considered, especially in chronological groups 2 and 3.

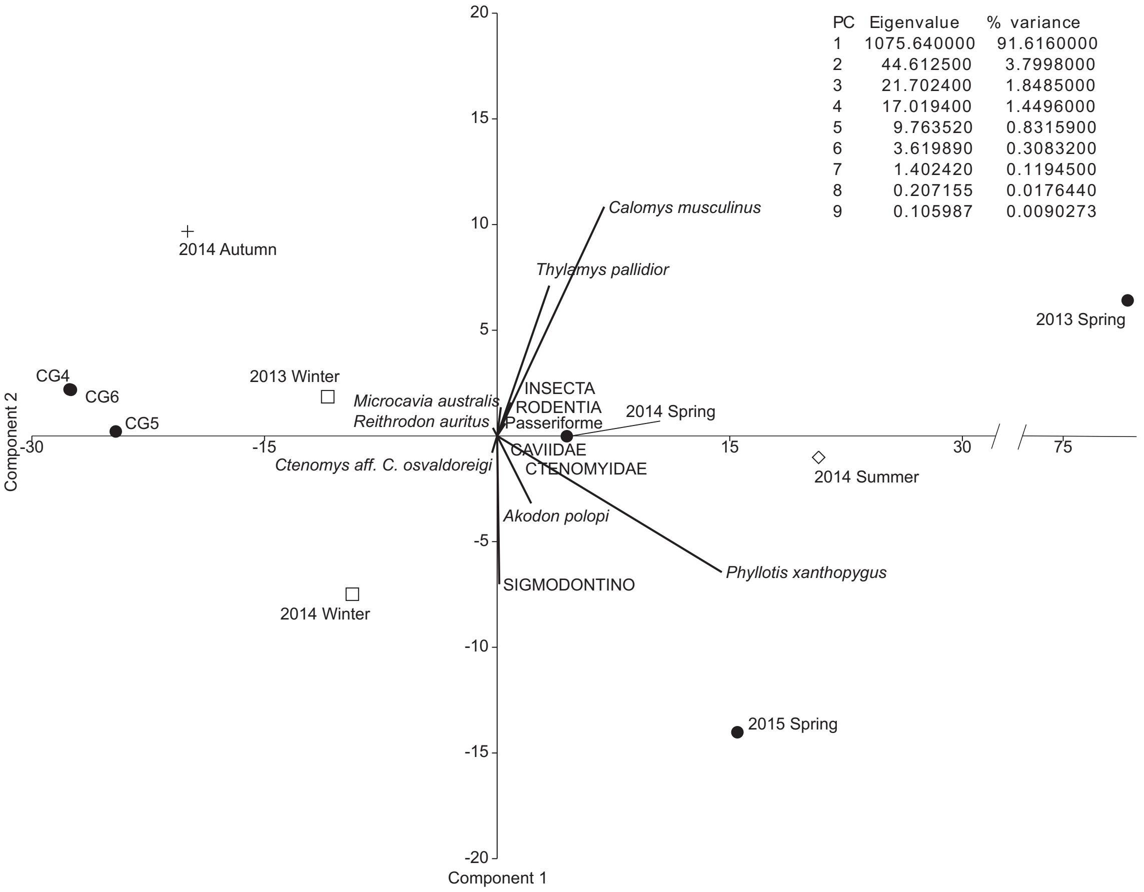
Finally, the data allow us to rule out the possibility of an anthropic genesis, resulting from the use, consumption or other exploitation of these species by humans in the archaeological site (Crandall and Stahl, 1995) The absence of traits associated with processing marks, as well as to the low frequency of burned remains, suggests the lack of use of small mammals as a food supply or for other human-related activity. It is likely that the thermal alterations observed correspond to activities or processes following mammal deposition, which, in isolation, would have resulted in small charcoal spots or partial carbonization (Bennet, 1999, Mignino, 2017).

To complement these past interpretations, and in an exploratory mode, a principal component analysis was carried out to assess the similarity between actualistic and archaeological assemblages - in relation to current taxonomic composition of each season - and thus attempt to enlarge the interpretation of the archaeological case for seasonality.

Fig. 7 shows that Component 1 explains > 91.61% of the variation in the database. In principle this variance allows segregation of the samples in relation to environmental conditions– spring and summer (higher temperatures and precipitation; Fig. 3) versus fall and winter (lower temperatures and less precipitation; Fig. 3). These conditions also explain, as seen above, how some species (*Phyllotis* sp., *Calomys* sp., etc.) are associated with spring/summer assemblages, while autumn and winter groups are defined primarily by the presence of small mammals (hystricognath rodents).

In contrast, the archaeological samples defined as part of chronological groups 4, 5, and 6 are associated with the actualistic assemblage of colder seasons. The presence of both *Reithrodon auritus* samples, a sigmodontine rodent that prefers colder habitats and is currently distributed more uniformly in the Patagonian region, and in certain places located in the high grasslands of Córdoba, Catamarca, Tucumán and Jujuy provinces, could explain why archaeological collections are grouped together with modern assemblages bounded to lower temperature environments. This allows us to interpret a scenario at the beginning of the Late Holocene with lower average temperatures than those at present (see Yanes et al., 2014 and Izeta et al., 2017 for an independent proxy suggesting the same scenario).

Therefore, data on current environmental conditions such as temperature, relative humidity, and precipitation over several years (2011–2015 and 2017) has allowed comparison of the two information sets to identify how climate variables affect barn owl diet, and, on that basis, to use these data for comparison with other archaeological collections. Indeed, the analysis of pellets showed seasonal variations in the *Tyto alba* diet, presence/absence, abundance and distribution patterns that fluctuated over the periods analyzed as observed in other parts of the world (e.g. Chausson et al., 2014; Williams, 2001). The observations suggest that in the spring of 2013 (warm season); sigmodontine rodents reached their maximum value. During that season the presence of caviomorph rodents, marsupials, and the incorporation of insects and birds was also recorded, although in a lesser frequency. The



PC	Eigenvalue	% variance
1	1075.640000	91.6160000
2	44.612500	3.7998000
3	21.702400	1.8485000
4	17.019400	1.4496000
5	9.763520	0.8315900
6	3.619890	0.3083200
7	1.402420	0.1194500
8	0.207155	0.0176440
9	0.105987	0.0090273

Fig. 7. Principal Component Analysis, including modern and archaeological assemblages. Component 1 segregates between warm and cold season assemblages. Software: PAST 3.15 (Hammer et al., 2001).

registration of Emberizidae exhibited maximum values in the spring of 2013 and summer of 2014, highlighting its absence in the rest of the seasons sampled. Carabid insects were also found, contributing to the diet in the spring of 2013 and 2014, but absent in the rest of the periods. By contrast, in the autumn of 2014 (cold season), minimum values were recorded, with only the presence of sigmodontine rodents and Didelphimorphia marsupials in the pellets.

The diversity and breadth of the trophic niche were highest in the warm 2013 season, corresponding to the maximum levels of annual rainfall, where the consumption of rodents, marsupials, birds and insects was observed. This is replicated in the 2014 and 2015 warm seasons.

The cold seasons showed a correspondence in terms of diversity and breadth of the trophic niche only with the incorporation of sigmodontine rodents and, to a lesser extent, marsupials.

4. Conclusions

The actualistic study of *Tyto alba* through pellets can be used to enrich our understanding of many aspects of paleoecology. In the first place, studying the specific environments preferred by this predator, its current hunting preferences, how it eats and digests its prey, and prey fluctuation in different seasons (wet and dry) has allowed us to interpret the causes that affected the formation of archaeological assemblages recovered in ADR, contributing to a greater understanding of the site formation processes. From a taphonomic perspective, we described six groups classified into two types according to their characteristics: those possibly caused by owl pellets, as found in the rock shelter today and representing most of the cases studied; and others resulting from death in caves and burrows, as attested by the stratigraphic information describing the units where the remains were recovered.

In addition, our research on the environments and climates of each predator has contributed data that add to paleoecological interpretations with greater precision.

Finally, in the case of the archaeological contexts, from the variety of taxa represented in the *Tyto alba* diet, these studies have allowed us to gather information and make new interpretations of the seasonality in which the occupation of the rock shelter probably took place to gain greater insights into human occupation (cool or warm season). Understanding the seasonal variations in the diet of this owl allows us to complement information with that of other detailed environmental data so as to broaden the understanding and development of more precise paleoenvironmental models.

Although we believe that a greater number of actualistic samples are required - in a broader range over time and space - as well as a better understanding of the current situation of some species in our region, the possibility of having ethological and ecological studies on birds and small mammals, combined with climatic information (i.e., taking into account endogenous and exogenous factors) and the taphonomic history of the assemblages, will allow us to gain greater insights into the seasonality of the accumulation of fossils and the conditions under which human occupations took place. From this perspective, and with the objective of estimating their environmental significance, the study and comparison of current and archaeological collections require a consideration of all of these actors.

Accordingly, it is essential to know in greater detail the causes affecting the quantitative and qualitative taxonomic structures in the archaeological record based on actualistic studies that take into account these aspects. We hope future studies will contribute to a better understanding of this issue.

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