SPECIAL ISSUE PAPER

Exploring Human Subsistence Strategies and Environmental Change through Stable Isotopes in the Dry Puna of Argentina

C. T. SAMEC,[a]* M. R. MORALES[b] AND H. D. YACOBACCIO[b]
[a] *CONICET – Instituto de Geocronología y Geología Isotópica, Buenos Aires, Argentina*
[b] *CONICET – Universidad de Buenos Aires, Instituto de Arqueología, Buenos Aires, Argentina*

ABSTRACT   This article explores the feeding and territorial behaviour of the wild camelids – guanacos and vicuñas – consumed by the inhabitants of the Dry Puna during the Early and Mid-Holocene, as a way to deal with the strategies for resource exploitation employed by these human groups. We present 38 stable isotope values (δ^{13}C and δ^{15}N) generated from bone collagen extracted from the faunal remains obtained from the Hornillos 2 archaeological site (Susques, Jujuy Province, Argentina). These bone assemblages were recovered from nine layers that comprise human occupations corresponding to both periods (from 9710 to 6130 years BP). These data will be discussed considering ecological and ethological information about wild camelids, especially regarding territorial behaviour and dietary selectiveness of vicuñas and guanacos that currently inhabit the Puna. Finally, the trends and patterns identified in these isotopic evidences will be analysed in the light of the environmental and cultural changes that took place during the mentioned chronological span.

Our results show no significant differences between camelid species, implying that δ^{13}C and δ^{15}N values of bone collagen constitute a poor taxonomical indicator, dismissing the possibility to identify the early incidence of human intervention in animal diet as an initial step to deal with the problem of domestication. In chronological terms, the δ^{15}N results from Early and Mid-Holocene show certain differences that can be linked to the preponderance of arid conditions during the latter. This underscores the usefulness of this line of evidence when evaluating environmental changes. On the other hand, the δ^{13}C values show no substantial differences, meaning that carbon isotopic composition of bone collagen in mixed C_3–C_4 systems is not a reliable paleoenvironmental proxy. Copyright © 2013 John Wiley & Sons, Ltd.

Key words: wild camelids; stable isotopes; environmental change; Early and Mid-Holocene; Dry Puna; isotopic ecology

Introduction

Several authors consider environment as the main limiting factor in hunter-gatherer adaptations (Kelly, 1995; Binford, 2001) and particularly high-mountain environments are presented as a set of constraints within which human populations must operate (Aldenderfer, 1998). In dealing with these conditions, hunter-gatherers must minimise cost and risks by developing a series of behavioural responses involving a certain degree of residential mobility, an emphasis on logistic movements, the location of camps in 'optimal' localities and the development

* Correspondence to: Celeste T. Samec, CONICET, Instituto de Geocronología y Geología Isotópica, Pabellón INGEIS, Ciudad Universitaria (C1428EHA), Buenos Aires, Argentina.
e-mail: celestesamec@gmail.com

of balanced reciprocity, among other features (Kelly, 1995). Thus, in this scenario, we can establish certain interdependence between environmental conditions and human actions (Schutkowski, 2006).

In the southern part of the Central Andes, the Mid-Holocene (8000–3500 years BP) represents a dryer period in relation to the Early Holocene (10,000–8000 years BP), composing a more arid environment that becomes the scenario for a specialisation process on camelids exploitation (Yacobaccio, 2003). This process is revealed in the faunal remains of the Andean Highlands archaeological sites as an increase in the Artiodactyla Index in the occupations dated during this time span. In this paper, we will present and discuss new data obtained from the Hornillos 2 rockshelter faunal assemblages as a way to discuss the human strategies related to resource use in

the Dry Puna of Argentina in relation to these environmental and cultural changes. The archaeological sequence in this site includes seven layers assigned to the Early Holocene and two assigned to the first half of the Mid-Holocene, ranging from 9710 to 6130 years BP. The recovered faunal remains correspond to different mammal species such as camelids, cervids and rodents (Yacobaccio *et al.*,). In this work, we will focus only on the analysis of the stable isotope values obtained from camelids, within which we can distinguish two species: (i) small-size camelids representing vicuñas (*Vicugna vicugna*) and (ii) large-size camelids corresponding to guanacos (*Lama guanicoe*). At the same time, the presence of very large camelids, similar to *llamas*, in the layer 2 of the site (6130–6340 years BP), points to the existence of primal domesticated forms, providing a good opportunity to evaluate human intervention in camelid diet in the earliest stages of domestication ('protective herding') in the Southern Andes (Yacobaccio, 2004).

Therefore, a total of 38 pairs of stable isotope values ($\delta^{13}C$ and $\delta^{15}N$) measured on bone collagen extracted from small and large-size camelids will be presented and discussed here. These data will be compared with modern camelid values generated for the same region (Fernández & Panarello, 1999–2001a; Yacobaccio *et al.*, 2009, 2010; Samec, 2011, 2012) and then discussed considering two main analytical dimensions. First, we will emphasise a taxonomical approach: considering the current corpus of isotopic and ethological data, this work will discuss the dietary differences between wild camelid species, *vicuñas* and *guanacos* (including within this latter group the larger 'llama'-like forms, recovered in layer 2), represented in the Hornillos 2 assemblages. Second, we will consider these new stable isotope values from a chronological point of view, taking into consideration the climatic changes that took place during the time span of site occupation. Regarding the latter issue, it is essential to establish the environmental dimensions that introduce variability in the isotopic data as a necessary step to address human strategies through this line of evidence (Iacumin *et al.*, 1997). Thus, taking into account the environmental changes occurred in the Early to Mid-Holocene transition, we will evaluate the role of these in the behaviour of wild camelids, particularly in their mobility and dietary habits. We will also be able to discuss the stability of flora communities and the changes in water balance over time, in light of the $\delta^{13}C$ and $\delta^{15}N$ values obtained on bone collagen from the Hornillos 2 faunal remains. Finally, this work will address the implications of these data when evaluating aspects such as human subsistence strategies framed in a changing environment.

The Dry Puna

The Puna of Argentina constitutes a highland desert located between 22° and 27° S and between 3000 and 4500 masl. This area is dissected by several NE-SW oriented mountain ranges, and it is characterised by high solar radiation due to altitude, wide daily thermal amplitude and low atmospheric pressure. Primary productivity is mainly concentrated on stable hydrological systems such as primary basins, high ravines and wetlands. A few rivers and several springs scattered throughout the landscape are the only sources of freshwater, which is a critical resource for human and animal populations. The precipitation is seasonal and occurs during summertime, governed by the South American monsoon system (Zhou & Lau, 1998). This system produces about 80% of the annual rainfalls between December and February (Vuille & Keimig, 2004). In terms of precipitation distribution, the Argentinean Puna exhibits a latitudinal gradient that determines two sub-regions: (i) north of 24° S, the Dry Puna, with a mean annual precipitation of 340 mm/year; and (ii) south of 24° S, the Salt Puna, in which precipitations barely reach the average of 100 mm/year (Bianchi *et al.*, 2005).

In the Dry Puna, the wide altitudinal range also results in moisture variations that allow for a broad diversity of plant assemblages that can be typified in four main communities (Ruthsatz & Movia, 1975; Cabrera, 1976; Fernández & Panarello, 1999–2001a; Arzamendia *et al.*, 2006):

1. Shrub steppe (*Tolar*) is located between 3500 and 3900 masl and is dominated by *Parastrephia lepidophylla* and *Fabiana densa*, with a low proportion of herbs (5%). It includes mainly C_3 (shrubs and grasses) and C_4 (mostly grasses) plant species.
2. Herbaceous steppe (*Pajonal*) dominated by *Festuca* spp. and other grasses, like *Poa* spp. and *Stipa* spp., exhibits mostly C_3 plant species and can be found between 4100 and 4700 masl.
3. Wetlands (*Vegas*) constitute restricted patches composed by hygrophilous grasses. These dense vegetated areas covered by several grass species (*Deyeuxia* spp., *Mulembergia* spp., etc) are located in both altitudinal settings from 3500 to 4700 masl.
4. Mixed steppes, composed of grasses and shrubs with C_3 and C_4 plant species, can be found between 3900 and 4100 masl representing ecotonal landscapes.

The environmental setting described previously is defined by a patchy distribution of vegetal and animal resources employed by human populations. These implies the presence of limited areas with a higher biomass than the regional average, framed in a desert

landscape, also mentioned in archaeological literature as Nutrients Concentration Zones (Yacobaccio, 1994). Nevertheless, the Puna represents an environment with an overall low ungulate diversity. Only three species are found: two wild camelids – *guanaco* and *vicuña* (*Lama guanicoe* and *Vicugna vicugna*) – and one cervid, the *taruca* deer (*Hippocamelus antisensis*).

Environmental scenarios during the Early and Mid-Holocene

The information obtained from many paleoenvironmental records shows a complex and heterogeneous picture regarding the different effects of climate over the environment at several spatial scales (i.e. regional, sub-regional, local). Although stable, moister and colder conditions are generally accepted to characterise the Early Holocene, the complexity of Mid-Holocene paleoenvironmental signals has led to a heated debate about the nature of the regional climate during this period in the Puna de Atacama (Grosjean, 2001; Grosjean *et al.*, 2003; Latorre *et al.*, 2003, 2006). One of us has recently set his position on this topic, proposing a general trend towards aridization along the Mid-Holocene, which fostered a hydrologic stress process in the Tropical Andes and consequently in Northwestern Argentina (Tchilinguirian & Morales, in press). However, framed in a context of regional aridity, several localities seem to have retained wetter conditions during this period, increasing the contrast between highly productive environments – in terms of primary productivity and abundance of mammal species – and the general dry landscape (Morales, 2011).

We can briefly characterise both periods, Early and Mid-Holocene, as follows. The climate through most of the Early Holocene (10,000–8000 years BP) is considered stable and regionally homogeneous (Thompson *et al.*, 1995, 1998, 2000; Bradbury *et al.*, 2001; Ramírez *et al.*, 2003). This broad-scale stability is also evidenced by pollen records (Markgraf, 1985) that indicate the presence of vegetation typical of herbaceous steppe in lower altitudes - below 3800 masl - than observed in recent times. Consistent with this is the regional positive hydrological balance inferred from the higher levels of the most important lake systems in the area (Geyh *et al.*, 1999; Bradbury *et al.*, 2001; Abbott *et al.*, 2003). Finally, the regional abundance of pack rat middens (Latorre *et al.*, 2003, 2006) and paleosoils (Morales, 2011) also point towards more stable and moister environments during the 10,000–8000 years BP span. The end of these conditions

is not synchronous, presenting later dates (ca 8000 years BP, or even a few centuries later) in the southern part of the Central Andean region (Northern Chile and NW Argentina). This late chronology is mainly evidenced in water bodies with broad catchment areas and in those located at altitudes above 4000 masl (Morales, 2011).

In turn, Mid-Holocene records show that several lakes dried out, numerous wetlands disappeared and the grassland steppe migrated upwards and reached over the 4000 masl contour, suggesting a regional trend towards aridization (Morales, 2011). Framed in these general conditions, the 8000–6000 years BP span can be characterised as a transitional environment, between the moister and colder Early Holocene and more arid and warmer conditions that were also less stable. During this transitional period, the high groundwater levels reached during Early Holocene allowed the retention of wetland characteristics in several localities until ca 7000 years BP, as shown by the alluvial sediment and peat deposits in settings like Quebrada Puripica (Grosjean, 2001) and Quebrada Lapao (Yacobaccio & Morales, 2005). Afterwards, the second part of the Mid-Holocene – between 6000 and 3500 years BP – could be characterised as a moment of extreme regional aridity, but with better conditions in the western and lower parts (below ~3000 masl) of the Andes. Locations over 3000 masl evidenced more or less synchronic interruption in moisture input at about 6200 BP, and a strong desiccation event ca 5000 years BP. This pattern is clearly compatible with the onset of the first El Niño-type events (Villagrán, 1993; Veit, 1996; Riedinger *et al.*, 2002), related to both the increase of moisture in the lowlands and the extreme aridity in the highlands and eastern slope of the Andes.

Behaviour and general ecology of the Puna wild camelids

Guanacos are spread all over the Andean range from Peru to Tierra del Fuego (from 8° to 55° S), inhabiting a variety of open habitats and forest environments (González *et al.*, 2006). The social structure of this wild camelid during the breeding season comprises three basic social units: territorial family groups, male groups (non territorial) and solitary males (Franklin, 1982). Family groups' territoriality is directly correlated with stable food supplies. When a severe drop in food availability occurs, usually in winter, *guanaco* populations relocate, losing territoriality and forming mixed groups (Cajal, 1985). Regarding forage selectivity,

González *et al.* (2006) classified *guanacos* as intermediate herbivores or opportunistic (mixed) feeders that forage on a highly diverse range of food sources such as shrubs and herbs. At the same time, this species is considered drought-tolerant, because they are able to spend several days without consuming water (Franklin, 1982). While *guanaco* populations are relatively large in Patagonia, in other areas like Peru, NW Argentina, northern Chile, and the Bolivian and Paraguayan Chaco, it is considered an endangered species (González *et al.*, 2006; Censo 2010). For this reason, behavioural data obtained from Patagonian *guanacos* must be taken with caution when studying Puna groups. In the latter area, the distribution of this species is restricted to small populations, generally occupying high-altitude environments (Censo, 2010).

The other wild camelid species, the *vicuña*, inhabits the Puna region from Peru to Argentina and Chile (between 9° 30′ and 29° S), and it is found exclusively at high altitudes – that is, above 3400 masl (Laker *et al.*, 2006). *Vicuñas* are adapted to habitats such as open grasslands, steppes and wetlands. Although the species can be classified as a grazer – as it feeds preferably on herbs and grasses, exhibiting great efficiency for processing C_4 plants – they also feed on variable proportions of shrubs in steppe habitats (Borgnia *et al.*, 2010). According to Benítez and coauthors (2006), *vicuñas* can eat shrub vegetation at the end of the rainy season in order to obtain specific proteins when these plant communities offer better quality forage than *vegas*. Regarding social structure, the *vicuña* lives in family groups whose mean composition is one male, three or four females and two offspring. These groups remain territorial throughout the year. On the other hand, bachelor groups, composed of calves that are expelled of the family group during the new birth season and males without territory, can vary in number and location several times a day (Vilá, 1991). Unlike *guanacos*, *vicuñas* are obligate drinkers (i.e. they must drink water every day). Therefore, water location operates as a limiting factor for the distribution of this species (Vilá, 2000). Despite its dependence on water resources and territorial behaviour, *vicuñas* can utilise different plant communities on a seasonal basis (Arzamendia & Vilá, 2003). This species was nearly extinct in the mid-20th century, although today populations have recovered in most parts of the Andes because of protection policies (Vilá, 2000).

There are few observations of *vicuña* and *guanaco* behaviour in sympatric situations. At the San Guillermo Reserve (San Juan Province, Argentina), Cajal (1979) recorded a partial overlapping between populations of both species. This study evidenced that the *guanacos* have a wider distribution, higher mobility and less defined territoriality than the *vicuñas*; the mean size of *guanaco* territories covered around 260 hectares, whereas those of *vicuñas* included 138 hectares only (Cajal, 1979).

Isotopic ecology of camelids

In recent years, the study of camelid feeding behaviour through stable isotopes had experienced a great development in Argentina. Research on this subject has focused on generating reference values for interpreting human diet or the study of husbandry strategies employed by agropastoral groups in the past (Mengoni Goñalons, 2007; Barberena *et al.*, 2009; Izeta *et al.*, 2009; Tessone & Belardi, 2010). In order to deal with these issues, it is important to establish the variables that influence the isotopic signal of the herbivores that inhabit any study area (Iacumin *et al.*, 1997).

Here, we present a summary of the tendencies in the $\delta^{13}C$ and $\delta^{15}N$ values measured on the camelids species that inhabit the Dry Puna today and their implications in terms of their feeding behaviour (Table 1). These data were generated through the analysis of bone collagen extracted from carcasses recovered in different localities and altitudes in the area (Fernández & Panarello, 1999–2001a; Samec, 2011).

Several studies have demonstrated that altitude is a key variable in the conformation of camelid tissues $\delta^{13}C$ values because of the differential distribution of C_3 and C_4 plant species along an altitudinal gradient (Fernández *et al.*, 1991; Fernández & Panarello, 1999–2001a; Yacobaccio *et al.*, 2009, 2010; Samec, 2011). Considering the values generated from bone collagen corresponding to wild and domesticated camelid specimens, we can identify an obvious trend: when altitude increases, the $\delta^{13}C$ values become lower, reflecting a major proportion of C_3 plants included in the diet (Table 1). The incidence of altitude in C_3 and C_4 vegetal species abundances has been documented in areas where this feature notably varies (Tieszen *et al.*, 1979; Cavagnaro, 1988; Llano, 2009), and some authors have proposed that when altitude raises above a given point, C_4 grasses are replaced by C_3 grasses (Tieszen, 1994). In the Puna area, we still do not count with information about C_3 and C_4 plant abundances and distribution along the complete altitudinal range. However, the strong correlation between altitude and $\delta^{13}C$ values of camelids bone collagen allows us to think that this variable is in fact a determinant of C_3 and C_4 abundance, being the latter photosynthetic pattern practically absent in elevated locations (Cavagnaro, 1988; Fernández & Panarello, 1999–2001a; Samec, 2011).

Table 1. Summarised statistics of the total $\delta^{13}C$ and $\delta^{15}N$ values meassured on bone collagen extracted from wild and domesticated camelids of the Dry Puna

	Sample N	Camelid species	Mean (‰)	Minimum (‰)	Maximum (‰)	SD	Altitudinal range (masl)	Correlation with altitude	Publications
$\delta^{13}C$	7	*Lama guanicoe*	−18.0	−18.6	−17.5	0.45	4000–4600	$r = 0.32\ p > 0.01$	Fernández *et al.*, 1991;
	30	*Vicugna vicugna*	−17.3	−19.1	−13.1	0.34	3480–4500	$r = -0.92\ p < 0.01$	Fernández & Panarello,
	6	*Lama pacos*	−17.5	−20.1	−16.6	1.34	3550–3600	$r = -0.54\ p > 0.01$	1999–2001a, 1999–2001b;
	53	*Lama glama*	−17.3	−22.0	−12.3	1.89	3550–4700	$r = -0.80\ p < 0.01$	Yacobaccio *et al.*, 2009,
	96	All species	−17.4	−22.0	−12.3	1.79	3480–4700	$r = -0.74\ p < 0.01$	2010; Samec, 2011
$\delta^{15}N$	17	*Vicugna vicugna*	4.8	2.2	11.3	2.90	3480–4400	$r = -0.94\ p < 0.01$	Samec, 2012
	35	*Lama glama*	6.6	3.7	12.1	1.97	3600–4700	$r = -0.82\ p < 0.01$	
	52	All species	6.0	2.2	12.1	2.44	3480–4700	$r = -0.88\ p < 0.01$	

At the same time, $\delta^{15}N$ values recently produced by our research on *vicuñas* and *llamas* have proven that altitude represents an important variable in this case as well (Table 1). This is probably related to variations in water availability, which is also correlated with altitude in the Dry Puna (Samec, 2012). In this situation, the analysis shows a negative correlation between altitude and camelid tissue $\delta^{15}N$ values, which is related to higher water availability at higher altitudes (Ambrose & DeNiro, 1986; Amundson *et al.*, 2003; Swap *et al.*, 2004).

Because of the current lack of *guanaco* populations in the area, analysing the dietary differences between the two wild camelids species that today inhabit the Puna presents certain difficulties. So far, the $\delta^{13}C$ values for *guanacos* are scarce, and no $\delta^{15}N$ values have been measured on any tissue to date (Fernández & Panarello, 1999–2001a). However, the few $\delta^{13}C$ values presented by Fernández & Panarello (1999–2001a) do not show a great range of variability and provide evidence for a mixed C_3–C_4 diet, which fits what is known about the ecology of this species. On the other hand, the comparison between *guanaco* $\delta^{13}C$ values with those of *vicuña* does not exhibit statistically significant differences (Samec, 2011). In the case of *vicuñas*, a wider body of isotopic data is available, generated by stable isotope measurements of bone collagen extracted from carcasses recovered at different altitudes. The $\delta^{13}C$ values indicate that *vicuñas* that feed in ranges below 3900 masl have a diet with more C_4 plants, in comparison with the *llamas* that feed at the same altitude (Samec, 2011). The existence of certain selectiveness in *vicuña* feeding behaviour concerning an enhanced consumption of C_4 plants when these are available agrees with the existing ethological information previously discussed (Borgnia *et al.*, 2010). On the other hand, $\delta^{15}N$ values for *vicuñas* are lower when compared with *llama* ones (Samec, 2012), probably in relation to the status of the *vicuña* as an obligate

drinker in comparison to the drought-tolerant *llamas* (Ambrose & DeNiro, 1986; Sealy *et al.*, 1987).

In order to analyse the isotopic data obtained from the faunal remains recovered from the Hornillos 2 rockshelter, we will consider a subset of the modern reference values for comparison (Fernández & Panarello, 1999–2001a; Yacobaccio *et al.*, 2009, 2010; Samec, 2011). The data selected are constituted by $\delta^{13}C$ and $\delta^{15}N$ values measured on bone collagen of *L. glama*, *L. guanicoe* and *V. vicugna* obtained from localities between 3900 and 4200 masl, at a similar altitude to the archaeological site (Table 2). We have decided to include domesticated camelid isotopic data because of the scarcity of values obtained from wild camelids so far and considering the possible presence of transitional forms of these animals among the site's faunal remains, in relation to the early stages of the domestication process.

The Early and Mid-Holocene faunal assemblages in the Hornillos 2 rockshleter

Hornillos 2 is a rockshelter located in the Dry Puna of Jujuy Province in Argentina (23° 13′ 47″ S, 66° 27′ 22″ W, 4020 masl; Figure 1). Nine archaeological layers, dated between 9710 and 6130 years BP, were identified in its stratigraphic sequence. The earlier seven levels correspond to the Early Holocene, whereas the remaining two are dated between 7760 and 6130 years BP, both ascribable to the first part of the Mid-Holocene (Table 3). Several differences have been detected between the human occupations during both periods, such as the extent of the occupied surface, the intensity of activities, the technological patterns and the change in the use of faunal and vegetal resources (Hoguin *et al.*, 2012). The rockshelter also presents rock art representations (anthropomorphs and camelids) assigned to the Early

Table 2. Summarised isotope values corresponding to modern camelids recovered at localities between 3900 and 4200 masl.

	N	Camelid species	Mean (‰)	Minimum (‰)	Maximum (‰)
$\delta^{13}C$	26	All species	−18.3	−20.1	−16.9
	2	*Lama guanicoe*	−18.2	−17.8	−18.6
	5	*Vicugna vicugna*	−17.9	−18.1	−17.6
	19	*Lama glama*	−18.4	−20.1	−16.9
$\delta^{15}N$	13	*Lama glama*	5.8	4.0	7.6

The $\delta^{13}C$ values (corrected for Suess Effect for comparison to archaeological data) were published in the works of Fernández & Panarello (1999–2001a), Yacobaccio *et al.* (2009, 2010) and Samec (2011). The $\delta^{15}N$ values were generated as a part of the Susques Archaeological Project and are still unpublished (Samec, 2012).

Holocene (Yacobaccio *et al.*, 2008). At the same time, in one of its earliest archaeological layers (6A), a piece of wood carving was recovered.

Four well-represented mammalian taxa have been recovered from Hornillos 2: the *guanaco*, the *vicuña*, the *taruca* and a large rodent, the *vizcacha* (*Lagidium* sp.). The good preservation of the remains recovered from the site is noteworthy, given the low stages of weathering registered. Nevertheless, the assemblage exhibits a high fragmentation index and a noticeable incidence of fire, especially in the Early Holocene layers. Regarding species frequencies, the percentage of camelid remains increased from nearly 15% in the Early Holocene to

Table 3. Radiocarbon dates for the archaeological levels of the Hornillos 2 site

Level	Sample	Radiocarbon date (years BP)	Material
2	Beta-111392 (LSC)	6130 ± 70	Charcoal
	UGA-7829 (LSC)	6340 ± 110	Charcoal
3	UGA-7830 (LSC)	7430 ± 80	Charcoal
	UGA-8722 (LSC)	7760 ± 160	Charcoal
4	LP-757 (LSC)	8280 ± 100	Charcoal
6	UGA-8723 (AMS)	9150 ± 50	Charcoal
	UGA-8724 (AMS)	9590 ± 50	Wood (C_3)
6d	UGA-13550 (LSC)	9710 ± 270	Charcoal

about 24% in the next period (Table 4). During the Mid-Holocene occupations, the use of camelids is rather low in comparison with their frequency in other sites of the region, which have an average of 81% (N sites = 6). However, in Hornillos 2, camelid use might be underestimated since almost 30% of the remains dated to the Mid-Holocene were identified as Artiodactyla because the fragmentation resulting from cultural practices limits the degree of species identification. The rest of the fauna is composed of Cervidae (*Hippocamelus* sp.) with almost 1% in all layers, and by Chinchillidae (*Lagidium* and *Chinchilla* spp.) and small rodents (especially *Ctenomys* spp. and *Abrocoma* spp.), which represent the remaining percentages in each layer.

Osteometry was used as a tool for assessing the different camelid species represented in the site's
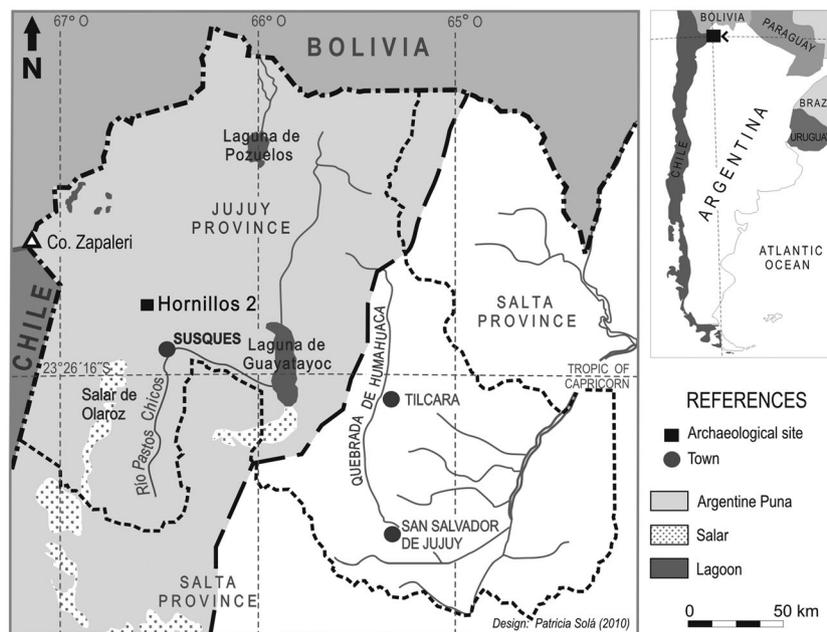
Figure 1. Hornillos 2 archaeological site location in the Jujuy Province, Argentina.

Table 4. Figures of total number of identified specimens (NISP), camelid NISP and percentages for both Early and Mid-Holocene periods

Period	Total NISP	Camelid NISP	Percentage of Camelid NISP
Mid-Holocene	5106	1222	2393
Early Holocene	7555	1124	1487
Total	12661	2346	1853

assemblages. The main bone sample comes from layer 2, which has specimens suitable for measurement: complete (at least in one epiphysis), fusioned and not weathered. Nevertheless, the absence of some measure points prevented us to include all measurable items. We employed measures of camelids (*vicuñas*, *guanacos* and *llamas*) of local origin as osteometric standards. Three different groups of bones were analysed:

1. Distal metapodials. As can be seen in Figure 2(A), the Principal component analysis shows two groups: (i) a large-size group composed by *guanacos* and *llamas*; and (ii) another one of small size, grouping *vicuñas* and two samples of Hornillos 2.
2. Proximal phalanges. Two measurements of the proximal epiphysis are compared (Bp and Dp, von den Driesch, 1976). Figure 2(B) shows three samples of Hornillos 2 grouping either with *guanacos* or *llamas*.
3. Scapulae (glenoid cavity). The two measures taken (LG and BG, von den Driesch, 1976) show that the scapula from Hornillos 2 is wider than those of modern *llamas*, far from *guanacos* standards, as can be seen in Figure 2(C).

Osteometric data at Hornillos 2 point towards the presence of two main size groups – small and large – indicating the presence of individuals pertaining to both wild taxa (*vicuñas* and *guanacos*). However, the larger group can be also divided into two subgroups when we consider the remains recovered in layer 2: those that meet *guanaco* size standards and those that exhibit a larger size, similar to modern *llamas*. These very large camelid specimens could be interpreted as the first ones subjected to human management (i.e. protective herding, Yacobaccio, 2004).

Sampling and techniques

Thirty eight pairs of stable isotope values ($\delta^{13}C$ and $\delta^{15}N$) were measured on bone and dentin collagen

obtained from camelid remains recovered from all the archaeological layers of the Hornillos 2 site.

We have followed three main criteria during sample selection from the total 15,000 bone fragments: (i) good preservation (not weathered); (ii) identificability to a species or group-size degree, and to different individuals (considering bone type, age and laterality); and (iii) stratigraphic location. These criteria seek to avoid multiple measurement of the same animal specimen. All analysed bone specimens were segregated in two main size groups conformed osteometrically: small camelids (i.e. *vicuñas*) and large camelids (i.e. *guanacos* and perhaps *llamas*).

The samples obtained from the Hornillos 2 rockshelter faunal remains were processed and measured in the Enviromental Isotope Laboratory of Waterloo University (Canada) following the protocol employed by Cormie & Schwarcz (1996). The equipment employed in this analysis was a Thermo Finnigan Delta plus EA-IRMS (Bremen, Germany) resulting in analytical precision values of 0.1‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$. All values are reported in parts per 1,000 or 'per mil' (‰) relative to internationally defined standards for carbon (Vienna Pee Dee Belemnite) and nitrogen (Ambient Inhalable Reservoir) (Craig, 1957; Coplen et al., 1992).

Results and discussion

The Hornillos 2 faunal isotopic compositions, C:N ratios and associated contextual information are presented in Table 5. From the 38 pairs of values obtained, 10 pairs were discarded because of anomalies in their C:N ratios (out of the 2.9–3.6 range), indicating low collagen quality and showing that the original isotope values were not preserved (DeNiro, 1985). Therefore, all the trends and patterns described will be related to the 28 remaining pairs.[1]

Taken as a whole, the $\delta^{13}C$ and $\delta^{15}N$ values considered here fit the diet expectations for a mixed feeder herbivore species inhabiting an arid setting (Pate & Anson, 2008; Hartman, 2011). As can be seen in Table 6, carbon isotopic compositions ranged between −19.3‰ and −12.4‰ suggesting a diet including both C_3 (shrubs and grasses) and C_4 (mainly grasses) plant species, with a larger contribution of the former. This mixed diet suggests a feeding behaviour consistent with an ecotonal setting where both plant classes are

---

[1] Nevertheless, it is important to mention that five samples with C:N values of 2.8 or 3.7, falling near but outside the 2.9–3.6 range, were included in previous analysis exhibiting no remarkable differences in stable isotope composition with the rest of the samples and not altering the tendencies discussed in the following paragraphs (see Yacobaccio et al., for details).
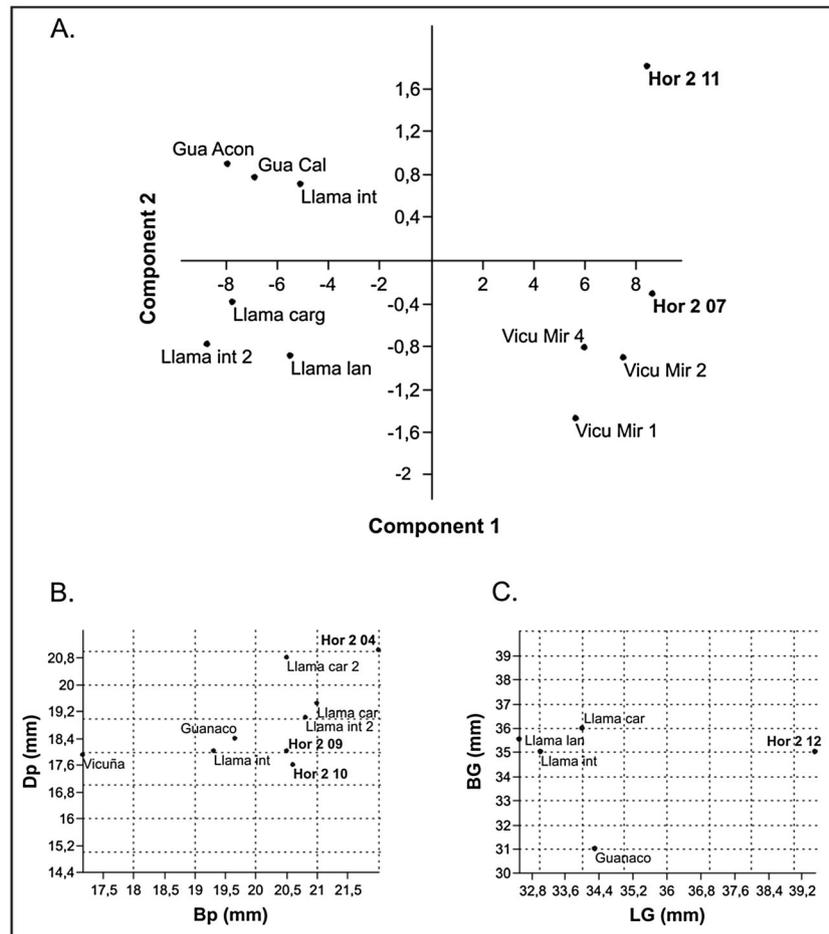
Figure 2. Principal component analysis (A) and measurements taken on phalanges (B), and scapula (C) from Layer 2 of the Hornillos 2 Rockshelter.

available, although C_3 species are more abundant (see *supra*). On the other hand, the $\delta^{15}N$ values vary between 3.7‰ and 10.7‰, exhibiting a great range and a mean value of 7.4‰, which fits the expected values for herbivores living in arid environments (Murphy & Bowman, 2006).

Figure 3 summarises $\delta^{13}C$ and $\delta^{15}N$ for small and large-size camelids, respectively. When considering the $\delta^{13}C$ results in a taxonomical dimension, no statistically significant differences are detected [one-way ANOVA $F = 0.67$ $p = 0.41 > 0.01$; Figure 3(A)]. The same pattern has been observed in modern isotopic data for both species, showing an overlap in their diets when feeding above 3900 masl (Samec, 2011). On the other hand, when comparing the $\delta^{15}N$ values of both size groups, no statistically significant differences are present (one-way ANOVA $F = 1.62$ $p = 0.21 > 0.01$) although the large camelid group is characterised by greater variability, related to the larger sample size of this group [Figure 3(B)].

As mentioned before, the 'large camelid' group recovered in layer 2 (dated between 6130 and 6340 years BP) can be divided into two subgroups: those that meet *guanaco* size osteometric measures and those that present a larger size, consistent with *llama* osteometric criteria. Although the samples assigned to this later group are scarce so far, the five individuals analysed for isotopic compositions do not present great differences when compared with those specimens identified as *guanaco* (Table 5).

In sum, the absence of significant differences when comparing the diets of camelid species rules out measurements of isotopic compositions as a taxonomical indicator, given that $\delta^{13}C$ and $\delta^{15}N$ values of small-size camelids (*vicuña*) and large-size camelids (*guanaco* and possibly *llama*) are not significantly different. At the same time, no dietary variations were recorded through stable isotope analysis within this large size-group, making it impossible to differentiate human intervention in 'llamas' diet, at least for these early stages in the domestication process in the Dry Puna area.

Table 5. Hornillos 2 faunal remains δ^{13}C and δ^{15}N bone collagen values

Sample	Layer	Skeletal part	Camelid size	δ^{13}C (‰)	δ^{15}N (‰)	C:N
H2 01[*]	2	Metatarsal Proximal end	Large camelid	−19.3	9.3	4.1
H2 02[*]	2	Proximal Metacarpal	Large camelid	−18.8	10.2	3.7
H2 03[**]	2	First Phalange diaphysis	Large camelid	−16.8	10.3	3.0
H2 04[**]	2	Phalange 1 proximal end	Large camelid	−16.9	8.7	3.0
H2 05[**]	2	Metapodial distal end	Large camelid	−12.4	10.7	3.0
H2 06[**]	2	Metapodial distal end	Large camelid	−17.2	9.3	2.9
H2 07	2	Metapodial distal end	Small camelid	−15.8	10.0	3.0
H2 08[**]	2	Metapodial distal end	Large camelid	−18.7	6.2	3.0
H2 09	2	Phalange 1 proximal end	Large camelid	−18.8	6.0	3.0
H2 10	2	Phalange 1 proximal end	Large camelid	−19.0	6.2	3.1
H2 11[*]	2	Metapodial distal end	Small camelid	−18.2	7.8	3.7
H2 12[**]	2	Scapula	Large camelid	−17.5	7.3	2.9
H2 16	2	Mandible	Small camelid	−16.7	7.1	2.9
H2 18	2	Teeth incisive 3	Large camelid	−19.0	9.0	3.6
H2 20	2	Teeth incisive 1	Large camelid	−18.1	9.2	2.9
H2 25	2	Long bone fragment	Small camelid	−16.4	9.9	3.0
H2 14	3	Long bone fragment	Small camelid	−17.0	7.3	3.0
H2 21	4	Metapodial distal end	Large camelid	−16.7	10.5	3.0
H2 27	4	Proximal Phalange	Large camelid	−17.5	8.2	2.9
H2 28	4	Long bone fragment	Small camelid	−19.3	5.6	3.1
H2 29	4	Proximal Phalange	Small camelid	−17.4	5.6	2.9
H2 43	5	Long bone fragment	Large camelid	−18.3	6.9	3.2
H2 45	5	Long bone fragment	Small camelid	−18.4	7.1	3.2
H2 47	6	Femur	Large camelid	−19.1	6.1	2.9
H2 48[*]	6	Long bone fragment	Small camelid	−21.1	11.3	6.7
H2 50	6	Long bone fragment	Small camelid	−17.7	5.0	2.9
H2 51	6	Teeth incisive	Large camelid	−17.6	10.0	3.0
H2 52[*]	6A	Radius ulna	Large camelid	−16.7	7.6	2.8
H2 53	6A	Long bone fragment	Small camelid	−17.2	4.9	2.9
H2 24	6B	Phalange indeterminate	Indeterminate	−17.8	5.9	3.0
H2 31[*]	6B	Long bone fragment	Large camelid	−18.4	4.5	2.8
H2 32[*]	6B	Long bone fragment	Small camelid	−20.3	9.0	4.5
H2 33	6B	Teeth incisive	Large camelid	−19.2	3.7	2.9
H2 35	6C	Metapodial shaft	Small camelid	−16.7	5.9	2.9
H2 37	6C	Rib proximal	Large camelid	−18.6	5.2	3.0
H2 22[*]	6D	Scapula	Large camelid	−21.2	10.0	5.4
H2 41[*]	6D	Metapodial	Indeterminate	−16.0	8.1	2.8
H2 42[*]	6D	Phalange indeterminate	Indeterminate	−21.1	8.1	5.0

[*] Samples not considered due to low collagen quality, [**] Specimens assigned to '*llama* size'.

Considering the chronological dimension of our analysis, there are no statistically significant differences between the Early and Mid-Holocene δ^{13}C datasets [one-way ANOVA $F = 2.38$ $p = 0.13 > 0.01$; Figure 4(A)]. This could indicate that either (i) plant forage and its access and location did not undergo substantial change during the analysed periods; or (ii) proportions of C_3 and C_4 species in camelid diet remained stable through time, even if there were changes in the relative abundances of these plant groups. In the latter case, carbon isotope composition of bone collagen would be a stronger indicator of selective feeding by camelids, rather than of variation in C_3–C_4 relative regional abundances due to climate change. In relation to present altitudinal ranges, Early Holocene values do not exhibit differences when compared with modern ones ($F = 1.54$ $p = 0.22 > 0.01$), although camelid specimens from the Mid-Holocene are characterised by higher δ^{13}C values, presenting differences when compared with present ones ($F = 8.52$ $p = 0.006 < 0.01$). These values with a relatively ^{13}C-enriched signal can be linked to an upward advance of shrub steppe vegetation during the Mid-Holocene in relation to modern times. This is consistent with a slight increment in the availability of C_4 plant species, as has been sustained by other paleoenvironmental evidence (see previous discussion).

On the other hand, the δ^{15}N values present strong differences when comparing Early and Mid-Holocene faunal remains [one-way ANOVA $F = 7.86$ $p = 0.009 < 0.01$; Figure 4(B)]. Although the δ^{15}N values corresponding to the Early Holocene exhibit little difference when compared with modern samples ($F = 0.82$ $p = 0.37 > 0.01$), the Mid-Holocene samples are characterised by significantly higher δ^{15}N values ($F = 22.32$ $p = 0.00008 < 0.01$). This aspect is coherent with paleoclimatic data concerning an increment of arid conditions during the

Table 6. Summary statistics for $\delta^{13}C$ and $\delta^{15}N$ values according to chronology and size group (Early Holocene n = 14, Mid-Holocene n = 14; small-size n = 10, large-size n = 17)

		General	Early Holocene	Mid-Holocene	Small camelids	Large camelids
$\delta^{13}C$ (‰)	Mean	−17.6	−18.0	−17.2	−17.3	−17.7
	Minimum	−19.3	−19.3	−19.0	−19.3	−19.2
	Maximum	−12.4	−16.7	−12.4	−15.8	−12.4
$\delta^{15}N$ (‰)	Mean	7.4	6.5	8.4	6.8	7.9
	Minimum	3.7	3.7	6.0	4.9	3.7
	Maximum	10.7	10.5	10.7	10.0	10.7

latter period (see previous discussion). In this sense, several studies performed on arid environments, such as South Africa or Australia, point to a negative correlation between $\delta^{15}N$ values and mean precipitation in soils (Austin & Vitousek, 1998; Amundson *et al.*, 2003), plants (Heaton, 1987; Hartman & Danin, 2010) and herbivore bone collagen (Sealy *et al.*, 1987; Murphy & Bowman, 2006; Pate & Anson, 2008) as well as other animal tissues (Hartman, 2011). Although some have appealed to physiological mechanisms to explain the high $\delta^{15}N$ values for animals in arid areas, suggesting the recycling of nitrogen within the body through the kidneys (Ambrose, 1991), the results of both experimental and field research provide support to reject the physiological hypothesis in favour of those that emphasise changes in the nitrogen balance of the ecosystems (Ambrose, 2000; Murphy & Bowman, 2006; Hartman, 2011). These arguments are based in the presence of a strong negative correlation between soil and plant $\delta^{15}N$ values and precipitation in diverse parts of the globe, related to the relative openness of the nitrogen cycle, as well as the predominant fraction of the soil – organic or inorganic (Austin & Vitousek, 1998; Amundson *et al.*, 2003). Thus, given the identified trend in the $\delta^{15}N$ data from the Hornillos 2 camelid remains and its consistency with patterns identified in other paleoenvironmental proxys, we consider that the higher values registered during the Mid-Holocene can be explained by the

preponderance of inorganic soils over organic ones during this period, which will be reflected in higher values for plants and, consequently, for camelid tissues.

As a result, we can affirm that in a chronological analysis, the camelid diet is not characterised by major changes in the relative proportions of C_3 and C_4 plants between the Early and Mid-Holocene. Nevertheless, as shown by the $\delta^{15}N$ values, a change in the nitrogen cycle may have occurred between these periods, caused by broader environmental changes.

Implications for human–camelid relations through time

The onset of arid conditions is undoubtedly reflected in the Hornillos 2 rockshelter faunal remains through the higher $\delta^{15}N$ values assigned to Mid-Holocene specimens, coinciding with the specialisation process on camelids proposed by Yacobaccio (2003). This process is recurrently evidenced in the faunal remains of archaeological sites in the Andean Highlands as an increase in the Artiodactyla Index in the occupations dated to the Mid-Holocene, such as the Hornillos 2 record. In a regional scale, we can argue in favour of a
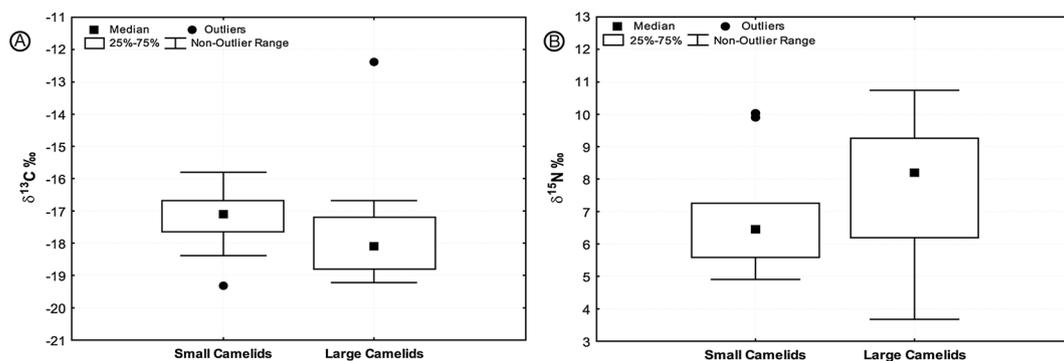
Figure 3. $\delta^{13}N$ (A) and $\delta^{15}N$ (B) values according to size criteria, considering samples assigned to 'small camelids' and 'large camelids' from all layers.
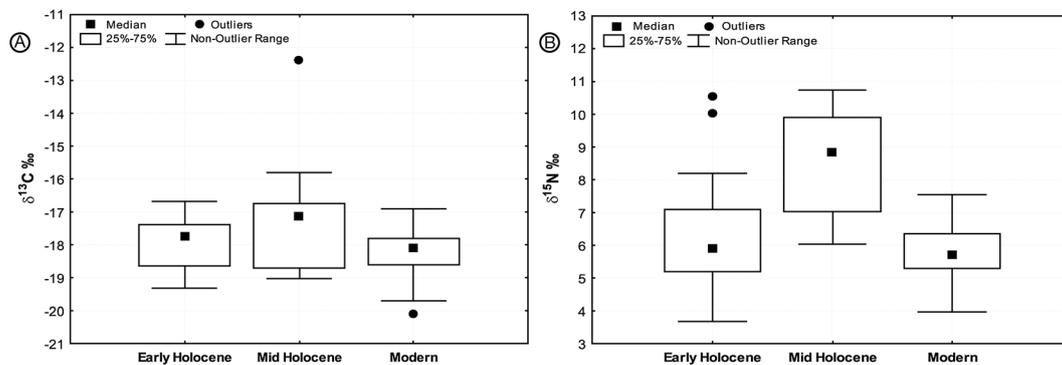
Figure 4. δ^{13}C (A) and δ^{15}N (B) values according to chronological criteria. Modern values are included in both cases as a reference for comparison.

change in the importance of camelids as a food staple for the inhabitants of the Puna, triggered by the fragmentation of its habitat generated by Mid-Holocene aridity. This specialisation process can be linked to, at least, two facts: (i) the increased predictability of camelid groups location due to the scarcity of Nutrients Concentration Zones, implying a reduction in the search costs in comparison with the more homogeneous Early Holocene environment; and (ii) the increase in the costs of acquiring alternative low-rank resources such as big rodents, which were scarce during the Mid-Holocene (Grosjean *et al.*, 2003). Thus, Mid-Holocene climate changes did not necessarily generate local extinction and/or population reduction of wild camelids. Instead, these changes could have caused the grouping of camelids populations in discrete, well-watered areas with higher pasture availability, as could be the case for Hornillos 2 area. At the same time, considering the relation between altitude and δ^{13}C values in camelid tissues previously discussed, we can evaluate the spatial ranges in which these animals would have been feeding for the Early and Mid-Holocene and hypothesise about the provisioning areas used by the Hornillos 2 occupants in connection with environmental change. Taking into consideration the similarity between the camelid δ^{13}C signals from both periods, the home ranges of these human groups do not seem to have involved great variations through time, at least in what concerns the altitude of the *locus* where the preys were obtained. Nevertheless, certain degree of variation could be underestimated because of camelid feeding selectiveness and mobility between vegetal communities, although not affecting this general trend. Thus, independently of the environmental changes that occurred in broad spatial scales (regional-hemispherical), in the local scenario, the ecological conditions that allowed the occupation of Hornillos 2 seem to have continued through the first half of the Holocene. Given the local conditions in the site's vicinity and its occupational continuity, we can consider

it as a privileged *locus* for human habitation in terms of water and resource availability.

At the same time, the intense use of camelid resources recorded during the Mid-Holocene is correlated with an increment in body size of the individuals recovered in sites such as the Hornillos 2 rockshelter. This aspect could be related to an early manifestation of the camelid domestication process, perhaps in the form of a 'protective herding' strategy, comprising the first appearance of domestic forms, similar to modern *llamas*, at least in body size, as posited for other sites of the region during later periods (Yacobaccio, 2003). This strategy involves certain degree of human intervention in camelid feeding behaviour and territorial habits, which we were initially seeking to discuss through stable isotope analysis. So far, the small number of samples assigned to these early forms of 'domesticated camelids' prevents us from drawing definitive conclusions. However, the δ^{13}C and δ^{15}N values measured on large camelids specimens (*llama* size) presented and discussed here do not exhibit great differences with those unequivocally assigned to wild camelids. This aspect suggests two possibilities: (i) the incidence of human selectiveness over camelid diet for these early moments was null; or (i) this incidence cannot be distinguished by δ^{13}C and δ^{15}N measurements alone. Considering the modern values, especially the δ^{13}C standards for *llamas*, *guanacos* and *vicuñas* for the Dry Puna, the latter seems to be the correct option, given that no significant differences can be identified between wild and domesticated species in the area today (Fernández & Panarello, 1999–2001a; Samec, 2011).

Concluding remarks

During the Mid-Holocene, the frequencies of wild camelid remains show a noticeable increase in the assemblages recovered at the scarce archaeological sites recorded in the Puna. This could be indicative of a

regional tendency in resource use strategies employed by hunter-gatherers, further supported by the appearance of large camelids (like *llamas*), pens and other contextual evidences (i.e. rock art) that point towards the implementation of camelid management techniques as an initial step towards their domestication (Yacobaccio, 2003). Keeping these regional patterns in mind, the Hornillos 2 faunal record shows the presence of large camelids that meet *llama* osteometrical criteria. Nevertheless, the stable isotope values obtained from these very large camelids show no significant difference in comparison with the small-size group ones assigned to *vicuña*. This hinders the employment of this line of enquiry as an accurate domestication indicator for the early stages of this process. Conversely, stable isotope values obtained from the faunal remains of Hornillos 2 have proven to be a good paleoenvironmental indicator, particularly in the case of $\delta^{15}N$ (Pate & Anson, 2008). The soil and vegetation nitrogen enrichment inferred from $\delta^{15}N$ values occurred as a result of the onset of general arid conditions during the Mid-Holocene, leading to a progressive habitat fragmentation and a more patched environment during this period in the Dry Puna. To deal with these harsh conditions, human groups must have employed particular strategies, focusing on favoured *loci* for resource extraction, such as the Hornillos 2 site, and predictable resources, such as wild camelids.

At this point, we can highlight the potential of stable isotope composition measurements of animal tissues as a proxy for paleoenvironmental studies, as it conforms a general indicator of mammalian strategies to cope with climatic change (Iacumin *et al.*, 1997; Bocherens, 2011). However, the isotopic data presented and discussed here come from the analysis of the faunal remains of a single locality, the Hornillos 2 rockshelter, in the Dry Puna of Argentina. In order to test the relevance of these trends and patterns at a regional level, other contexts must be included in future analysis.

Acknowledgements

References

Abbott M, Wolfe B, Wolfe A, Seltzer G, Aravena R, Mark B, Polissar P, Rodbell D, Rowe H, Vuille M. 2003. Holocene palaeohydrology and glacial history of the central Andes using multiproxy lake sediments studies. *Palaeogeography, Palaeoclimatology, Palaeoecology* **194**: 123–138.

Aldenderfer MS. 1998. Montane Foragers. Asana and the South-Central Andean Archaic. University of Iowa Press: Iowa City.

Ambrose SH. 1991. Effects of diet, climate and physiology on nitrogen isotope ratios in terrestrial foodwebs. *Journal of Archaeological Science* **18**(3): 293–317.

Ambrose SH. 2000. Controlled diet and climate experiments on nitrogen isotope ratios in rats. In Biochemical Approaches to Paleodietary Analysis, SH Ambrose, MA Katzenberg (eds.). Kluwer Academic/Plenum Publishers: New York; 243–259.

Ambrose SH, DeNiro MJ. 1986. The isotopic ecology of East African mammals. *Oecologia* **69**: 395–406.

Amundson R, Austin AT, Schuur EAG, Yoo K, Matzek V, Kendall C, Uebersax A, Brenner D, Baisden WT. 2003. Global patterns of the isotopic composition of soil and plant nitrogen. *Global Biogeochemical Cycles* **17**(1): 1031.

Arzamendia Y, Vilá B. 2003. Estudios de comportamiento y organización social de vicuñas en la RB Laguna de Pozuelos, Jujuy, Argentina, como línea de base para el manejo sostenible de la especie. In *Actas del III Congreso Mundial sobre Camélidos*. Potosí, Bolivia, 187–191.

Arzamendia Y, Cassini MH, Vilá BL. 2006. Habitat use by *Vicugna vicugna* in Laguna Pozuelos Reserve, Jujuy, Argentina. *Oryx* **40**: 198–203.

Austin AT, Vitousek PM. 1998. Nutrient dynamics on a precipitation gradient in Hawaii. *Oecologia* **113**: 519–529.

Barberena R, Zangrando AF, Gil AF, Martínez GA, Politis GG, Borrero LA, Neme GA. 2009. Guanaco (*Lama guanicoe*) isotopic ecology in southern South America: Spatial and temporal tendencies, and archaeological implications. *Journal of Archaeological Science* **36**: 2666–2675.

Benítez V, Borgnia M, Cassini MH. 2006. Ecología nutricional de la vicuña (*Vicugna vicugna*): Un caso de estudio en la Reserva Laguna Blanca, Catamarca. In Investigación, conservación y manejo de vicuñas, B Vilá (ed.). MACS Project: Buenos Aires, Argentina; 51–67.

Bianchi AR, Yañez CE, Acuña LR. 2005. Bases de datos mensuales de las precipitaciones del Noroeste Argentino. Informe del Proyecto Riesgo Agropecuario. INTA-SAGPYA.

Binford LR. 2001. Constructing Frames of Reference. An Analytical Method for Archaeological Theory Building Using Ethnographic and Environmental Data Sets. University of California Press: California.

Bocherens H. 2011. Late Quaternary mammal ecology: Insight from new approaches. *Quaternary International* **245**(2): 183–185.

Borgnia M, Vilá BL, Cassini MH. 2010. Foraging ecology of Vicuña, *Vicugna vicugna*, in dry Puna of Argentina. *Small Ruminant Research* **88**(1): 44–53.

Bradbury PJ, Grosjean M, Stine S, Sylvestre F. 2001. Full and late glacial lake records along the PEP 1 transect: Their role in developing interhemispheric paleoclimate interactions. In Interhemispheric Climate Linkages. Academic Press: San Diego; 265–291.

Cabrera AL. 1976. Regiones Fitogeográficas Argentinas. Editorial Acme: Buenos Aires.

Cajal JL. 1979. Estructura social y área de acción del guanaco en la Reserva de San Guillermo (San Juan). Subsecretaría de estado de Ciencia y Técnica, 18.

Cajal JL. 1985. Comportamiento. In Estado actual de las investigaciones sobre camélidos en la República Argentina, JL Cajal JN Amaya (eds.). SECYT: Buenos Aires; 87–100.

Cavagnaro JB. 1988. Distribution of C_3 and C_4 grasses at different altitudes in a temperate arid region of Argentina. *Oecologia* 76: 273–277.

Censo. 2010. Manejo de Fauna Silvestre en Argentina. Primer Censo Nacional de Camélidos Silvestres al Norte del Río Colorado. Secretaría de Ambiente y Desarrollo Sustentable de la Nación: Buenos Aires.

Coplen TB, Krouse HR, Böhlke JK. 1992. Reporting of Nitrogen-Isotope Abundances. *Pure and Applied Chemistry* 64: 907–908.

Cormie AB, Schwarcz HP. 1996. Effects of climate on deer bone $\delta^{15}N$ and $\delta^{13}C$: Lack of precipitation effects on $\delta^{15}N$ for animals consuming low amounts of C_4 plants. *Gecohimica et Cosmochimica Acta* 60(21): 4161–4166.

Craig H. 1957. Isotopic standards for carbon and oxygen and correction factors for massspectrometric analysis of carbon dioxide. *Geochimica et Cosmochimica Acta* 12: 133–137.

DeNiro MJ. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317: 806–809.

von den Driesch A. 1976. A guide to the measurement of animal bones from archaeological sites. Harvard University: Cambridge.

Fernández J, Panarello HO. 1999–2001a. Isótopos del carbono en la dieta de herbívoros y carnívoros de los Andes Jujeños. *Xama* 12–14: 71–85. Mendoza.

Fernández J, Panarello HO. 1999–2001b. Los isótopos estables del carbono en pelo de animales silvestres de ambientes altiplánicos de Argentina. *Xama* 12–14: 61–69. Mendoza.

Fernández J, Markgraf V, Panarello HO, Albero M, Angiolini FE, Valencio S, Arriaga M. 1991. Late Pleistocene/Early Holocene Environments and climates, fauna and human occupation in the Argentine Altiplano. *Geoarchaeology* 6(3): 251–272.

Franklin WL. 1982. Biology, ecology and relationship to man of the South American Camelids. In Mammalian Biology in South America, MA Mares, HH Genoways (eds.). Special Pub Nº 6. Pymatuning Lab. of Ecology, University of Pittsburgh: Pittsburgh; 457–489.

Geyh M, Grosjean M, Núñez L, Schotterer U. 1999. Radiocarbon reservoir effect and the timing of the late-glacial/early Holocene humid phase in the Atacama Desert (northern Chile). *Quaternary Research* 52: 143–153.

González BA, Palma RE, Zapata B, Marín JC. 2006. Taxonomic and biogeographical status of guanaco *Lama guanicoe* (Artiodactyla, Camelidae). *Mammal Review* 36: 157–178.

Grosjean M. 2001. Mid-Holocene climate in the south-central Andes: Humid or dry? *Science* 292: 2391.

Grosjean M, Cartagena I, Geyh MA, Núñez L. 2003. From proxy data to paleoclimate interpretation: The mid-Holocene paradox of the Atacama Desert, northern Chile. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194: 247–258.

Hartman G. 2011. Are elevated $\delta^{15}N$ values in herbivores in hot and arid environments caused by diet or animal physiology? *Functional Ecology* 25(1): 122–131.

Hartman G, Danin A. 2010. Isotopic values of plants in relation to water availability in the Eastern Mediterranean region. *Oecologia* 162: 837–852.

Heaton THE. 1987. The $^{15}N/^{14}N$ ratios of plants in South Africa and Namibia: Relationship to climate and coastal/saline environments. *Oecologia* 74: 236–246.

Hoguin R, Catá MP, Solá P, Yacobaccio HD. 2012. The spatial organization in Hornillos 2 rockshelter during the Mid-Holocene (Jujuy Puna, Argentina). *Quaternary International* 256: 45–53.

Iacumin P, Bocherens H, Delgado Huertas A, Mariotti A, Longinelli A. 1997. A stable isotope study of fossil mammal remains from the Paglicci cave, Southern Italy: N and C as palaeoenvironmental indicators. *Earth and Planetary Science Letters* 148: 349–357.

Izeta AD, Laguens AG, Marconetto MB, Scattolin MC. 2009. Camelid handling in the meridional Andes during the first millennium AD: A preliminary approach using stable isotopes. *International Journal of Osteoarchaeology* 19: 204–14.

Kelly R. 1995. The Foraging Spectrum. Smithsonian Institution Press: Washington D.C.

Laker J, Baldo J, Arzamendia Y, Yacobaccio HD. 2006. La vicuña de los Andes. In Investigación, conservación y manejo de vicuñas Proyecto MACS, B Vilá (ed.). Proyecto MACS, Universidad Nacional de Luján: Buenos Aires; 37–50.

Latorre C, Betancourt J, Arroyo M. 2006. Late Quaternary vegetation and climate history of a perennial river canyon in the Río Salado basin (22°S) of Northern Chile. *Quaternary Research* 65: 450–466.

Latorre C, Betancourt JL, Rylander KA, Quade J, Matthei O. 2003. A vegetation history from the arid prepuna of northern Chile (22–23°S) over the last 13,500 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194: 223–246.

Llano C. 2009. Photosynthetic pathways, spatial distribution, isotopic ecology, and implications for pre-Hispanic human diets in central-western Argentina. *International Journal of Osteoarchaeology* 19: 130–143.

Markgraf V. 1985. Paleoenvironmental history of the last 10,000 years in northwestern Argentina. *Zentralblatt für Geologie und Paläontologie* 11/12: 1739–1749.

Mengoni Goñalons GL. 2007. Camelid management during Inca times in N. W. Argentina: Models and archaeozoological indicators. *Anthropozoologica* 42(2): 129–141. Paris, Publications Scientifiques du Muséum Nacional d'Histoire Naturelle.

Morales MR. 2011. Arqueología ambiental del Holoceno Temprano y Medio en la Puna Seca argentina. Modelos paleoambientales multi-escalas y sus implicancias para la Arqueología de Cazadores-Recolectores. British Archaeological Reports (BAR), South American Archaeology Series 15. Archaeopress, Oxford.

Murphy BP, Bowman D. 2006. Kangaroo metabolism does not cause the relationship between bone collagen $\delta^{15}N$ and water availability. *Functional Ecology* **20**: 1062–1069.

Pate FD, Anson TJ. 2008. Stable nitrogen isotope values in arid-land kangaroos correlated with mean annual rainfall: potential as a palaeoclimatic indicator. *International Journal of Osteoarchaeology* **18**(3): 317–326.

Ramírez E, Hoffmann G, Taupin JD, Francou B, Ribstein P, Caillon N, Ferron FA, Landais A, Petit JR, Pouyaud B, Schotterer U, Simoes JC, Stievenard M. 2003. A new Andean deep ice core from Nevado Illimani (6350 m), Bolivia. *Earth and Planetary Science Letters* **212**: 337–350.

Riedinger MA, Steinitz-Kannan M, Last WM, Brenner M. 2002. A 6100 ^{14}C yr record of El Niño activity from the Galápagos Islands. *Journal of Paleolimnology* **27**: 1–7.

Ruthsatz B, Movia C. 1975. Relevamiento de las estepas andinas del noreste de la provincia de Jujuy, República Argentina. Fundación para la Educación, la Ciencia y la Cultura: Buenos Aires.

Samec CT. 2011. Perspectiva isotópica sobre la alimentación de camélidos domésticos y silvestres de la Puna Jujeña: Construyendo un marco de referencia para estudios arqueológicos. Grade thesis. Universidad de Buenos Aires. MS.

Samec CT. 2012. Primeros pasos hacia una ecología isotópica de la Puna Seca (Jujuy, Argentina): variaciones en los valores isotópicos de la vegetación y los camélidos sudamericanos. Oral dissertation at the 54 International Congress of Americanists, Vienna, Austria.

Schutkowski H. 2006. Human Ecology. Biocultural Adaptations in Human Communities. Springer: Berlin-Heidelberg-New York.

Sealy JC, Van Der Merwe NJ, Lee Thorp JA, Lanham J. 1987. Nitrogen isotope ecology in southern Africa: Implications for environmental and dietary tracing. *Geochimica et Cosmochimica Acta* **51**: 2707–2717.

Swap RJ, Aranibar JN, Dowty PR, Gilhooly WP, Macko SA. 2004. Natural abundance of ^{13}C and ^{15}N in C_3 and C_4 vegetation of southern Africa: Patterns and implications. *Global Change Biology* **10**: 350–358.

Tchilinguirian P, Morales MR. in press. Mid-Holocene Paleoenvironments in Northwestern Argentina: Main patterns and discrepancies. *Quaternary International*. DOI: http://dx.doi.org/10.1016/j.quaint.2012.12.028

Tessone A, Belardi JB. 2010. Evaluación del $\delta^{13}C$ y $\delta^{15}N$ en el colágeno de herbívoros de las cuencas de los lagos Tar y San Martín (provincia de Santa Cruz, Patagonia). In Zooarqueología a Principios del Siglo XXI. Aportes Teóricos, Metodológicos y Casos de Estudio, MA Gutiérrez, M De Nigris, PM Fernández, M Giardona, A Gil, A Izeta, G Neme, H Yacobaccio (eds.). Editorial Espinillo: Buenos Aires.

Thompson L, Davis M, Mosley-Thompson E, Sowers TA, Henderson K, Zagorodnov VS, Lin PN, Mikhalenko VN, Campen RK, Bolzan JF, Cole-Dai J, Frncou B. 1998. A 25,000-year tropical climate history from Bolivian ice cores. *Science* **282**: 1858–1864.

Thompson L, Mosley-Thompson E, Davis M, Lin PN, Henderson K, Cole-Dai J, Liu K. 1995. Late glacial stage and Holocene tropical ice core records from Huscarán, Peru. *Science* **269**: 46–50.

Thompson L, Mosley-Thompson E, Henderson K. 2000. Ice-core palaeoclimate records in tropical South America since the Last Glacial Maximum. *Journal of Quaternary Science* **15**(4): 377–394.

Tieszen L. 1994. Stable isotopes on the plains: Vegetation analyses and diet determinations. In Skeletal Biology in the Great Plains: Migration, Warfare, Health and Subsistence, DS Owsley, RL Jantz (eds.). Smithsonian Press: Washington DC.

Tieszen L, Hein D, Qvortrup D, Troughton J, Imbamba S. 1979. Use of $\delta^{13}C$ values to determine vegetation selectivity in East African herbivores. *Oecologia* **37**: 351–359.

Veit H. 1996. Southern Westerlies during the Holocene deduced from geomorphological and pedologlacial studies in the Norte Chico, Northern Chile (27-33° S). *Palaeogeography, Palaeoclimatology, Palaeoecology* **123**: 107–119.

Vilá BL. 1991. Vicuñas (*Vicugna vicugna*) agonistic behavior during the reproductive season. *Ongulés/Ungulates* **91**: 475–482. Proceedings of the International Symposium. SFEPM & IRGM. Toulouse.

Vilá BL. 2000. Comportamiento y Organización Social de la Vicuña. In Manejo Sustentable de la Vicuña y el Guanaco. B González, F Bas, C Tala, Santiago IA (eds.). Servicio Agrícola y Ganadero: Pontificia Universidad Católica de Chile, Fundación para la Innovación Agraria; 175–191.

Villagrán C. 1993. Una interpretación climática del registro palinológico del último glacial-postglacial en Sudamérica. *Bulletin de l'Institute Francaise des Etudes Andines* **22**(1): 243–258.

Vuille M, Keimig F. 2004. Interannual variability of summer-time convective cloudiness and precipitation in the central Andes derived from ISCCP-B3 data. *Journal of Climate* **17**: 3334–3348.

Yacobaccio HD. 1994. Biomasa Animal y Consumo en el Pleistoceno-Holoceno Surandino. *Arqueología* **4**: 43–71.

Yacobaccio HD. 2003. Procesos de intensificación y de domesticación de camélidos en los Andes Centro-Sur. *Memorias del Tercer Congreso Mundial sobre Camélidos* **1**: 211–216. Potosí, Bolivia.

Yacobaccio HD. 2004. Social dimensions of camelid domestication in the Southern Andes. *Anthopozoologica* **39** (1): 237–247. Paris, Publications Scientifiques du Muséum National d'Histoire Naturelle.

Yacobaccio H, Morales M. 2005. Mid-Holocene environment and human occupation of the Puna (Susques, Argentina). *Quaternary International* **132**: 5–14.

Yacobaccio HD, Catá MP, Solá P, Alonso S. 2008. Estudio Arqueológico y Físico-Químico de Pinturas Rupestres en Hornillos 2 (Puna jujeña, Argentina). *Estudios Atacameños* **36**: 5–28.

Yacobaccio HD, Morales MR, Samec CT. 2009. Towards an isotopic ecology of herbivory in the Puna ecosystem: New results and patterns in Lama glama. *International Journal of Osteoarchaeology* **19**: 144–155.

Yacobaccio HD, Morales MR, Solá P, Samec CT, Hoguin R, Oxman BI. in press. Mid-Holocene occupation of the Dry Puna in NW Argentina: Evidence from the Hornillos 2 rockshelter. *Quaternary International*. DOI: http://dx.doi.org/10.1016/j.quaint.2012.09.028

Yacobaccio HD, Samec CT, Catá MP. 2010. Isótopos estables y zooarqueología de camélidos en contextos pastoriles de la puna (Jujuy, Argentina). In Zooarqueologia a principios del siglo XXI. Aportes teóricos, metodológicos y casos de estudio, MA Gutiérrez, M De Nigris, PM Fernández, M Giardona, A Gil, A Izeta, G Neme, H Yacobaccio (eds.). Editorial del Espinillo: Buenos Aires; 77–86.

Zhou J, Lau KM. 1998. Does a monsoon climate exist over South America? *Journal of Climate* **11**: 1020–1040.