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SPECIAL ISSUE PAPER

δ^{13}C and δ^{15}N Variability in Modern Guanaco (*Lama guanicoe*) Assemblages in Southern Patagonia: Implications for Zooarchaeological Studies

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ABSTRACT We study the isotopic variability of modern social groups of guanacos (*Lama guanicoe*) and discuss the implications of these results for the analysis of archaeofaunas from archaeological sites of Patagonia. The aim of this work is to evaluate whether the study of the isotope composition of carbon and nitrogen from collagen (δ^{13}C and δ^{15}N) is a methodology that allows the discussion of hunting strategies – individual versus mass – carried out by human populations in this particular case of the guanaco from southern Patagonia. Samples come from five modern assemblages of guanacos located in the west margin of the Cardiel Lake and are the result of a catastrophic mortality episode produced by winter stress. The isotopic variability of these samples is compared with that of a mesoregional attritional assemblage built from multiple sites and chronologies. The results indicate, in the first place, that there is no differentiation between males and females, second, that the offspring show no increase of signals when compared to the other age categories and finally, juveniles recorded the lowest δ^{15}N values. In relation to the main purpose of this research, measurements of variability from modern assemblages and the attritional groups have been compared. The three assemblages with lower variability are modern ones. However, the two remaining modern assemblages record a variability higher than or equal to the attritional groups. Thus, for southern Patagonian guanacos, the hypothesis that proposes that the isotopic variability of a herd would be lower than the one obtained from multiple populations and different hunting events is rejected. Finally, we analyze the possible causes for these results together with situations in which δ^{13}C and δ^{15}N can be used in the study of the guanaco hunting strategies in southern Patagonia. Copyright © 2013 John Wiley & Sons, Ltd.

Supporting information may be found in the online version of this article.

Key words: carbon; collagen; guanaco; Holocene; hunter–gatherer; nitrogen; Patagonia; Zooarchaeology

Introduction

Stable isotope studies in archaeology have diversified, transcending the paleodietary analysis of human remains and incorporating, among other issues, those specifically related to the zooarchaeological record (Burton *et al.*, 2001; Balasse & Tresset, 2002; Hughes, 2004; Ugan & Coltrain, 2011; Szpak *et al.*, 2012). Different hunting strategies used by human populations have been studied in order to differentiate between individual hunt and mass kill using stable isotopes analysis (Hoppe, 2004; Widga, 2004; Fenner, 2008, 2009). These studies are based on the single assumption that the isotopic variability of an archaeofaunal assemblage from multiple populations and different hunting events should be greater than that resulting from an equal number of individuals coming from a single population in one hunting event (Hoppe, 2004:131; Fenner, 2008:704). This assumption of lower variability is founded on the idea that individuals from the same population of a gregarious species share a common

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history of habits and foraging. So far, three species have been studied: mammoths (*Mammuthus* sp.) (Hoppe, 2004), bison (*Bison bison*) (Widga, 2004) and pronghorn antelope (*Antilocapra americana*) (Fenner, 2008, 2009).

In this paper, we evaluate this hypothesis based on the degree of variability of the $\delta^{13}C$ and $\delta^{15}N$ values of five modern bone assemblages of guanacos (*Lama guanicoe*) from the Central West of Santa Cruz, Patagonia, Argentina (Rindel & Belardi, 2006; Belardi & Rindel, 2008) (Figure 1). We study the isotopic variability of modern social groups of guanacos, and we also discuss the implications of these results on the archaeofaunal analysis from southern Patagonia archaeological sites. The characteristics of the sample described above are suitable to assess the range of isotopic variability of a local population because it is the product of a catastrophic mortality episode.

The verification of this hypothesis requires an attritional group that represents the isotopic variability of a bone assemblage from multiple populations and different hunting events. To form this group, $\delta^{13}C$ and $\delta^{15}N$ signals of modern guanaco isolated carcasses and archaeofaunas from different sites and chronologies from the center west of Santa Cruz are used (Tessone, 2010; Tessone & Belardi, 2010). Therefore, we will evaluate if the $\delta^{13}C$ and $\delta^{15}N$ in the collagen fraction constitutes a valid methodology to discuss hunting strategies – individual hunt versus mass kill – by human populations in the past for the specific case of the southern Patagonia guanaco. In

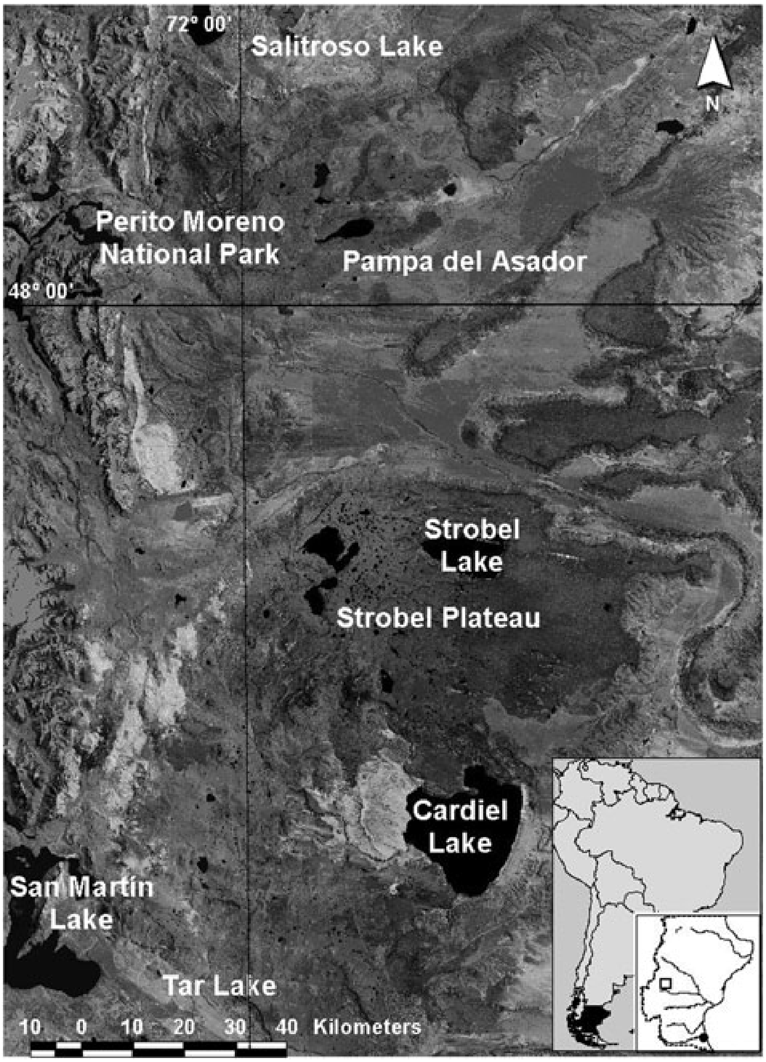

Figure 1. Central west of Santa Cruz province with the main sectors referred in this paper. Also include Cardiel lake, where were recorded the modern guanacos assemblages.

the same way, a second aim is to evaluate the $\delta^{13}C$ and $\delta^{15}N$ variability associated with sex and age of the individuals.

This research is relevant because, in Patagonia, the guanaco is the most widely consumed prey of the terrestrial environment by the hunter–gatherer populations since the early occupations in the late Pleistocene and throughout the Holocene (Borrero, 1990; Mengoni Goñalons, 1995; Miotti & Salemme, 2005). Besides, archaeological detection of mass kills or multiple predation events has important implications for the organizational systems of human populations and the way in which they have interacted with their prey. It has been pointed out (Binford, 1978, 1981) that hunting strategies have a strong impact, not only in the zooarchaeological assemblage – such as the frequency of skeletal parts, processing evidence and the sex and age composition of preys (Speth, 1983; Frison, 2004) – but also in other aspects of human organizational systems, such as the importance of logistics over the residential component (*sensu* Binford, 1980) and the use of storage techniques. Finally, another remarkable aspect is the detection of mass or catastrophic mortality episodes in the fossil record. The isotopic data in conjunction with other lines of evidence, such as spatial association criteria and geological evidence, could be used to recognize such events in the fossil record (Fricke, 2007; Trueman, 2007).

Summing up, we discuss the relevance of this research in the context of Patagonian archaeology. When presenting the materials, emphasis will be placed upon the formation of the assemblages that are compared for; on the one hand, there are the modern assemblages, which are a product of a catastrophic mortality event, and on the other hand, we have the attritional group, with samples from different sites and temporal contexts of the same region. In the discussion, the isotopic variability in modern assemblages associated with sex and age of individuals is evaluated. Finally, concerning the main aim of this study, the measurements of variability derived from modern assemblages are compared with those of the attritional group. Therefore, we assess the usefulness of $\delta^{13}C$ and $\delta^{15}N$ variability to discuss hunting strategies in the zooarchaeological record of Patagonia.

Mass kills in hunter–gatherer societies of Patagonia

This study uses the concept of mass kills or multiple predation, which is determined by the number of prey hunted in a single event (*sensu* Borrero, 1990; Mengoni Goñalons, 1995). It must be pointed out that, first, this concept is dependent on the ethology and composition of the social structures of the studied species; and, second, it is independent of the number of hunters involved in hunting, which is relevant to define the concept of communal or cooperative hunting (*sensu* Driver, 1990), although both of them are clearly related (Brink & Rollans, 1990; Frison *et al.*, 1990; Gordon, 1990; Brink, 2008; Santiago & Salemme, 2009).

In Patagonia, there is a huge ethnohistoric record that shows that there were mass and communal kills of animals. Numerous records from expeditionaries clearly describe the encirclement strategies, especially of guanaco and choique (lesser rhea, *Pterocnemia pennata*), which were then carried to residing campments (Guinnard, 1961; Moreno, 1969; Claraz, 1988; Bourne, 1998; Lista, 1998; Musters, 1998). However, such descriptions correspond to the time of adoption of the horse by the hunter–gatherer, when changes in the hunting strategies together with an increase of logistical mobility were expected (Goñi, 1988, 2000; Borrero, 1990).

Within the context of Patagonian archaeology, mass kills and communal hunting of guanaco have been previously discussed (Borrero, 1990; Mengoni Goñalons, 1995; Miotti *et al.*, 1999; Prieto *et al.*, 2007; Santiago & Salemme, 2009). For prehistoric hunter–gatherer groups, the relevance of these hunting strategies has been minimized based on behavioural aspects of this species (Borrero, 1990) and on specific features of known zooarchaeological assemblages (Borrero, 1990; Mengoni Goñalons, 1995).

Regarding the behavioural aspects, this proposal is based on the small size of guanaco family groups and the lack of predictability on spatial use by major social units, such as groups of males. Thus, it would be unlikely to find large numbers of guanacos together in the same place. This fact would raise search costs up to a point where mass kills would not be efficient. However, under certain conditions, groups of guanacos could meet at one place. Oporto (1983) has described situations in which small ponds are shared by different social groups of guanacos. The existence of these common spaces where territoriality is relaxed allows for the coexistence of large numbers of guanacos (an average of 57 animals per km^2) and makes their spatial behaviour more predictable during short periods of time throughout the year. In these cases, both water and good quality pastures draw the animals together. Moreover, these areas are mostly chosen to copulate, and it is there, too, where young animals learn these intra-specific behaviours (Oporto, 1983; Bank *et al.*, 2003), therefore stressing the importance of these wetlands in guanaco preservation (Bank *et al.*, 2003).

As regards specific features of known zooarchaeological assemblages, it has been suggested that the chance to obtain numerous preys in each kill event is low, especially when considering the small numbers of individuals represented in most archaeological assemblages in Patagonia. This would show that few animals were hunted in each event and would suggest an accretional process of bone assemblage formation. This seems to be the characteristic pattern found in archaeological sites in caves and rock shelters in the study area. However, in Patagonia, these places have usually been used for specific purposes (Goñi, 1995; Cassiodoro *et al.*, 2000; Rindel, 2003; among others) or as residing campsites (Mengoni Goñalons & Silveira, 1976; Silveira, 1979; De Nigris, 2004; among others). This means that, within the stage continuum that characterize the processing of animal preys, only the last stages have been systematically sampled, that is, those involving secondary processing and final consumption. As a result, our knowledge of the Patagonian faunistic record is skewed because, as Borrero *et al.* (1985) point out, almost no killing sites or initial processing sites have been identified.

In this respect, in the central west of the province of Santa Cruz in particular, during the late Holocene, a logistical use of the plateaus has been proposed, being occupied only in summer (Goñi, 2000; Belardi & Goñi, 2006). Archaeological researches in Strobel, Pampa del Asador, San Adolfo and Cardiel Chico plateaus showed that the sites were equipped with semicircular stone structures that were used as hunting blinds associated with a high frequency of lithic projectile points (Rindel *et al.*, 2007; Espinosa *et al.*, 2009; Goñi *et al.*, 2010; Belardi *et al.*, 2013). Furthermore, the spatial configuration of many of these clusters of hunting blinds suggests their use in a coordinated manner by several hunters. Moreover, a hypothesis proposes that open-air spaces associated to bodies of water (lakes and ponds) like Cerro Pampa 2 Ojo de Agua in Pampa del Asador plateau and Istmo Lago Belgrano in Perito Moreno National Park were used as guanaco mass kill sites and initial processing sites (Rindel, 2009). The evidences in favour of this hypothesis are the numerous individuals represented, the different etary ranges and the frequency of skeletal parts, all of them showing a low degree of anatomical completion due to transportation to other areas in order to be consumed.

These hunting strategies have also been considered in other contexts of Isla Grande de Tierra del Fuego and the Patagonian mainland. In the latter, contexts of collective hunting have been postulated for the Pleistocene–Holocene transition, considering landscape features and zooarchaeological assemblages, with similar characteristics to those described by the explorer Claraz in his journey through Patagonia in the 19th century (Miotti *et al.*, 1999, 2004). Meanwhile, in Tierra del Fuego and based on several criteria of the zooarchaeological assemblages – demographic profiles, cultural marks, carcasses integrity, radiocarbon dating and geoarchaeological evidence –, mass kills events have been proposed in Las Vueltas 1 (Santiago, 2009; Santiago & Salemme, 2009) and Myren 2 (Prieto *et al.*, 2007). Finally, other archaeological indicators of the existence of such a strategy of predation come from rock art representations from sites like Cueva de las Manos (Aschero, 2012).

Thereby, this paper aims to establish if for the specific case of the guanaco in Patagonia, the analysis of stable isotopes is a suitable method for the discussion of hunting strategies, together with the other osteological indicators as it has been used in other species and contexts (Hoppe, 2004; Widga, 2004; Fenner, 2008, 2009).

The guanaco (*Lama guanicoe*)

The guanaco is a wild ungulate with the largest spatial distribution in South America, ranging from Peru to Tierra del Fuego, at the southern end of America. It is a generalist herbivore, mainly grazer but also browser under certain circumstances. It lives in a variety of habitats with marked differences in vegetation, climate and topography (Gonzáles *et al.*, 2006).

It is a gregarious species (Figure 2). Three basic social structures can be distinguished. First, the family groups that consist of a dominant male (neigh), females and offspring from 10 to 15 months old. These groups are formed by 5 to 13 individuals, with an average of 8.2 individuals (Puig & Videla, 1995). Second, the male groups composed of 7 to 20 individuals, with an average of 10 individuals of various ages (Puig & Videla, 1995). Third, although strictly not a social structure, it has been described solitary individuals-physically mature. Finally, family groups without males and mixed groups are described in some populations. In the case of family groups without males, they could be juvenile or adult females with or without offspring, who left their territory, possibly due to the chasing off of juveniles by the neigh. All the authors that have identified these groups pointed out their transitional nature (Franklin, 1982; Ortega, 1985; Merino, 1988; Merino & Cajal, 1993). Mixed groups consist of aggregations of several types of social groups that are

Figure 2. Group of guanaco males watering in a pond near the site CP2 OA in Pampa del Asador.

formed in the late fall and which migrate to winter areas; spreading out during the reproductive season (Puig, 1986; Ortega & Franklin, 1995; Puig & Videla, 1995). Mixed groups are highly variable in size reaching up to 150 individuals (Franklin, 1982), although available estimates show lower mean values (Puig & Videla, 1995). Thus, many authors have pointed out these seasonal variations in the composition, size and proportion of the guanaco population (see review in Puig & Videla, 1995).

Materials

Modern guanaco bone assemblages

Samples were obtained from five assemblages of guanaco bones located near the western shore of Cardiel Lake in the central west of the province of Santa Cruz, Patagonia, Argentina (Figure 1). These assemblages are the result of a catastrophic mortality episode of winter stress that took place in the year 2000. They have been previously studied, first, to discuss taphonomic aspects in relation to natural deposition in rockshelters and the potential mixing with zooarchaeological remains; and, second, related to the potential scavenging niche that it is offered to the hunter–gatherer populations (Rindel & Belardi, 2006; Belardi & Rindel, 2008). Arturo Olivero, an employee at 'La Carlina' farm, knew about those guanaco assemblages and pointed out that they were formed during the intense snowfalls in July 2000. All assemblages were formed at the same time in a span of less than one week. A total of 70 individuals from the following assemblages were sampled: Alero Los Guanacos 1 (ALG1), Alero Los Guanacos 3 (ALG3), Alero Los Guanacos 4 (ALG4), Olivero (OLI) and La Encajada (LE) (Table 1).

During the 2009 and 2010 field works, skulls from each of the assemblages were collected and are now at the INAPL. The samples which were used for this work were taken from those skulls so as to ensure that all age categories and sexes were present in each assemblage. In all the instances, the fraction sampled is above 0.35, and in two groups it exceeds the 0.70 (Table 1). These assemblages were recovered from two different locations, rockshelters (ALG1, ALG3 and ALG4) and open air spaces (OLI and LE) (Figure 3).

The ages of individuals were estimated considering the tooth eruption and wear pattern developed by Raedeke (1978) for guanaco populations of Tierra del Fuego. The author established five subadult age classes, from birth to two and a half years old, and one adult class, between the latter and 14 and a half years old. For the purposes of this article, such detailed age classification was not necessary; accordingly, three general age classes have been considered: young (<1 year),

Table 1. Main characteristics of the analyzed modern guanaco assemblages

Assemblages	Location	Area (m^2)	Frequency of individuals	Individuals sampled	Fraction sampled
Alero Los Guanacos 1	rockshelter	300	36	13	0.36
Alero Los Guanacos 3	rockshelter	360	29	11	0.37
Alero Los Guanacos 4	rockshelter	56	15	6	0.40
Olivero	open air site	3514.5	33	29	0.87
La Encajada	open air site	994.5	15	11	0.73
Total	-	-	128	70	-

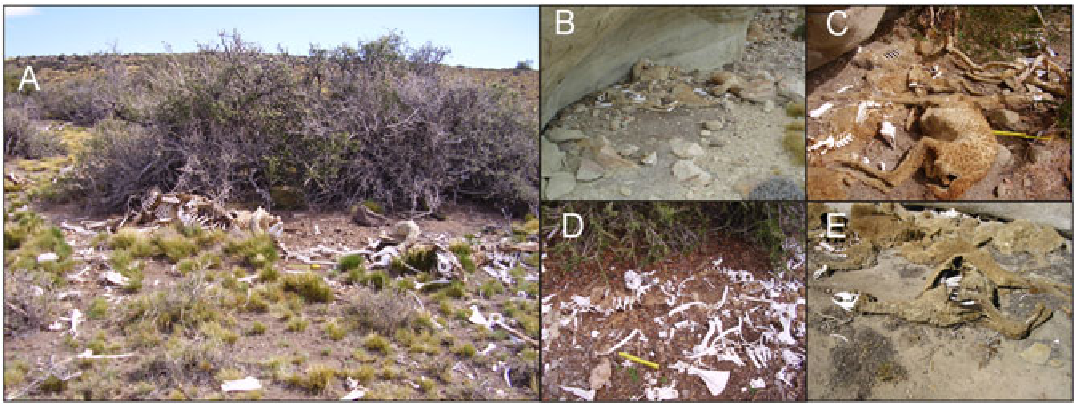

Figure 3. Locations where assemblages were collected: a) OLI, b) ALG1, c) ALG3, d) LE and e) ALG4. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

juvenile (1 to 2 years) and adult (>2 years). An age between 7 and 8 months was recorded for the young individuals, which indicates a death time between June and July, 2000.

The methodology proposed by De Lamo (1983) was used for sex determination. The author developed a canine index to be used on individuals over 3 years, similar to that proposed by Raedeke (1978). Height and width of the permanent maxillary canine were taken. The index was defined according to the following equation: $Ic = (h-H)/a$. Where: Ic = canine index, h = canine height, H = average height of the sample and a = width of the canine (De Lamo, 1983). This index allows the discrimination of males and females according to the sign (negative numbers correspond to females while positive to males), and when it is applied to the upper canines, it is effective in 100% of cases (De Lamo, 1983). As shown in Tables 3-7, both sexes were recorded in all the assemblages, and the presence of more than one male in each group (except LE) indicates that sampling was carried out on mixed groups (Belardi & Rindel, 2008).

Attritional group

This group was formed with modern isolated carcasses and samples recovered from archaeological sites with chronologies ranging from the Pleistocene/Holocene transition to the Late Holocene. It is used as a measure of temporal and spatial variability of guanaco in order to be compared with modern catastrophic assemblages. They were grouped into six areas corresponding to a meso-scale (*sensu* Dincauze, 2000) (Figure 1).

Unlike modern catastrophic assemblage samples, there is no data about sex or age for these samples due to representation and fragmentation conditions of the samples. To summarize, this information Table 2 was drawn, in which three considerations are highlighted. The first refers to the sample size, which varies between 6 and 29 individuals, similar to the number of the modern catastrophic assemblage samples (see Table 1). The second consideration is the number of sites from where these samples were extracted, which varies from 1 to 9. In this regard, it is important to note that stratigraphic and anatomical criteria were followed to avoid reanalysis of the same individual

Table 2. Characteristics of the sample of the attritional group, according to mesoscale

Attritional group	N modern samples	N archaeological samples	N total	Number of archaeological sites	Temporal scale (years BP)
Cardiel Lake (CL)	4	6	10	5	Modern- 6387
Pampa del Asador Plateau (PAP)	2	7	9	6	Modern- 2010
Perito Moreno National Park (PMNP)	7	7	14	3	Modern- 11000
Salitroso Lake (SL)	1	5	6	5	Modern- 1600
Strobel Plateau (SP)	5	1	6	1	Modern- 3200
Tar and San Martín Lake (TSML)	6	23	29	9	Modern- 9760
Total	25	49	74	29	Modern- 11000

when more than one specimen per site was sampled. In turn, modern individuals were collected from available carcasses in these spaces, with great care to avoid repetition of the analysis of an individual based on the distance between the sampling points (Tessone, 2010).

Finally, the temporal scale ranges from 11000 BP to modern-day samples. Modern samples were collected from all regions and vary between 1 and 6 individuals (Table 2). The maximum age was established from two different situations. In the Cardiel, Tar and San Martin Lakes, the Perito Moreno National Park and Pampa del Asador Plateau, the age considered was determined by direct radiocarbon dating that was carried out on the samples. In the Strobel plateau and the Salitroso Lake, where there was no radiocarbon dating of samples, the maximum age was determined based on the long count (*sensu* Borrero *et al*., 1992), i.e. the most ancient chronological data from archaeological materials available for the region. Therefore, the formation of this attritional group guaranteed that the analyzed individuals came from different populations and different hunting events, and therefore it fulfills the required principle for being compared with modern assemblages.

Methods

For collagen extraction, the bone fragments were cleaned with abrasive elements and ultrasonic baths. Approximately, 1 g of bone was introduced in 0.1 M NaOH for 24 h and then demineralized in 2% HCl for 72 h, renewing the acid every 24 h. Finally, the fragment was placed for another 24 h in 0.1 M NaOH. The samples were subjected to lipid extraction for 24 h in a 2:1:0.8 chloroform, methanol and de-ionized water solution. The resulting material was dried in an oven at 40 °C (Tykot, 2004). Measurement of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ relations in the collagen fraction was performed with a Carlo Erba EA1108 Elemental Analyzer, which is connected to a Thermo Scientific Delta V Advantage continuous flow mass spectrometer through a Thermo Scientific ConFlo IV interfase. Stable isotope results are expressed as the ratio of the heavier isotope to the lighter isotope ($^{13}C/^{12}C$ or $^{15}N/^{14}N$) and reported as δ values in parts 'per mil' (‰) relative to internationally defined standards for carbon (Vienna Pee Dee Belemnite) and nitrogen (ambient inhalable reservoir) (Schwarcz & Schoeninger, 1991). Finally, to allow comparison between modern and archaeological samples, the former were corrected by adding 1.5‰ for Suess effect (Marino & Mc Elroy, 1991). We did not introduce corrections accounting for changes in atmospheric CO_2 $\delta^{13}C$ during the Pleistocene/Holocene transition, since they affect only a few samples (N = 3) and in a minor proportion lying within the analytical uncertainty (Schmitt *et al*., 2012).

In statistical terms, the strategy proposed by Fenner (2008, 2009) was used to compare the modern catastrophic assemblages with the attritional group. First, outliers were removed from each of the assemblages and groups, considering a coefficient of 1.5 times more than the interquartile range. The standard deviation was used as a measure of variability, and values were scaled based on the adaptation of Equations (1) to (3) proposed by this author (Fenner, 2008:708) as follows:

$$\delta^{13}\mathrm{C}_{\mathrm{s}} = \left(\delta^{13}\mathrm{C}_{\mathrm{m}}\text{–}\mathrm{C}_{\mathrm{g}}\right)\mathrm{R}_{\mathrm{n}}/\mathrm{R}_{\mathrm{e}} \tag{1}$$

$$\delta^{15}\mathrm{N}_{\mathrm{s}} = \delta^{15}\mathrm{N}_{\mathrm{m}}\text{–}\mathrm{N}_{\mathrm{g}} \tag{2}$$

where 's' subscript identifies the resulting value scale, 'm' subscript identifies the raw value measured of each element, 'Eg' (where E stands for element, in this case C or N) represents the average value of the isotope ratio of this element for the group, either a modern assemblage or an attritional group, 'Rn' is the range of the element with greater variability of the sample and 'Re' is the range of the element in question, considering all the samples. Equation (4) from Fenner (2008:708) was also adapted for the calculation of the two dimensional Euclidean distances:

$$\mathrm{D}_{\mathrm{i}} = \left(\left[\delta^{13}\mathrm{C}_{\mathrm{s}}(\mathrm{i})^{2}+\delta^{15}\mathrm{N}_{\mathrm{s}}(\mathrm{i})\right]^{2}\right)^{0.5} \tag{3}$$

where 'Di' is the two-dimensional Euclidean distance of individual i. The purpose of these equations is to obtain a measure of variability for each group which facilitates the comparison between them (Fenner, 2008, 2009).

Results and discussion

An initial aspect to highlight is that modern guanaco assemblages present a C/N ratio that allows to state that the obtained isotopic signals are primary (2.9–3.6; De Niro, 1985; van Klinken, 1999; Tables 3–7). The results of the modern assemblages are also presented in Tables 3 to 7, with the mean and standard deviation of each modern guanaco assemblage.

The $\delta^{13}C$ means varied between −19.6‰ and −19.0‰, with standard deviations <0.4‰, which implies a reduced variability (Tables 3–7, Figure 4).

Table 3. δ^{13}C and δ^{15}N of Alero Los Guanacos 1 modern guanaco assemblage

Assemblage	Individual	Lab. code	Height (mm)	Width (mm)	Canine index	Sex	Age	δ^{13}C‰	δ^{15}N‰	C/N
Alero Los Guanacos 1	1	AIE 24300	10	7	−0.01	H	Adult	−19.7	7.7	3.3
	2	AIE 24301	11	11	0.08	M	Adult	−18.7	6.9	3.3
	4	AIE 24303	11	9	0.09	M	Adult	−19.6	7.4	3.3
	5	AIE 24304	9	5.5	−0.2	H	Adult	−18.7	7.5	3.3
	8	AIE 24307	-	-	-	-	Adult	−19.3	7.2	3.2
	9	AIE 24308	3	5	−3.6	H	Adult	−19.4	7.9	3.3
	10	AIE 24309	-	-	-	-	Adult	−19.3	5.7	3.2
	11	AIE 24310	-	-	-	-	Adult	−19.1	6.8	3.3
	3	AIE 24302	-	-	-	-	Young	−20.1	6.3	3.3
	14	AIE 24312	-	-	-	-	Young	−19.1	6.9	3.3
	6	AIE 24305	-	-	-	-	Juvenile	−18.9	5.4	3.3
	7	AIE 24306	-	-	-	-	Juvenile	−20.0	6.7	3.2
	12	AIE 24311	-	-	-	-	Juvenile	−19.1	6.4	3.3
Mean								−19.3	6.8	3.2
Standard deviation								0.4	0.7	0.04

Table 4. δ^{13}C and δ^{15}N of Alero Los Guanacos 3 modern guanaco assemblage

Assemblage	Individual	Lab. code	Height (mm)	Width (mm)	Canine Index	Sex	Age	δ^{13}C‰	δ^{15}N‰	C/N
Alero Los Guanacos 3	11	AIE 24317	13.5	10	0.33	M	Adult	−19.5	7.0	3.2
	14	AIE 24318	12.5	10.5	0.22	M	Adult	−19.8	6.1	3.2
	24	AIE 24320	11.5	8	0.17	M	Adult	−20.2	6.2	3.2
	25	AIE 24321	10	8	−0.01	H	Adult	−19.7	6.1	3.2
	29	AIE 24323	-	-	-	-	Adult	−19.5	8.5	3.3
	3	AIE 24314	-	-	-	-	Young	−19.7	6.3	3.2
	4	AIE 24315	-	-	-	-	Young	−19.4	7.3	3.4
	5	AIE 24316	-	-	-	-	Young	−19.5	7.3	3.2
	1	AIE 24313	-	-	-	-	Juvenile	−19.6	5.8	3.3
	17	AIE 24319	-	-	-	-	Juvenile	−20.0	6.1	3.2
	27	AIE 24322	-	-	-	-	Juvenile	−19.4	6.2	3.2
Mean								−19.6	6.6	3.2
Standard Deviation								0.2	0.8	0.06

The δ^{15}N means showed a larger dispersion between 6.0‰ and 6.8‰, with a more pronounced variability in the standard deviations between 0.7‰ and 1.2‰ (Tables 3–7, Figure 4). An interesting feature is that one of the guanaco modern assemblages – OLI – produced three outliers in the δ^{15}N; these are two adults (individuals 19 and 28) and a young (individual 30). Considering all modern guanaco assemblages, minimum and maximum values ranged from −20.2‰ to −18.5‰ and from 4.8‰ to 8.5‰ for δ^{13}C and δ^{15}N, respectively (Tables 3–7).

The central west of the province of Santa Cruz is dominated by C_3 plant species, with values ranging from −30.3‰ to −20.6‰ and from −8.3‰ to 6.1‰ in δ^{13}C and δ^{15}N, respectively (Tessone, 2010). This large variation in the isotopic signals was associated with the precipitation gradient and vegetational changes that take place in Patagonia, with higher values in the steppe and lower ones in the Andean Patagonia forest (Tessone, 2010). If a diet is estimated, the relationship between the isotopic values of modern assemblages of the Cardiel Lake and the enriched ^{13}C and ^{15}N area is clear. Therefore, in dietary terms, these values reflect the consumption of plants with C_3 photosynthetic pathways from the steppes of eastern continental Patagonia. This interpretation is consistent with the location of the Cardiel Lake in the steppe, the distance to the edge of the Andean Patagonian forest (*ca*. 70 km) and the range of action of the species (Raedeke, 1978; Young & Franklin, 2004; Burgi, 2007).

The attritional group exhibited δ^{13}C means between −19.9‰ and −18.7‰, with standard deviations <1.2‰, while the δ^{15}N means were between 5.2‰ and 7.1‰ with standard deviations of up to 2.1‰ (Table 8; Tessone, 2010). These mean values are similar to those reported for modern assemblages, which are subsumed within the variability of the

Table 5. $\delta^{13}C$ and $\delta^{15}N$ of Alero Los Guanacos 4 modern guanaco assemblage

Assemblage	Individual	Lab. code	Height (mm)	Width (mm)	Canine index	Sex	Age	$\delta^{13}C$‰	$\delta^{15}N$‰	C/N
Alero Los Guanacos 4	10	AIE 24327	7	6.5	−0.47	H	Adult	−19.6	8.5	3.2
	12	AIE 24328	11.5	10	0.13	M	Adult	−19.1	5.8	3.2
	15	AIE 24329	13	12	0.24	M	Adult	−19.0	6.5	3.2
	7	AIE 24326	-	-	-	-	Young	−19.1	7.0	3.3
	14	AIE 24325	-	-	-	-	Young	−18.5	5.7	3.2
	3	AIE 24324	-	-	-	-	Juvenile	−18.5	5.0	3.2
Mean								−19.0	6.4	3.2
Standard deviation								0.4	1.2	0.04

mesoregional signals. The reason for that is probably associated to a greater variability at the base of the food chains, because these six mesoregions cover a great spatial area (Table 2).

Sex and age variability of modern guanaco assemblages

One of the aims of this research is to study the variability of each assemblage, relative to sex and age of individuals. Regarding the first variable, little can be said for each assemblage because few sexual determinations have been done, between three and five individuals for each group (Tables 3–7). If all modern catastrophic samples are pooled together, the comparison is carried out with eight females and ten males. Females recorded a $\delta^{13}C$ mean of −19.5‰ ± 0.3‰ and $\delta^{15}N$ 7.5‰ ± 1.1‰, while in males $\delta^{13}C$ mean was −19.5‰ ± 0.4‰ and $\delta^{15}N$ 6.5‰ ± 0.6‰. Although the $\delta^{15}N$ means differed in 1‰, in neither of the two stable isotopes, significant statistical differences were found (test *One-Way Anova*: $\delta^{13}C$ F = 0.02639, p = 0.873; $\delta^{15}N$ F = 1.305, p = 0.2724). If the analysis is done by assemblages, not all of them follow the general trend explained above, since some present lower female values than males – ALG3 and LE. This absence of differentiation between females and males has also been recorded in European deer populations (Stevens *et al.*, 2006).

Furthermore, as regards the three age categories (young, juvenile, adult), two plots were prepared in which variations are evaluated based on the mean for each category in each assemblage (Figures 5 and 6). When considering the $\delta^{13}C$, the greatest differences were found in ALG4 among juvenile and adult, with a difference of 0.7‰ (Figure 5). This cluster has the smallest number of sampled individuals, with few values per category. The lowest variability was recorded in ALG3, although there is a slight tendency to depletion (0.2‰) as the age increases. OLI recorded the same pattern with a difference of 0.3‰. On the contrary, ALG1 displays the inverse trend with enrichment relative to the increase in age, with a difference of 0.3‰ between young and adults. Moreover, the remaining two assemblages (ALG4 and LE) recorded similar trends, with higher signals in juvenile compared to the other two categories. Young and adult in LE reported similar signals (0.5‰ lower than juvenile), while in ALG4, adults mean is depleted in 0.7‰ and young, in 0.3‰ with respect to juvenile (Figure 5). Once again, if the assemblages are pooled together, the juvenile recorded the highest

Table 6. $\delta^{13}C$ and $\delta^{15}N$ of La Encajada modern guanaco assemblage

Assemblage	Individual	Lab. code	Height (mm)	Width (mm)	Canine index	Sex	Age	$\delta^{13}C$‰	$\delta^{15}N$‰	C/N
La Encajada	6	AIE 24294	14	11	0.35	M	Adult	−19.7	7.2	3.2
	7	AIE 24295	5	5	−1.02	H	Adult	−19.5	6.1	3.2
	9	AIE 24297	7	5	−0.62	H	Adult	−19.4	5.5	3.2
	8	AIE 24296	-	-	-	-	Young	−19.5	5.9	3.2
	1	AIE 24289	-	-	-	-	Juvenile	−18.8	5.3	3.2
	2	AIE 24290	-	-	-	-	Juvenile	−18.5	5.1	3.2
	3	AIE 24291	-	-	-	-	Juvenile	−18.7	5.7	3.2
	4	AIE 24292	-	-	-	-	Juvenile	−18.8	6.3	3.2
	5	AIE 24293	-	-	-	-	Juvenile	−19.4	7.2	3.2
	10	AIE 24298	-	-	-	-	Juvenile	−19.4	6.0	3.3
	11	AIE 24299	-	-	-	-	Juvenile	−19.4	5.4	3.3
Mean								−19.2	6.0	3.2
Standard deviation								0.4	0.7	0.04

Table 7. δ^{13}C and δ^{15}N of Olivero modern guanaco assemblage

Assemblage	Individual	Lab. code	Height (mm)	Width (mm)	Canine index	Sex	Age	δ^{13}C‰	δ^{15}N‰	C/N
Olivero	1	AIE 24701	9	4	−0.27	H	Adult	−19.4	-	-
	2	AIE 24702	11	10	0.1	M	Adult	−19.7	-	3.2
	10	AIE 24710	-	-	-	-	Adult	−20.1	6.2	3.2
	18	AIE 24717	-	-	-	-	Adult	−19.8	5.6	3.2
	19	AIE 24718	-	-	-	-	Adult	−20	7.9	3.2
	21	AIE 24721	-	-	-	-	Adult	−19.6	5.8	3.2
	28	AIE 24727	-	-	-	-	Adult	−19.2	7.6	3.2
	29	AIE 24728	13	11.5	0.25	M	Adult	−19.5	5.7	3.2
	6	AIE 24706	-	-	-	-	Young	−19.4	5.9	3.2
	16	AIE 24719	-	-	-	-	Young	−19.8	5.8	3.2
	22	AIE 24722	-	-	-	-	Young	−19.4	6.1	3.2
	25	AIE 24724	-	-	-	-	Young	−19.2	4.8	3.2
	30	AIE 24729	-	-	-	-	Young	−18.9	7.7	-
	3	AIE 24703	-	-	-	-	Juvenile	−19.2	-	-
	4	AIE 24704	-	-	-	-	Juvenile	−19.3	-	-
	5	AIE 24705	-	-	-	-	Juvenile	−19.2	6.1	3.1
	7	AIE 24707	-	-	-	-	Juvenile	−19.2	5.7	3.2
	8	AIE 24708	-	-	-	-	Juvenile	−19.6	4.8	3.2
	9	AIE 24709	-	-	-	-	Juvenile	−19.1	4.9	3.2
	11	AIE 24711	-	-	-	-	Juvenile	−19.4	5.3	3.2
	12	AIE 24712	-	-	-	-	Juvenile	−19.9	6.5	3.2
	13	AIE 24713	-	-	-	-	Juvenile	−19.2	6.9	3.2
	14	AIE 24714	-	-	-	-	Juvenile	−19.3	6.8	3.2
	15	AIE 24715	-	-	-	-	Juvenile	−19.2	5.4	3.2
	17	AIE 24716	-	-	-	-	Juvenile	−19.8	5.9	3.2
	20	AIE 24720	-	-	-	-	Juvenile	−19.9	5.7	3.2
	23	AIE 24723	-	-	-	-	Juvenile	−19.5	5.2	3.2
	26	AIE 24725	-	-	-	-	Juvenile	−19.1	5.6	3.2
	27	AIE 24726	-	-	-	-	Juvenile	−19.2	6.1	3.2
Mean								−19.4	6.0	3.1
Standard Deviation								0.3	0.8	0.02

average, but differences do not exceed 0.3‰ (young (n = 13) = −19.3‰ ± 0.4‰; juvenile (n = 30) = −19.3‰ ± 0.3‰; adult (n = 27) = −19.5‰ ± 0.3‰).

The δ^{15}N presents a different scenario, showing, in all the assemblages, the lowest mean values in the juvenile category (Figure 6). Once again, the greatest differences were found in ALG4, with a distance between juvenile and adult of 1.9‰, while the lowest differences presented a maximum spread of 0.4‰ in LE. Meanwhile, only ALG3 recorded the highest mean in the young category while, in the remaining assemblages, the adults are the ones placed in that position. This trend is maintained if we pool together the assemblages; adult turned out to be the highest category (n = 25 δ^{15}N = 6.8‰ ± 0.9‰) and juvenile, the lowest one (n = 28 δ^{15}N = 5.8‰ ± 0.6‰), while the young category occupied an intermediate position (n = 13 δ^{15}N = 6.4‰ ± 0.8‰). The juvenile category presented a statistically significant difference with the other two categories (One-Way Anova: versus young F = 5.717, p = 0.02172/ versus adult F = 18.96, p = < 0.01).

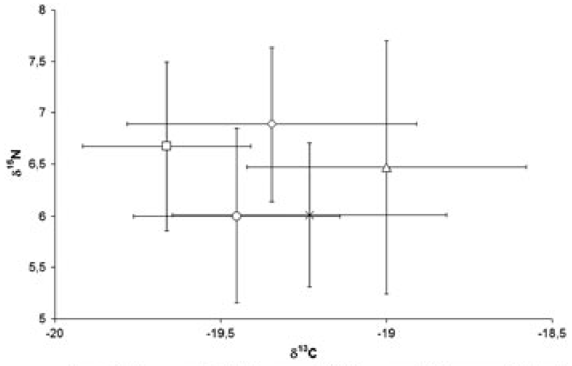

Figure 4. δ^{13}C and δ^{15}N variations in modern guanaco assemblages.

Summing up, two issues relative to the isotopic variability according to age must be pointed out. First, in several mammals, the δ^{13}C and δ^{15}N values for young individuals presented higher values than the remaining classes which has been related to the nursing of offspring (Jenkins *et al.*, 2001; Polischuk *et al.*, 2001; Newsome *et al.*, 2006; Valenzuela *et al.*, 2010). In the analysis performed here, an increase of the signals in young individuals compared to the

Table 8. Descriptive statistics of the attritional groups. Reference: CL: Cardiel Lake; PAP: Pampa del Asador Plateau; PMNP: Perito Moreno National Park; SL: Salitroso Lake; SP: Strobel Plateau; TSML: Tar and San Martín Lakes

	CL		PAP		PMNP		SL		SP		TSML	
	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰
N	10	10	9	9	14	14	6	6	6	6	29	29
Mean	−19.8	5.97	−19.47	6.25	−19.91	5.24	−19.59	7.1	−18.78	6.58	−19.29	6.42
Standard Deviation	0.9	0.89	0.42	1.1	0.76	0.93	1.28	2.16	0.89	1.55	0.89	1.63
Minimum	−20.9	4.76	−20.05	4.54	−21.19	3.2	−21.22	5.8	−19.8	3.82	−20.3	3.6
Maximum	−18.43	7.55	−18.97	8.02	−18.69	6.64	−17.4	11.46	−17.7	7.92	−16.7	9.7

other two categories was not observed. Ethological studies state that the offspring of the guanaco begins to graze within the first month of age and by the eighth month – estimated age of the young sampled in this study – weaning is complete in all individuals (De Lamo, 1995; Garay *et al.*, 1995). Therefore, it is understandable that the young category does not record the highest signals. According to this, Stevens and co-authors (2006:18) did not find an increase of the signals in deer populations in individuals from 6 to 7 months.

Second, individuals between the first and second year of age (juvenile) showed the lowest δ^{15}N values in the different assemblages, which were statistically significant when assemblages were pooled together. A possible explanation for this pattern refers to the higher growth rates of the guanaco for this age, who reaches 90% of its adult weight in the first two years of life (De Lamo, 1995). This explanation has been suggested for different species and is related to metabolic aspects during periods with high rate of growth that influence the levels of discrimination of ^{15}N (Hare *et al.*, 1991; Martínez del Río & Wolf, 2005; Trueman *et al.*, 2005; Reich *et al.*, 2008; also see Waters-Rist & Katzenberg, 2010).

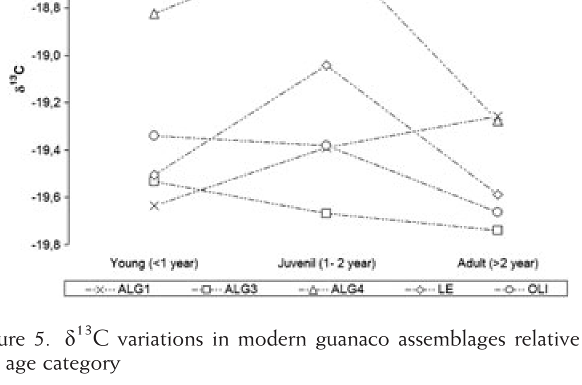

Figure 5. δ^{13}C variations in modern guanaco assemblages relative to the age category

Comparison of modern assemblages to the attritional group

The hypothesis referred to the variability of the groups should be evaluated to explore the potential of stable isotopes for discriminating individual hunt versus mass kill by hunter–gatherer populations. This hypothesis is founded on foraging history and common habits of gregarious species. Such verification is regional and specific to each species because particular aspects related to the isotopic variability with a regional basis and ethology of the chosen species are combined.

Following the statistical strategy proposed by Fenner (2008, 2009), outliers were eliminated. In this sense, an individual from the Salitroso Lake and eight from Tar and San Martin Lakes were removed at both ends of the distribution. Furthermore, three individuals coming from OLI were also removed in the modern assemblages. In this last assemblage, four individuals that only had δ^{13}C values were also excluded. It is important to highlight that the effect of sample size on the variability of the assemblages can be discarded because neither of the two stable isotopes showed a correlation between the number of the samples and the standard deviation.

In Figure 7 and Table 9, the standard deviations of the modern and the attritional assemblages from the scaling of stable isotopes of carbon and nitrogen (Equations (1)–(2)) are presented. The range of variation of the sum of the standard deviations is between 0.93 and 2.60. The modern assemblages show low variation, between 0.93 and 1.73, while the attritional assemblages range from 1.25 to 2.60. The three assemblages with the lowest variability were modern ones, OLI, ALG3 and LE. The two remaining modern assemblages – ALG1 and ALG4 – show a variability equal to or greater than some attritional groups. On the one hand, ALG1 had a sum of standard deviations similar to SL, which is the attritional group with the lowest variability of all. Last, ALG4 was the

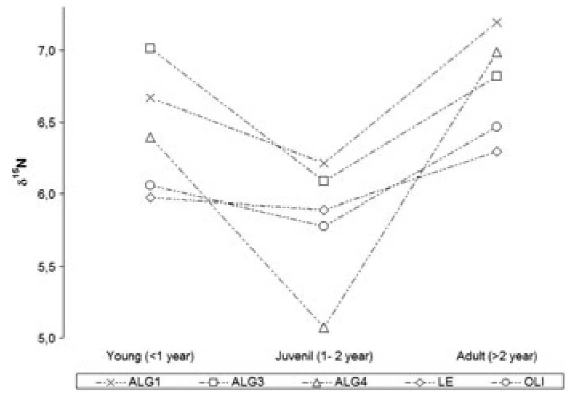

Figure 6. δ^{15}N variations in modern guanaco assemblages relative to the age category.

modern assemblage that presented the highest variability (1.73) higher or equal to three attritional groups: SL, PAP and TSML (Table 9, Figure 7).

The stable isotope that presents greater variation is different in each of the assemblages. For example, Tar and San Martin Lakes recorded an intermediate position in the sum of deviations, but much of that variance occurs in the δ^{13}C, while the δ^{15}N standard deviation is small. On the other hand, ALG4 had the highest variation in δ^{15}N. The group that recorded the highest variation was the Strobel plateau, with a standard deviation for both isotopes above 1. A noteworthy aspect is that the highest variability in modern assemblages was provided by the δ^{15}N with percentages of variation between 59% and 72% of the total. On the contrary, in attritional assemblages, the highest variations were recorded on both isotopes alike. A possible explanation could be that, in the modern catastrophic assemblages, δ^{15}N recorded a great variability in relation to age; a factor that was expected to be minimized in the assemblages of the attritional group as the fraction of subadult individuals in these archaeological assemblages is expected to be lower than in the modern assemblages.

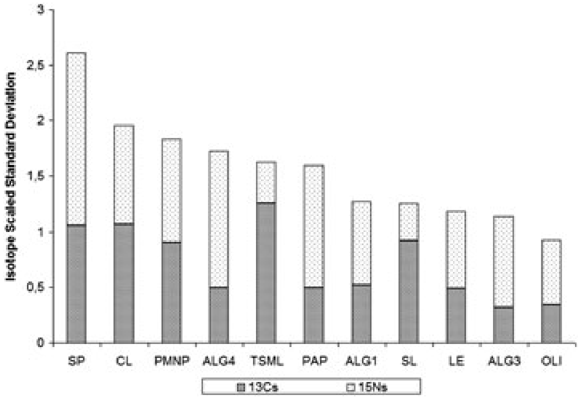

Figure 7. Scaled isotope ratio standard deviations for modern and mesoregion assemblage.

In Figure 8 and using Equation (3), scaled values of carbon and nitrogen stable isotope were combined into two-dimensional Euclidean distances. The ranges of variation for these measurements are between 0.32 and 0.79. Consistent with our proposal, the three assemblages that have less variability are modern groups OLI, LE and ALG1. Conversely, ALG3 recorded a slightly higher variability than two assemblages that come from attritional group. These assemblages are those from SL and CL, which were formed with samples from five archaeological sites and chronologies up to 2000 and 6000 years BP, respectively (Table 2). In addition, the standard deviation corresponding to CL is similar to that obtained in LE and ALG1 (Table 9 and Figure 8). This situation becomes more evident if we consider the remaining modern assemblages; ALG4 had the highest variability of all groups, being greater than all the assemblages coming from the attritional group. Among them, the PMNP and TSML can be singled out. These assemblages were formed with samples from different sites – 3 and 9, respectively – and two other characteristics were found that are relevant to this discussion. First, samples showed chronologies up to 11000 years BP, and secondly, they came from regions where great variability at the base of the food chain has been recorded associated to changes in precipitation and vegetation so a great isotopic variability in herbivores, like the guanaco, would be expected.

Therefore, in the case of the guanaco in southern Patagonia, this study rejects the hypothesis that isotopic variability of a social structure would be lower than that obtained from multiple populations and different hunting events. However, this should not be understood as the impossibility of applying stable isotopes for researches concerning the study of hunting techniques in the past. On the contrary, this allows setting parameters for evaluating isotopic zooarchaeological assemblages where there is a hypothesis of mass kill event, which had emerged from any other evidence (Fenner, 2008; also see application in Fenner, 2009). For example, if a zooarchaeological assemblage shows a standard deviation equal to or less than the one obtained in OLI, it is possible to think that we are dealing with a sample consisting of a mass kill event.

Finally, three possible causes can be discussed regarding the results obtained in the comparison between the modern assemblages and the attritional group. First, regarding the social groups that have been

Table 9. Scaled standard deviations and two dimensional euclidean distance of modern and mesoregional assemblages

			Scaled values			Euclidean distances	
Assemblages		N	$\delta^{13}C_S$ SD	$\delta^{15}N_S$ SD	Sum	Average	SD
Modern	ALG1	13	0.52	0.75	1.27	0.79	0.39
	ALG3	11	0.32	0.82	1.14	0.73	0.42
	ALG4	6	0.50	1.23	1.73	0.85	0.79
	LE	11	0.49	0.70	1.19	0.73	0.38
	OLI	22	0.34	0.58	0.93	0.58	0.32
Attritional group	CL	10	1.07	0.88	1.95	1.26	0.39
	PAP	9	0.49	1.10	1.59	1.05	0.46
	PMNP	14	0.91	0.93	1.83	1.10	0.62
	SL	5	0.92	0.33	1.25	0.79	0.41
	SP	6	1.06	1.55	2.61	1.60	0.67
	TSML	21	1.25	0.37	1.62	1.04	0.67

sampled, age and sex profiles indicate that these modern assemblages belong to mixed groups, gathered around fall/winter, due to the aggregation of family groups with male groups and solitary individuals. It can be hypothesized that, when sampling this assemblage, a higher isotopic variability might be expected than if each group was registered separately, because these social structures grouped individuals from different sectors in the study area and from different ranges of action. However, it should be pointed out that very large spatial scales would not be expected according to the available knowledge on the range of action and movement from other guanaco populations and their different social structure. A second argument relates to the isotopic variability of the base of the food chain and the guanaco food preferences; even though this species is generalist in its feeding habits, stable isotope studies are showing a preference for an almost exclusive consumption of the steppe vegetation, not incorporating the full range of variety of the base of the food chains to the diet. Thus, the isotopic variability recorded in the different regions and assemblages is relatively limited and similar, although definitively steppe and transitional environments of forest and steppe vegetation were sampled, e.g. PNPM and Tar and San Martin Lakes. Third, as was mentioned, a possible argument refers to $\delta^{15}N$ variability registered in relation to age in modern catastrophic assemblages. This variable is expected to be minimized in the attritional group because it is expected that in these groups most individuals correspond to adulthood. Thus, it is possible that the spatial and temporal variability expected for attritional groups is compensated by the age-related variability recoded in the modern catastrophic assemblages.

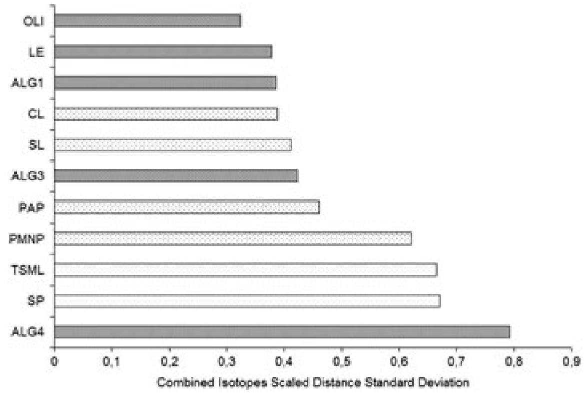

Figure 8. Combined isotopes scaled distance standard deviation using carbon and nitrogen.

Final remarks

The assemblages studied were a first opportunity to estimate the range of isotopic variability present in a wild population of guanacos. As mentioned before, the interest lied on establishing parameters to explore variability in the zooarchaeological assemblages to study mass kill events by hunter–gatherers in Patagonia. The hypothesis proposed was that the isotopic variability of a social group or a local population which would have died simultaneously was going to be smaller than that obtained from analyzing individuals from multiple populations. As discussed in the previous section, this expectation was not fulfilled. Finally, we should remark that this is a first step in the investigation. The next step is to incorporate oxygen and strontium isotopes from the bone mineral fraction to this discussion in order to incorporate geographic isotopic tracers. This is conducted considering diagenetic aspects and, in turn, from the incorporation of teeth isotopic studies. This multi-isotopic approach could result in a significant contribution to the zooarchaeological analysis of skeletal transport, thus supplementing inferences based on the frequency of skeletal parts and processing evidence recovered in the sites.

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