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First approach to the paleodiet of hunter-gatherers through stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) in the eastern Pampa-Patagonia transition during the Middle Holocene

G. Flensborg[a,*], G. Martínez[a], A. Tessone[b]

[a] Instituto de Investigaciones Arqueológicas y Paleontológicas del Cuaternario Pampeano (INCUAPA-CONICET), Facultad de Ciencias Sociales, Universidad Nacional del Centro de la Provincia de Buenos Aires (UNICEN), Olavarría, Argentina
[b] Instituto de Geocronología y Geología Isotópica (INGEIS-CONICET), Universidad de Buenos Aires, Ciudad Autónoma de Buenos Aires, Argentina

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ABSTRACT

The main objective of this paper is to assess paleodiets and subsistence patterns in hunter-gatherer groups of the eastern Pampa-Patagonia transition during the Middle Holocene (ca. 6000–4100 years BP). Using a multivariate diet reconstruction model that incorporates $\delta^{13}C_{ap}$, $\delta^{13}C_{col}$, and $\delta^{15}N$ holistically, human palaeodiets were characterized through the identification of dietary patterns relative to the consumption of terrestrial (e.g., vegetal and animal) and marine resources (e.g., fish). Thus, both spatial and temporal variations in diet and subsistence, as well as issues related to mobility and the use of landscape (coast-inland), were explored. Nine adult individuals of both sexes from four archeological sites were analyzed. The results of $\delta^{13}C_{col}$ and $\delta^{15}N$ for the study area indicated that the individuals buried close to the Atlantic coast (Tres Bonetes 1-colección Donnay and Cantera de Rodados Villalonga sites) exhibited similar values among them, which differed statistically from those individuals buried in sites located inland (Loma de Los Morteros and La Modesta). While the first group of individuals showed a range of marine to mixed diets, the second group was characterized by terrestrial values. The observed differences were interpreted as the product of possible territorial demarcations. For the study area, Middle Holocene dietary trends were also compared with those of the Late Holocene, which indicated temporal variations in the diet between ca. 6000–400 years BP. Finally, at the macro-regional level, the results obtained here showed certain differences and similarities from those of northeastern Patagonia and southeastern Pampa. Such macro-regional trends in paleodiets are also discussed here.

1. Introduction

Since the 1970s, the study of stable isotopes into archeological research has produced a significant advance in discussions related to subsistence, the spatial organization of hunter-gatherers, migration, intra/inter group differentiation, and the origins and history of farming and pastoralist societies, among others (e.g., Ambrose, 1993; Koch, 1998; Pate, 1997). In recent decades, the archeology of South America and, particularly of Argentina, have become part of this process, and have generated a change in the quantity and quality of knowledge of past societies (Barberena, 2002; Panarello et al., 2006; Yesner et al., 1991; Zangrando et al., 2004). In Cuyo, the Pampas, and Patagonia regions, a significant amount of research has been carried out in order to characterize mainly the temporal and spatial trends of subsistence for hunter-gatherer and farmer groups (Barberena, 2002; Barrientos et al., 2015; Berón et al., 2009; Bonomo et al., 2013; Borrero et al., 2001; Favier Dubois et al., 2009; Giardina et al., 2014; Gil et al., 2006, 2011; Gómez Otero, 2007; Gordón et al., 2017; Novellino et al., 2004; Scabuzzo et al., 2016, among others). Particularly, in the southeast of the Pampean region, for the characterization of human paleodiets the analysis of stable isotopes in human remains has been conducted on samples that range from the Final Early Holocene to the Late Holocene (Barrientos et al., 2015; Bonomo et al., 2013; Politis et al., 2009; Scabuzzo et al., 2016). However, in northeastern Patagonia and the eastern Pampa-Patagonia transition, these studies have been mostly performed on Late Holocene samples (Favier Dubois et al., 2009; Martínez et al., 2009) due to the greater representation of the skeletal series for this period in relation to earlier times.

Archeological research in the eastern Pampa-Patagonia transition (Fig. 1) has dealt mainly with adaptive patterns, and the historical

* Corresponding author at: Instituto de Investigaciones Arqueológicas y Paleontológicas del Cuaternario Pampeano (INCUAPA-CONICET), Facultad de Ciencias Sociales, Universidad Nacional del Centro de la Provincia de Buenos Aires (UNICEN), Avenida del Valle 5737, Olavarría B7400JWI, Argentina.
E-mail addresses: gflensbo@soc.unicen.edu.ar (G. Flensborg), gmartine@soc.unicen.edu.ar (G. Martínez), gutitessone@gmail.com (A. Tessone).

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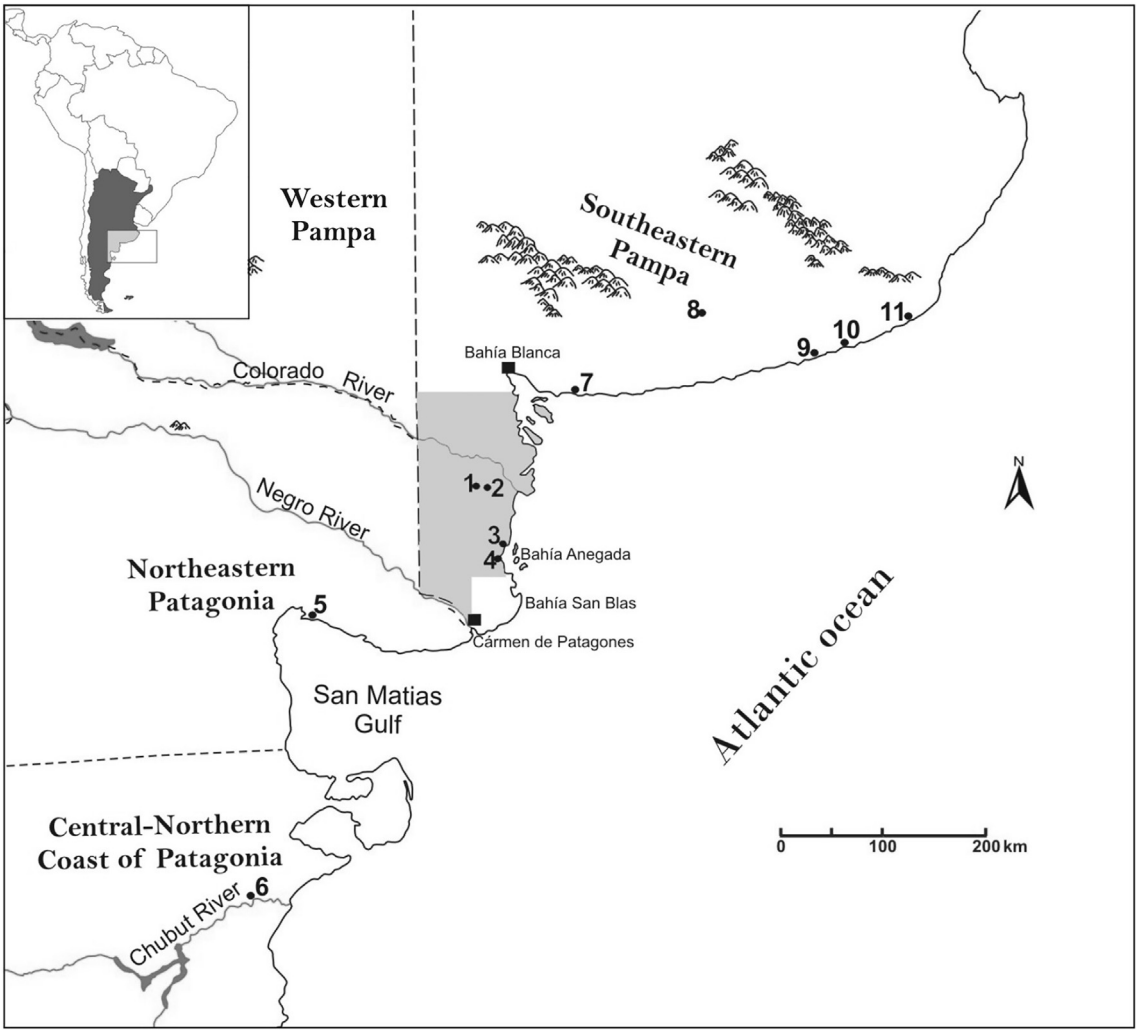

Fig. 1. Location of Middle Holocene archeological sites in the eastern Pampa-Patagonia transition (grey). Sites of southeastern Pampa and northeastern Patagonia with isotopic information from human bones for that time period. Note: 1. La Modesta; 2. Loma de Los Morteros; 3. Cantera de Rodados Villalonga; 4. Tres Bonetes 1- colección Donnay; 5. Bahía San Antonio; 6. Chacra 375; 7. Monte Hermoso 1; 8. Arroyo Seco 2; 9. Necochea; 10. Arroyo del Moro; 11. Meseta del Chocorí.

trajectories and population dynamics of hunter-gatherer groups in an arid-semiarid environment during the Middle to Late Holocene (ca. 6300–250 years BP; Martínez, 2008–2009, 2017). While subsistence and paleodiets represent some of the most widely developed topics, these have only been studied in depth for the Late Holocene (ca. 3000–250 years BP). To this end, the analysis of archeofaunal assemblages (Alcaráz, 2015, 2017; Stoessel, 2012, 2014), fatty acids adhered to ceramic (Stoessel et al., 2015), oral pathologies (Flensborg, 2011, 2013, 2015), and stable isotopes of carbon and nitrogen (Martínez et al., 2009) was performed. Archeological contexts for the Middle Holocene (Fig. 1) have very recently been recovered in the study area (see Section 3 below). A feature that is common to all archeological sites is the presence of human remains, which enables the characterization and discussion of human paleodiets through stable isotopes corresponding to the Middle Holocene (ca. 6000–4100 years BP; Martínez et al., 2012).

This paper focuses on the assessment of paleodiets and subsistence patterns in the hunter-gatherer groups of the eastern Pampa-Patagonia transition during the Middle Holocene (Fig. 1). The analysis of stable isotopes on collagen ($\delta^{13}C$ and $\delta^{15}N$) and apatite ($\delta^{13}C$) was used here to evaluate the consumption of terrestrial (e.g., vegetal and animal) and marine resources (e.g., fish) through time. Spatial and temporal variations in diet and subsistence in connection with mobility and the use of the landscape (coast-inland) at different spatial scales (northeastern Patagonia and southeastern Pampa) will be further discussed. Finally, temporal variation in the diet of the human groups that inhabited the study area between the Middle and Late Holocene (ca. 6000–400 years BP) is discussed here in order to achieve a better understanding of this issue.

2. Ecological setting

The eastern Pampa-Patagonia transition is crossed by the Colorado River, which runs from the Andes to the Atlantic Ocean. The study area is enclosed in the so-called 'Arid Diagonal', in the southernmost part of South America (Abraham de Vázquez et al., 2000). It is characterized by warm and dry steppe arid climate, with a mean annual rainfall of 466 mm (Sánchez et al., 1998). The dominant vegetation belongs to the 'Distrito del Caldén' and 'Provincia del Espinal', although vegetal communities of the 'Provincia del Monte' can also be observed in the area (Morello, 1958). Thus, this arid to semi-arid sandy area presents a shrub steppe, an open vegetal formation composed of xeric short trees mixed with hardy and scarce herbaceous grasses. While the area is dominated by C_3 flora (e.g., *Geoffroea decorticants* or 'chañar', *Prosopis* sp. or 'algarrobo', and *Condalia microphylla* sp. or 'Piquillín'), C_4 and CAM species are also present in a smaller proportion (Martínez et al., 2009; Villamil and Scoffield, 2003).

From a zoogeographical point of view, the area is located in the

'Subregión Patagónica', 'Distrito Patagónico', where the following species are recorded: *Lama guanicoe* (wild camelid called 'guanaco'), *Chaetophractus villosus* ('peludo', armadillo), *Zaedyus pichiy* ('piche', armadillo), *Dolichotis patagonum* ('mara', patagonic hare), *Lagostomus maximus* ('vizcacha', large rodent), and *Rhea americana* ('ñandú', greater Rhea), among others (Cabrera and Yepes, 1960). Ichthyogeographically, the area is located in the "Andino Cuyana" province, represented by Patagonian catfish (*Hatcheria macraei*), velvety catfish (*Olivaichthys cuyanus*), and perch (*Percichthys trucha*) (López et al., 2008). Between the mouths of the Colorado and Negro rivers, there is an overlap in the distribution of freshwater fish species from the Austral and Brasílica subregions (Almirón et al., 1997). Marine species present greater diversity and correspond to "Distrito Rionegrino" of the Argentine province (Balech and Ehrlich, 2008). This province shows significant heterogeneity in its composition as a result of the mixture of subtropical and subantarctic species, such as the Sciaenidae, Sparidae and Cheilodactylidae families, as well as chondrichthyes species (Balech and Ehrlich, 2008; Cousseau and Perrotta, 1998). According to the information provided above, the eastern Pampa-Patagonia transition is characterized as a region of high biological productivity and environmental variability that are consistent with the properties of an ecotone (Martínez et al., 2009; Morello, 1958; Paez et al., 2001; Pezzola et al., 2003; Schäbitz, 2003; Villamil and Scoffield, 2003).

Geomorphologically, the lower basin of the Colorado River represents the remnant of an ancient delta that extended from Bahía Blanca, in the north, to Bahía San Blas in the south (Melo et al., 2003) (Fig. 1), which is associated with a complex system of palaeochannels. Most archeological sites, such as La Modesta and Loma de Los Morteros (see below), are in dune fields associated with these palaeochannels (Martínez and Martínez, 2011). While the geomorphology of the coastal area to the north of Bahía Anegada is characterized by low and extended beaches (Piccolo and Perillo, 1997), the south of Bahía Anegada coastal geomorphology is characterized by cliffs, coastal deposits and aeolian deposits which correspond to the Late Pleistocene-Holocene (Fucks et al., 2012; Weiler, 1983). Two of the sites analyzed here are located in this landscape: Cantera de Rodados Villalonga and Tres Bonetes 1-colección Donnay (Fig. 1).

Palaeoclimatic and paleoenvironmental studies indicate that during ca. 7000–3000 years BP (Middle Holocene), climatic conditions would have been continually arid and semi-arid, with intense eolian morphodynamic processes (Fernández, 2012; Marcos and Ortega, 2014; Schäbitz, 1994, 2003). Arid and semi-arid conditions, with a higher frequency of rainfall, expansion of lagoons and a more marked seasonality, has been proposed for the Late Holocene since ca. 3000 years BP (Marcos et al., 2014; Martínez and Martínez, 2011; Schäbitz, 1994, 2003; Stoessel et al., 2008).

3. Middle Holocene archeological sites: some trends

The four Middle Holocene archeological sites from the lower course of the Colorado River were analyzed: La Modesta, Loma de Los Morteros, Tres Bonetes 1-colección Donnay and Cantera de Rodados Villalonga (Martínez et al., 2012; Martínez, 2017; Table 1). La Modesta and Loma de Los Morteros sites are located very close to one other (Fig. 1), in an area of deflated dunes, ca. 60 km from the Atlantic coast. Both sites are near an old paleochannel of the Colorado River. Grinding materials, projectile points, lithic debris, faunal remains (e.g., guanaco, fish, armadillos, rodents, and birds), engraved Rheidae eggshells, as well as human bone remains were recovered on the surface of the blowouts (Carden and Martínez, 2014; Martínez, 2017; Stoessel, 2015). The human remains corresponding to three individuals (Table 1) are represented by fragments, and no burial modality could be identified. Context and archeological information indicate that the sites correspond to residential settlements of multiple activities (Martínez, 2017; Stoessel, 2015). Cantera de Rodados Villalonga and Tres Bonetes 1-colección Donnay sites are located close to each other, along the Atlantic coast (Fig. 1). In both contexts, human remains were recovered on marine deposits in stratigraphic position. Bone preservation and anatomical integrity was good (Martínez et al., 2012), and six individuals could be identified (Table 1). Inhumations possibly correspond to the primary burial modality, and for the time being, these contexts have been interpreted as human burial settings (Martínez et al., 2012; Martínez, 2017).

The study of the different lines of archeological analysis carried out in these sites is still dissimilar, although some trends have been obtained in the case of zooarchaeology, lithic technology and use of rocks and decoration patterns on Rheidae eggshells. This information will be summarized here and integrated below with the results obtained from the stable isotopes. The zooarcheological analyses of inland sites corresponding to the Middle Holocene come from the faunistic assemblage of La Modesta site and indicate the exploitation of ungulates (*Lama guanicoe*) and smaller species, such as freshwater fish (*Percichthys* sp.), big rodents (*Myocastor coypus*) and possibly birds and armadillos (Alcaráz, 2015, 2017; Martínez, 2017; Stoessel, 2015). In the case of *Percichthys* sp. exploitation, the use of nets was proposed for the massive capture of this resource (Stoessel, 2017). Main trends in lithic studies and raw material provenience come also from La Modesta site. In the case of local rocks (silica and basalt/andesite), the size, morphology and knapping qualities of the pebbles suggest that their provisioning could have occurred in the Atlantic coast. There are also exotic rocks like orthoquartzites, metaquartzites, quartz sandstones, different kinds of cherts, sedimentary silex, and translucent chalcedony obtained from Southeastern and Western Pampa and Northeastern Patagonia (Fig. 1) (Santos Valero, 2017). During the Middle Holocene, Rheidae eggs were decorated with geometric rectilinear motifs and the designs are repeated on a macro-regional scale that also includes the eastern and western portions of the Pampas and northern Patagonia. The wide circulation of designs on Rheidae eggs is congruent with the distribution of exotic rocks previously mentioned. It was suggested that style may have reinforced a scenario of relatively open social networks where objects, raw materials, and images moved fluidly across long distances (Carden and Martínez, 2014; Carden and Borgez Vaz, 2017; Martínez, 2017).

Table 1
Radiocarbon and bioarchaeological data of the individuals analyzed in this paper.

Site-individual	Sex	Age-at-death	Code	Age ^{14}C BP	Age cal. BP 2σ	δ^{13}C	Reference
Loma de Los Morteros	Indeterminate	Indeterminate adult	AA-101876	4454 ± 60	4855–5284	−16.9	Carden and Martínez, 2014; Stoessel, 2015
La Modesta-E1	Indeterminate	Indeterminate adult	AA-105416	5890 ± 52	6501–6783	−15.5	Martínez, 2017
La Modesta-E2	Indeterminate	Indeterminate adult	AA-107619	5904 ± 37	6559–6783	−19.0	Martínez, 2017
Cantera de Rodados Villalonga-E1	Male	35–45	AA-91549	4889 ± 58	5330–5710	−15.1	Martínez et al., 2012
Cantera de Rodados Villalonga-E2	Male	35–45	AA-91550	4502 ± 56	4874–5288	−13.4	Martínez et al., 2012
Cantera de Rodados Villalonga-E3	Female	25–35	LP-2452	4100 ± 80	4297–4825	−20	Martínez et al., 2012
Tres Bonetes 1-E1	Male	35–50	AA-106786	5188 ± 40	5749–5992	−13.3	Martínez, 2017
Tres Bonetes 1-E2	Female	Indeterminate adult	AA-106787	5182 ± 46	5747–5991	−15.4	Martínez, 2017
Tres Bonetes 1-E3	Male	35–50	AA-106788	5339 ± 39	5941–6201	−13.1	Martínez, 2017

Table 2
Stable isotope values of plants and faunal remains from NE of Patagonia. Note: LCCR: lower course of the Colorado River; NCSMG: northern coast of the San Matías Gulf; CNCP-LVCR: central-northern coast of Patagonia and lower valley of the Chubut River.

Micro-region	Taxa	Common name	$\delta^{13}C_{col}$ ‰	$\delta^{15}N$ ‰	References
LCCR	*Ozotoceros bezoarticus*	Venado de las pampas	− 22.1	5.9	Martínez et al., 2009
	Rhea americana	Ñandú	− 22.25	4.36	Martínez et al., 2009
	Rhea americana	Ñandú	− 21.3	9.5	This paper
	Myocastor coypus	Coipo	− 20.7	5.1	This paper
	Zaedyus pichiy	Piche	− 20.0	10.8	Martínez et al., 2009
	Genidens barbus	Bagre de mar	− 20.1	13.7	Martínez et al., 2009
	Micropogonias furnieri	Corvina rubia	− 18.9	9.3	Martínez et al., 2009
	Lama guanicoe	Guanaco	− 18.2	10.1	This paper
	Lama guanicoe	Guanaco	− 18.9	10.8	This paper
	Ceratophrys ornata	Escuerzo	− 18.6	8.7	This paper
NCSMG	*Lama guanicoe*	Guanaco	− 19.4	7.4	Favier Dubois et al., 2009
	Otaria flavescens	Lobo marino	− 11.1	22.8	Favier Dubois et al., 2009
	Rhea americana	Ñandú	− 19.6	10.1	Favier Dubois et al., 2009
	Spheniscus magellanicus	Pingüino	− 12.2	21.1	Favier Dubois et al., 2009
	Micropogonias furnieri	Corvina rubia	− 12.0	15.4	Favier Dubois et al., 2009
	Condalia microphylla	Piquillín	− 26.5	5.6	Favier Dubois et al., 2009
	Schinus jahnstonii	Molle	− 26.0	6.1	Favier Dubois et al., 2009
	Prosopis flexuosa	Alpataco	− 23.9	0.3	Favier Dubois et al., 2009
	Geoffroea decorticans	Chañar	− 27.3	0.0	Favier Dubois et al., 2009
	Cereus aethiops	Cáctus de monte	− 12.8	0.6	Favier Dubois et al., 2009
CNCP-LVCR	*Percichthys* sp.	Perca	− 23.1	8.1	Gómez Otero, 2007
	Aulacomya ater	Cholga	− 21.6	6.6	Gómez Otero, 2007
	Sebastes capensis	Escrófalo	− 19.6	15.8	Gómez Otero, 2007
	Acanthistius brasilianus	Mero	− 16.9	16.9	Gómez Otero, 2007
	Spheniscus magellanicus	Pingüino	− 15.1	16.8	Gómez Otero, 2007
	Spheniscus magellanicus	Pingüino	− 14.6	17.1	Gómez Otero, 2007
	Otaria flavescens	Lobo marino	− 11.1	22.6	Gómez Otero, 2007
	Otaria flavescens	Lobo marino	− 14.1	20.6	Gómez Otero, 2007
	Pterocnemia pennata (coast)	Choique	− 24.9	7.1	Gómez Otero, 2007
	Pterocnemia pennata (inland)	Choique	− 22.3	4.3	Gómez Otero, 2007
	Lama guanicoe (coast)	Guanaco	− 21.3	8.2	Gómez Otero, 2007
	Lama guanicoe (inland)	Guanaco	− 21.4	5.2	Gómez Otero, 2007

4. Materials and methods

The skeletal series consists of nine adults of both sexes, with radiocarbon dates spanning a range of ca. 5900–4100 years BP (Table 1). The stable isotope analyses on bone collagen ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) were performed at the Arizona Radiocarbon AMS Facility, University of Arizona (United States), and at the laboratory of the Institute of Isotopic Geology and Geochronology (INGEIS, Buenos Aires, Argentina). The carbon stable analyses on the inorganic fraction ($\delta^{13}C_{ap}$) were conducted at the Department of Geosciences, University of Arizona (United States). C:N ratios were estimated in order to evaluate the collagen preservation of the samples (DeNiro, 1985; van Klinken, 1999). To analyze the trophic level, an enrichment of 4‰ was used for the $\delta^{15}N$, while an isotopic enrichment of 1‰ in $\delta^{13}C$ was estimated between the bone collagen signal of prey and predators (Bocherens and Drucker, 2003).

For the lower basin of the Colorado River, carbon and nitrogen stable isotopes indicate preferably the presence of C_3 plants ($\delta^{13}C$ mean = − 24.5‰) and herbivores that consume these primary resources ($\delta^{13}C$ mean = − 21‰; Martínez et al., 2009) (Table 2). However, while the isotopic values obtained from the available resources in the study area mainly correspond to $\delta^{13}C_{col}$, few $\delta^{15}N$ values were informed (Martínez et al., 2009: Tables 1 and 2). Therefore, a broader regional database was built with the isotopic values of $\delta^{13}C_{col}$ and $\delta^{15}N$ available for the northeast of Patagonia with a primary source corresponding to the monte-espinal biome. These include the micro-regions of the lower course of the Colorado River (Martínez et al., 2009 and new data published here; Table 2), the northern coast of the San Matías Gulf (Favier Dubois et al., 2009) and the central-northern coast of Patagonia and lower valley of the Chubut River (Gómez Otero, 2007) (Table 2; Fig. 1).

For the purposes of paleodietary interpretation, Froehle's model (2012) was used, which is a multivariate diet reconstruction model that incorporates $\delta^{13}C_{ap}$, $\delta^{13}C_{col}$ and $\delta^{15}N$ holistically. From the analysis of clusters and the discriminant function, it is possible to better differentiate diets with marine proteins from those based on the C_4 photosynthetic pathway (Froehle et al., 2012; Somerville et al., 2013). The model discriminates five different dietary subgroups, which differ both in their protein component and in the overall diet.

Statistically, the assessment of significant differences between sex and between individuals buried in different landscape sectors (coast/inland) was performed using the non-parametric Mann-Whitney test (differences at or below $p = 0.05$ were considered significant), with the PAST statistical program (version 2.08; Hammer et al., 2001). The studies were carried out in accordance with the professional ethical standards proposed by the Argentinean Association of Biological Anthropology ("Code of Ethics for the Study, Conservation and Management of Human Remains of the Populations of the Past") and National Law No. 25.743.

5. Results

The C:N ratio falls within the appropriate range for samples with no diagenetic alterations at 2.9 to 3.6 (DeNiro, 1985), and all samples represent the primary isotopic signal (Table 3).

The results obtained from the organic fraction showed variations. On the one hand, the arithmetic mean $\delta^{13}C_{col}$ exhibited a value of − 15.3‰ ± 2.0‰ (range from − 13.1‰ and − 19.0‰) and a mean $\delta^{15}N$ value of 14.5‰ ± 2.9‰ (range from 11.4‰ and 18.9‰). On the other hand, the inorganic fraction ($\delta^{13}C_{ap}$) also presented heterogeneous values, with mean − 9.6‰ ± 1.9‰ (range from − 6.7‰ and − 11.5‰).

No specific pattern in relation with the chronology of the individuals was registered and no differences between sexes were recorded (Table 4). The distribution of the isotopic values in relation to site location (coast vs. inland) did not indicate any statistical differences

Table 3
Stable isotope values of the human samples and discriminant functions defined by Froehle et al. (2012).

Site-individual	Sample	Lab code	% collagen	C:N	$\delta^{13}C_{col}$	$\delta^{15}N$	$\delta^{13}C_{ap}$	F1	F2
Loma de Los Morteros	Humerus	AA-101876	6	3.2	− 16.9	11.4	− 6.7	− 2.61886	− 1.19536
La Modesta-E1	Tibia	AIE-37791	18	3.2	− 17.6	11.7	− 8.1	− 3.52216	− 0.54686
La Modesta-E2	Tibia	AA-107619	3	3.3	− 19.0	11.4	− 13.0	− 6.1484	0.9698
Cantera de Rodados Villalonga-E1	Femur	AA-91549	6	3.5	− 15.1	13.1	− 11.5	− 2.4739	1.97605
Cantera de Rodados Villalonga-E2	Femur	AA-91550	7	3.4	− 13.4	17.3	− 7.8	0.8893	3.3408
Cantera de Rodados Villalonga-E3	Femur	AIE-37804	11	3.2	− 14.6	14.7	− 10.3	− 1.37682	2.57008
Tres Bonetes 1-E1	Rib	AA-106786	6	3.4	− 13.3	18.3	− 9.4	0.6658	4.6049
Tres Bonetes 1-E2	Tibia	AA-106787	2	3.4	− 15.4	14.5	− 10.2	− 1.9507	2.2764
Tres Bonetes 1-E3	Humerus	AA-106788	4	3.4	− 13.1	18.9	− 9.6	0.8782	5.0833

Table 4
Statistical values among individuals by sex and location in the study area.

Variable	$\delta^{13}C_{col}$	$\delta^{13}C_{ap}$	$\delta^{15}N$
Female/male	Z = − 1.157; p = 0.247	Z = − 0.694; p = 0.487	Z = − 0.794; p = 0.457
Coast/inland	Z = − 2.195; p = 0.028	Z = − 0.387; p = 0.698	Z = − 2.204; p = 0.027

at $\delta^{13}C_{ap}$ (Table 4). However, the $\delta^{13}C_{col}$ and $\delta^{15}N$ relation indicates that the values for those individuals buried close to the Atlantic coast (Tres Bonetes 1-colección Donnay and Cantera de Rodados Villalonga) are similar to each other (Fig. 2) and differ in statistical terms from those located in inland sites (Loma de Los Morteros and La Modesta) (Table 4). The first group of individuals is linked to marine and mixed diets, while the second group is associated with terrestrial diets (Fig. 2).

According to the model proposed by Froehle et al. (2012), three different situations can be observed (Fig. 3). A first group of values associated with Clusters 1, 4 and 5 corresponds to individuals located inland (La Modesta and Loma de Los Morteros sites). The data indicate that mainly terrestrial resources were consumed, with dominant proportions of resources of photosynthetic C_3 pathways. The opposite case is represented by three samples (TB1-E1, TB1-E3 and CRV-E2; Fig. 3) recovered near the sea and associated with Cluster 3, which reflects a diet of strongly marine-oriented protein and an overall C_3:C_4 diet of 50%. Finally, three other samples (TB1-E2; CRV-E1 and CRV-E3) from the coastal sector fall outside the clusters, between Clusters 4 and 3 (Fig. 3). The latter would be reflecting intermediate paleodietary situations at the two ends described above.

6. Discussion

6.1. Dietary patterns in the study area

The availability of both chronological information and that related to stable isotopes in connection with human remains represents a valuable data source to characterize the paleodiet of pre-Hispanic groups and to evaluate changes in subsistence through time (Barberena, 2008; Katzenberg et al., 2010; Pate, 1995; Tessone, 2010; Yesner et al., 2003). Results indicate that the individuals who occupied the eastern Pampa-Patagonia transition during the Middle Holocene possessed a varied diet within a limited spatial scale, with variations in the sources of protein and energy intake (Ambrose et al., 1997; Froehle et al., 2012; Schwarcz, 1991). The present case study shows the coexistence of different trends: on the one hand, individuals whose diets were characterized mainly by marine proteins with a similar C_3 and C_4 energy intake (Cluster 3, Fig. 3), and on the other hand, individuals whose diets were based mainly on protein and C_3 resources (Clusters 1, 4 and 5, Fig. 3). However, discrepancies were found within this last group of individuals. While in one case (e.g., La Modesta-E2), the diet was mainly characterized by the intake of C_3 plant-eating terrestrial

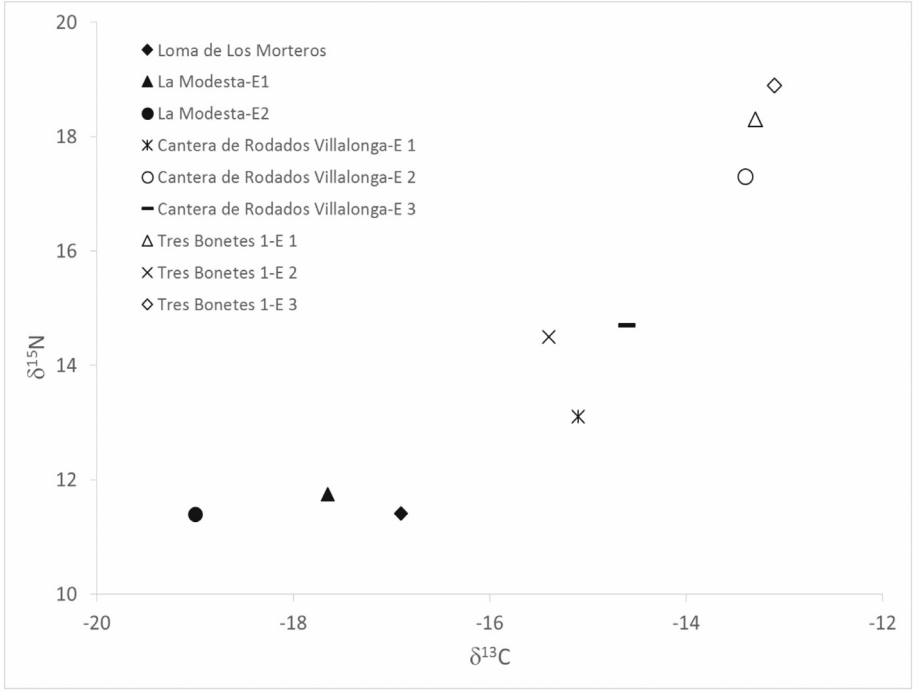

Fig. 2. Carbon and nitrogen stable isotope ratios for protein from human values.

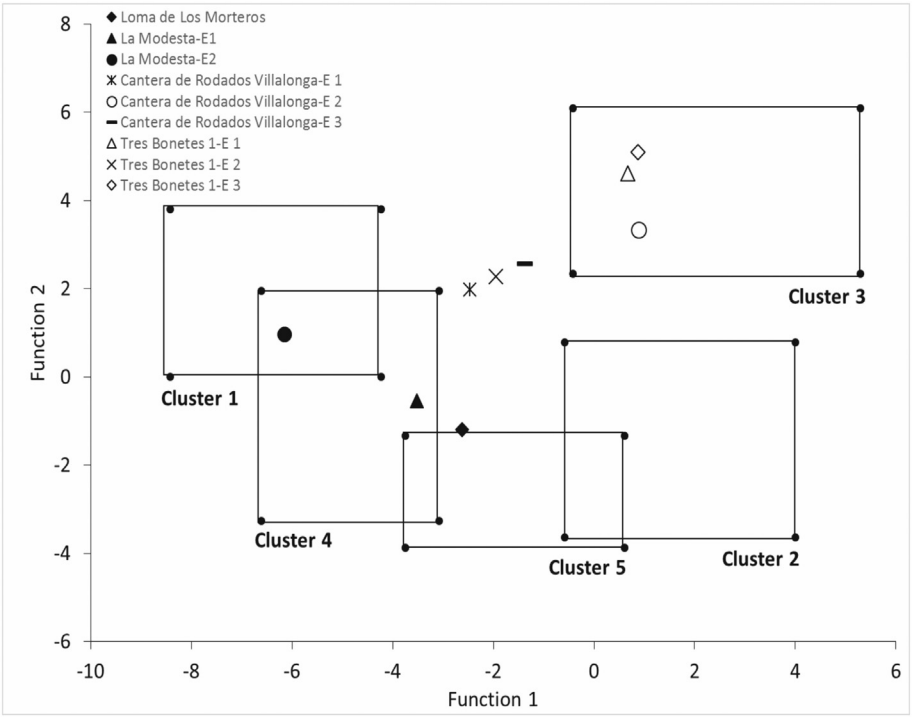

Fig. 3. F1 and F2 discriminant function values from individuals plotted against previously generated dietary clusters by Froehle et al. (2012).

resources, the other two individuals (e.g., La Modesta-E1 and Loma de los Morteros) showed a slight growth in their C_4 energy intake (Fig. 3). Finally, there was a group of individuals that had a very similar diet, which did not match the clusters proposed by Froehle et al. (2012). This case could represent an intermediate situation between the consumption of marine and terrestrial proteins, and a preference for C_3 energy.

Fig. 4 shows the isotopic values of the resources and those of human remains, and it can be seen that the values of certain individuals in Tres Bonetes 1-colección Donnay (TB1-E1 and TB1-E3) and Cantera de Rodados Villalonga (CRV-E2) sites are linked to the intake of marine resources. If an isotopic enrichment of 1‰ for $\delta^{13}C_{col}$ and of 4‰ for $\delta^{15}N$ is considered, then the consumption of different kinds of fish (e.g., *Genidens barbus* –catfish-, *Micropogonias furnieri* –White croaker-), as well as sea lions (*Otaria flavescens*) can be inferred (Fig. 4). The remaining individuals from these two sites (TB1-E3, CRV-E1 and CRV-E3), instead, would have fed both on marine fish and terrestrial herbivores (e.g., *Rhea americana* -ñandú-, *Lama guanicoe* -guanaco-, *Myocastor coypus* -coipo-). Lastly, individuals from La Modesta and Loma de Los Morteros sites show a preference for terrestrial herbivores and freshwater fish (e.g., *Percichthys* sp. -perch-). La Modesta-E2 exhibited the most negative $\delta^{13}C_{col}$ value in the sample, which was very similar to that of guanaco (see Table 2). Nevertheless, the values obtained for certain guanaco samples from the area are still under discussion, as they are more positive than would have been expected for an environment characterized by C_3 vegetation and in comparison with the values that were registered at a regional level (Table 2). As was proposed in a

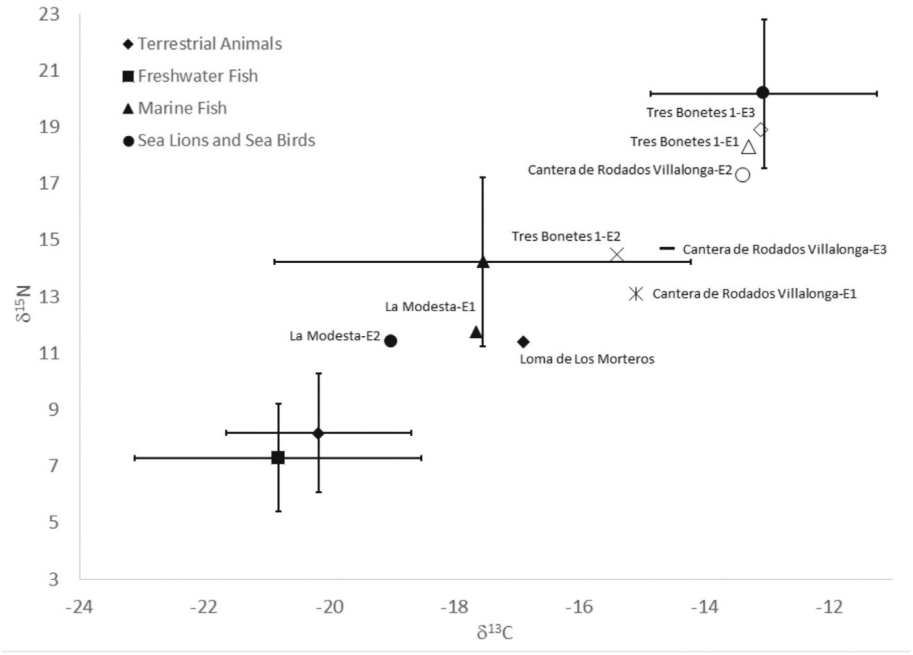

Fig. 4. Stable isotope values of $\delta^{13}C_{col}$ and $\delta^{15}N$ for different resources from the NE of Patagonia associated with human remains values from the study area.

previous work, the consumption of C_4 type vegetables (e.g., *Portulaca* sp. and *Distichis scoparia*) by guanacos may have introduced such variability in $\delta^{13}C_{col}$ values (Martínez et al., 2009).

This work has been the first to highlight the intake of resources such as pinnipeds in the study area. Although neither evidence of human exploitation of such fauna nor the presence of sea lion colonies have been registered in the area (Carrara, 1952; Martínez et al., 2009), isotopic values account for the intake of this kind of fauna during the Middle Holocene.

As commented in previous sections, the zooarchaeological record of the La Modesta site indicates that Middle Holocene subsistence was based on the exploitation of ungulates (*Lama guanicoe*) freshwater fish (*Percichthys* sp.), big rodents (*Myocastor coypus*) and possibly birds and armadillos (Alcaráz, 2015, 2017; Martínez, 2017; Stoessel, 2015). Isotopic results on individuals from this site are consistent with this trend, as both the intake of terrestrial herbivores and freshwater fish were observed. Likewise, numerous grinding artifacts were recovered, which suggest the exploitation of plant resources (Santos Valero, 2017), as is also indicated by isotopic results presented here (preferably C_3 vegetables). It is worth noticing that a significant number of marine gastropods, such as *Adelomelon* sp., were recovered from La Modesta and Loma de Los Morteros, which indicates that the groups who occupied these inland sectors of the landscape would have had access to resources coming from the Atlantic sector, as in the case of some lithic raw material (Santos Valero, 2017). However, isotopic results indicate that food resources from this setting may not have been consumed.

To sum up, isotopic results enable the establishment of very clear trends. In this regard, individuals showed diets that correspond to the place where inhumation took place; hence, the diet of those individuals buried near the sea was characterized by the intake of marine to mixed resources, while those buried inland exhibited terrestrial-continental diets. This is remarkable, as the highly mobile hunter-gatherer groups that inhabited the area during the Middle Holocene would be expected to have had a relatively homogenous diet, as can be seen in the Late Holocene (Martínez et al., 2009, see below). However, this is not the case, and moreover, such differences were not linked to either sex or chronological variables. Based on what has been proposed so far, the structure of the archeological record for the Middle Holocene would correspond to a stage of effective occupation of space, characterized by a stable occupation strategy (sensu Borrero, 1994–1995:28–33; see Martínez, 2017). In this sense, groups are known to have had vast knowledge of the territory, as well as of the distribution of resources in the area, and to have been in contact with other groups in nearby regions. Additionally, given that there were no geographical constraints that may have prevented their access to the coast, a likely explanation for the observed pattern could be the territorial behavior of groups. Based on the available archeological information, it seems unlikely that the same groups that settled inland and obtained shellfish and rocks directly from the Atlantic coast may not have simultaneously made use of marine resources as food. An alternative explanation could be that the provisioning of such resources (shellfish and rocks) might have taken place as part of an exchange system with groups that commonly settled in coastal areas, which suggests a certain degree of territorial demarcation. This may account for the contrasting dietary patterns between the coastal and inland areas (see a similar case in Dewar, 2010; Sealy, 2006). This scenario could have been better understood if coastal residential sites had been located, but only burial sites have been registered for the time being.

Certain differences can be observed when trends in terms of dietary patterns between the Middle and Late Holocene are compared for the study region (Fig. 5). In this regard, while the Middle Holocene (ca. 6000–4100 years BP) was characterized by a greater variety in terms of diet, which included marine and terrestrial components, as well as certain fluvial resources, the diet in the Late Holocene (ca. 3000–250 years BP) was relatively homogeneous, of the continental type, and characterized by the intake of protein coming from terrestrial herbivores (e.g., artiodactyls), and freshwater fish (see discussion in Martínez et al., 2009; Stoessel, 2012). The intake of marine resources was remarkably low for this time period, or at least imperceptible from stable isotopes. These results are highly relevant, since they account for the great variability in the dietary patterns of hunter-gatherer groups throughout time in the area.

6.2. Dietary patterns on a macro-regional scale

Due to the scarcity of the bioarcheological record for the Middle Holocene along with the lack of systematic studies on stable isotopes in human remains, this paper contributes to the discussion of the diet of hunter-gatherer groups in the eastern Pampa-Patagonia transition and northeastern Patagonia. In this sense, for the northern coast of the San Matías Gulf (Fig. 1), only one individual showed isotopic values that could be attributed to a marine diet (Table 5; Favier Dubois et al., 2009). Based on the analysis of the archeological record, it has been suggested that since ca. 6000 years BP, the intake of marine resources would have become intense (e.g., white croaker) through the use of fishing strategies and nets. The presence of abundant stone weights and otoliths found in the archeological sites located in Pleistocene terraces supports this argument (Favier Dubois et al., 2009; Favier Dubois and Scartascini, 2012). This trend continued during the Initial Late Holocene (ca. 3100–2200 years BP), and for this period, the values of stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) in human remains (n = 6) indicate a high intake of marine species (Favier Dubois et al., 2009). However, during the Final Late Holocene (ca. 1500–400 years BP), isotopic signals indicate the existence of mixed to predominantly terrestrial diets of lower trophic level (Favier Dubois et al., 2009).

In the case of the northern central coast of Patagonia (lower valley of Chubut river), a single individual corresponding to the Middle Holocene was recovered, and isotopic values indicated a mixed diet (Table 5; Gómez Otero, 2007). Based on the integration of the archeological record (e.g., the presence of stone weights, fish and guanaco remains, etc.) and the stable isotope values between ca. 6000–400 years BP, a great heterogeneity in the diet was observed. In this regard, mixed diets with a higher terrestrial component were recorded, and a greater use of pinnipeds and plants was detected particularly towards the Final Late Holocene (ca. 1000–400 years BP) (Gómez Otero, 2007). The observed heterogeneity would be linked to the different environmental settings in the study area with which each individual would have interacted most frequently (Gómez Otero, 2007:158).

The southeast of the Pampean region shows a different scenario, somehow due to the greater number of human burial sites belonging to the Final Early Holocene and Middle Holocene (Fig. 1; Table 5). Isotopic studies on human remains indicated variations in the sources of protein intake, including the consumption of terrestrial and marine resources in different proportions (Table 5; Bonomo et al., 2013; Politis et al., 2009; Scabuzzo, 2010). These results are coherent with the archeological information and the zooarcheological assemblages of the sites recorded in this period (e.g., La Olla 1 and 2, Barrio Las Dunas, Monte Hermoso 1, Alfar, Arroyo Seco 2, El Guanaco 1; Bayón et al., 2012; Bonomo and Leon, 2010; Bonomo et al., 2013; Frontini, 2010; Politis et al., 2009, among others). The overall trend is that human remains recovered inland showed a diet based on terrestrial resources, which included mainly animals and C_3 plants, but also C_4 type plants to a lesser degree (Arroyo Seco 2, Laguna Chasicó sites), mixed diets that contained marine protein (Arroyo Seco 2), and, in one case, a significant intake of marine resources (Table 5; Arroyo Seco 2-AS36; Politis et al., 2009). In contrast, the isotopic values for those individuals recovered from coastal areas indicate a diet based on marine resources (Monte Hermoso 1 site; Politis et al., 2009; Table 5) and mixed diets characterized by the consumption of C_3 plant-eating herbivores and the incorporation of marine proteins in different amounts (Arroyo del Moro, Meseta del Chocorí sites; Bonomo et al., 2013; Table 5). Contrary, an almost exclusive consumption of continental fauna is recorded

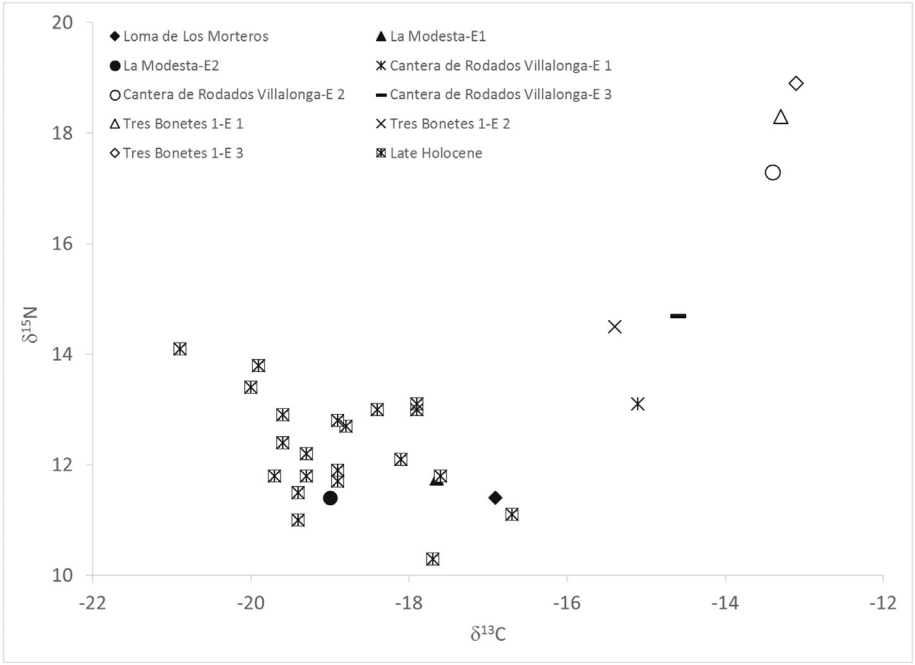

Fig. 5. Carbon and nitrogen stable isotope ratios for protein from human bone values for Middle and Late Holocene. Note: Late Holocene data taken from Martínez et al. (2009): Table 5).

Table 5
Isotopic values in adults in neighboring areas for the Final Early Holocene and Middle Holocene. Note: NCSMG: northern coast of the San Matías Gulf; CNCP-LVCR: central-northern coast of Patagonia and lower valley of the Chubut River; SPR: southeastern Pampas region.

Micro-region	Site	Age ^{14}C	$\delta^{13}C_{col}$	$\delta^{15}N$	$\delta^{13}C_{ap}$	References
NCSMG	Bahía San Antonio	4734 ± 59	− 11.5	–	–	Favier Dubois and Scartascini, 2012
CNCP-LVCR	Chacra 375	6000 ± 50	− 17.6	13.2	− 10.4	Gómez Otero, 2007
SPR	Arroyo Seco 2-AS7	7043 ± 82	− 18.3	–	− 8.8	Politis et al., 2009
	Arroyo Seco 2-AS14	6838 ± 73	− 17.0	–	− 10.1	Politis et al., 2009
	Arroyo Seco 2-AS15	7000 ± 80	− 17.7	12.6	–	Politis et al., 2009
	Arroyo Seco 2-AS19	6860 ± 60	− 17.4	–	− 10.4	Politis et al., 2009
	Arroyo Seco 2-AS21	6908 ± 76	− 18.5	–	–	Politis et al., 2009
	Arroyo Seco 2-AS24	7800 ± 115	− 17.6	–	− 11.1	Politis et al., 2009
	Arroyo Seco 2-AS26	7580 ± 50	− 19.6	–	− 9.6	Politis et al., 2009
	Arroyo Seco 2-AS31	7615 ± 90	− 17.3	–	− 11.0	Politis et al., 2009
	Arroyo Seco 2-AS32	7685 ± 95	− 18.4	–	− 9.9	Politis et al., 2009
	Arroyo Seco 2-AS36	7805 ± 85	− 12.4	–	− 10.6	Politis et al., 2009
	Arroyo Seco 2-AS38	6823 ± 69	− 18.2	–	–	Politis et al., 2009
	Arroyo Seco 2-AS40	6940 ± 75	− 17.1	–	− 10.7	Politis et al., 2009
	Monte Hermoso 1–1	6606 ± 79	− 13.6	–	–	Politis et al., 2009
	Monte Hermoso 1–2	7866 ± 75	− 13.2	–	–	Politis et al., 2009
	Arroyo del Moro-E1	6885 ± 73	− 16.7	15.7	− 8.5	Bonomo et al., 2013
	Meseta del Chocorí-E1	7623 ± 78	− 16.2	16.0	− 10.0	Bonomo et al., 2013
	Necochea-E1	7162 ± 74	− 18.5	–	–	Bonomo et al., 2013
	Necochea-E2	7013 ± 67	− 17.4	12.9	− 9.6	Bonomo et al., 2013
	Laguna Chasicó 7	3925 ± 54	- 17.5	–	–	Catella, 2014

for the Late Holocene (Bonomo et al., 2013). The similarity between diets from the eastern Pampa-Patagonia transition and the southeastern Pampean region during the Middle and Late Holocene is thus noteworthy.

7. Conclusions

The present paper contributes to the incorporation of paleodietary information for the eastern Pampa-Patagonia transition for the Middle Holocene by means of the use of stable isotopes. It is an original contribution for Pampa-Patagonia archeology, as it presents data coming from both isotopic fractions, integrated into a multivariate diet reconstruction model, which has scarcely been used in these regions. The results show a wide variety of diets for the hunter-gatherer groups that inhabited the area during the Middle Holocene, which ranged from marine to terrestrial diets. Likewise, the consumption of high trophic level marine fauna (e.g., pinnipeds) was observed for the first time. The different dietary patterns that were identified on the coast and inland have been interpreted as the result of possible territorial demarcations. However, this hypothesis still needs to be tested with a larger amount of data. Additionally, a clear temporal pattern in diet was detected between the Middle and Late Holocene, the latter being characterized by the intake of continental resources.

The variability observed in terms of paleodietary interpretations on a macro-regional scale can be related to the manner in which hunter-gatherers organized their subsistence strategies through time. While the northern coast of the San Matías Gulf showed dependence on the exploitation and consumption of marine resources during the Middle Holocene, other areas, such as the southeastern Pampean region, the eastern Pampa-Patagonia transition and the central northern coast of Patagonia, showed a more variable pattern. For the Late Holocene, however, with the exception of the latter, a continentalization of diets

was observed in every micro-region.

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