

## RESEARCH ARTICLE

# Stable isotope ecology and human palaeodiet in the northern coast of Santa Cruz (Argentine Patagonia)

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**Abstract**

The aim of this paper is to provide information on the analysis of stable isotopes obtained from bones of marine and terrestrial fauna used as potential food by hunter-gatherers on the northern coast of Santa Cruz province (Argentine Patagonia). The results from the isotopic ecology are analysed to contribute to dietary interpretations of the human populations who lived in this area. The mean of terrestrial resources is  $-19.1\text{‰} \pm 1.8\text{‰}$  and  $9.2\text{‰} \pm 2.6\text{‰}$  for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively. Meanwhile, marine resources recorded a mean of  $\delta^{13}\text{C} -12.5\text{‰} \pm 1.2\text{‰}$  and  $\delta^{15}\text{N}$  of  $19.4\text{‰} \pm 2.4\text{‰}$ . The analysed human samples come from different types of burials dated mainly in the Late Holocene. The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotopic values on human remains suggest the existence of different diets during the Late Holocene, including people who consumed mainly marine, terrestrial, and mixed proteins, with a range between  $-18\text{‰}$  to  $-10.4\text{‰}$  and  $12.4\text{‰}$  to  $23.4\text{‰}$  for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively. Some of these isotopic values, which indicate marine diets, are the highest recorded for Patagonia. The influence of the marine spray on the terrestrial trophic chains is suggested for the Patagonian Atlantic coast, evidenced by higher values in the  $\delta^{15}\text{N}$  of guanacos from the coast in relation to others studied from the hinterland.

**KEYWORDS**

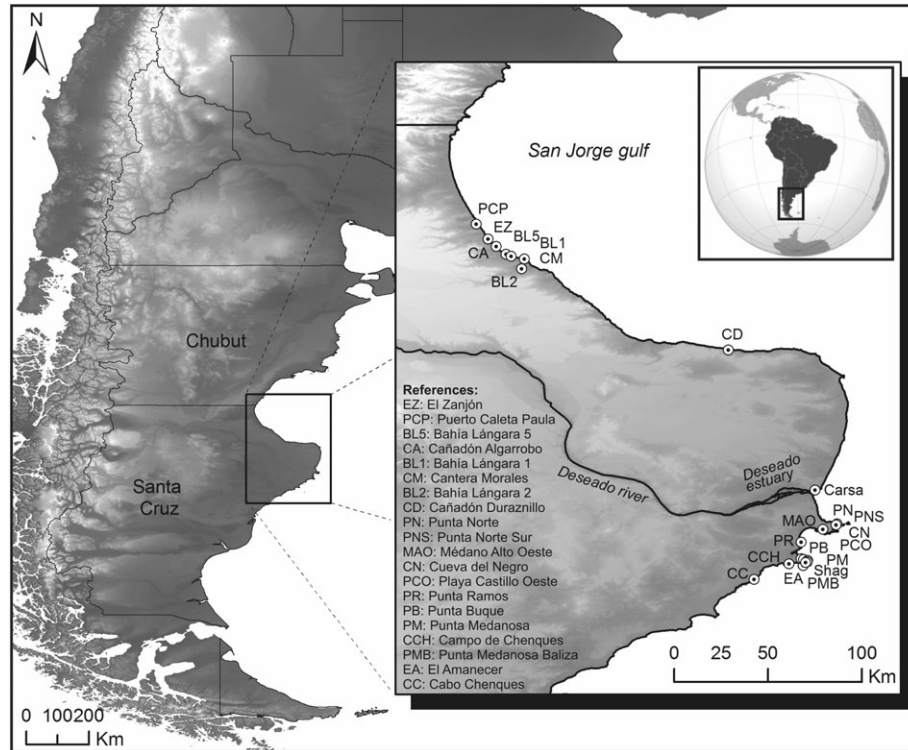
carbon and nitrogen isotopes, hunter-gatherers, isotopic ecology, Late Holocene, marine and terrestrial proteins, marine spray, Patagonia

**1 | INTRODUCTION**

Recently, a model about human mobility in the area of the northern coast of Santa Cruz province (NCSC) during the Late Holocene was proposed using multiple lines of evidence (Zilio, 2017). In this model, the Late Holocene was differentiated in two periods: Initial Late Holocene (ILH; from ca. 4,000 to 1,500 years BP) and Final Late Holocene (FLH; from ca. 1,500 to 300 years BP). For the first period, it was suggested that in the NCSC, the climatic conditions, as well as the availability of different types of food resources and freshwater, would have fluctuated. However, the climatic and environmental conditions would have been more favourable than during the FLH. During the ILH, different burial modalities were recorded, including in dunes, in pit, with flagstone cover, and in ring. The spatial patterns of human burials showed that the distribution of inhumations in the landscape

is relatively homogeneous along the coast. For this moment, the existence of a high residential mobility of the human populations and the use of different types of resources available in the coastal strip and in the inland were proposed (Zilio, 2017).

From the FLH, a period of drought would begin to develop, which would have caused the freshwater sources located in the coastal strip to be restricted to certain sectors, mainly to the south of the Deseado estuary (Figure 1). This drought would have started ca. 1,500 years BP, with a maximum peak around 900 years BP, as was recorded for other areas of Patagonia (Morales et al., 2009; Stine, 1994; Trivi de Mandri & Burry, 2007). From ca. 1,000 years BP, the only type of burial registered are the *chenques*. These burials are in the sector of the San Jorge gulf with low frequency and distributed in an isolated manner, whereas in the archaeological localities to the south of the Deseado estuary, their distribution contrasts remarkably



**FIGURE 1** Map showing the northern coast of Santa Cruz province and the human burials mentioned in this paper

because concentrations up to dozens of burials in bounded spaces are observed. The increase of dry conditions would have caused the populations to limit their home ranges to the coastal strip, mainly to those sectors located to the south of the Deseado estuary as these would have represented the most attractive places for human settlements due to the availability of marine resources (pinnipeds, seabirds, and mollusks), as well as the presence of freshwater sources.

During the FLH, the hunter-gatherers would have moved in a logistical fashion (*sensu* Binford, 1980). The home ranges would have covered the coast and part of the inland. However, unlike what was proposed for the ILH, these populations would have repeatedly occupied the coastal sectors with higher productivity (localities south of the Deseado estuary), and the coasts of the San Jorge gulf, due to freshwater scarcity, would not have allowed extended stays, or by large groups of people. The environments of the San Jorge gulf (coast and inland) during the FLH would only have encouraged the establishment of small human groups with high residential mobility, similar to what happened during the ILH, due to the lower coastal productivity influenced by the regional drought.

During the FLH in the NCSC, there was an increase in the number of residential sites, which in this coastal strip, correspond to shell middens (Hammond, 2015), as well as the emergence of artefacts oriented to the exploitation of marine resources, such as bone harpoons and “rompecráneos” (stone mace for the hunting of pinnipeds), grinding tools for the processing of terrestrial vegetables and pottery (Beretta, Zubimendi, Ciampagna, Ambrústolo, & Castro, 2013; Ciampagna, 2015; Moreno, 2008; Zubimendi, Ambrústolo, Zilio, & Castro, 2015). For this period, a process of intensification in the exploitation of marine resources was proposed (Zilio, 2017).

Also, for the FLH, archaeological evidence that suggests the existence of interactions or relationships at an extra-regional level were recognized. One of them corresponds to the mode of burial in chenque, which, unlike the other modalities registered in the NCSC, is represented in most of the Argentine-Chilean Patagonia (Goñi & Barrientos, 2004; Reyes & Méndez, 2010; Zilio, 2013; among others).

We consider that these changes in mobility and subsistence strategies must have had a correlate in the diet of hunter-gatherers based on a greater emphasis on the consumption of marine resources during the FLH. The present paper contributes to the dietary study of Late Holocene hunter-gatherers from the NCSC, by means of stable isotopic analysis and evaluation of dietary differences of individuals in marine and terrestrial proteins consumption.

The contribution of marine and terrestrial foods to the diet of individuals from this area still remains largely unknown due to the absence of a local isotopic ecology. For the interpretation of human palaeodiets, it is important to know the natural distribution of stable isotopes as well as fractionation factors that establish the trophic relationships in an ecosystem (Fry, 2006). For this purpose, results of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  studies, performed on organic bone fractions from vertebrate fauna used as potential food by hunter-gatherers, such as artiodactyls, marine mammals, dasypodids, fish, and birds recovered in archaeological sites on the NCSC, are presented.

The aim of this paper is to provide a stable isotope ecology from the NCSC. In this sense, the results on human diets are presented and discussed in the framework of the isotopic ecology. The human samples analysed come from different modalities of burials dated mainly in the Late Holocene (see below). The isotopic results obtained are utilized to characterize human palaeodiets and to identify dietary patterns in relation to the consumption of terrestrial and marine proteins.

One of the specific objectives of this work is to evaluate what kind of faunal proteins were used in the past by hunter-gatherer groups, and recognize temporal variations in the diet in relation to the types of proteins consumed by individuals, as well as the mobility and subsistence model over the Late Holocene presented for the NCSC (Zilio, 2017).

## 1.1 | Stable isotopes of carbon and nitrogen in archaeology

In archaeology, the stable isotopes of carbon and nitrogen measured on human remains are used for palaeodietary studies of past populations (Ambrose, 1993; Schoeninger, 1995). The argument of the implementation of this methodology is based on the fact that the different tissues of the organisms are directly related to the resources consumed (Ambrose, 1993; Schoeninger, 1995). This process is mediated by an isotopic enrichment, which is defined as the difference between the product and the source (Schoeninger, 1995). Bone collagen is among the most used tissues in archaeology, which is a reflection mainly of the protein diet consumed. In ecosystems, the natural distribution of stable isotopes of carbon and nitrogen is conditioned by diverse climate–environmental variables, among which are precipitation, relative humidity, temperature, altitude, solar irradiance, pH, and soil nutrients. Coastal environments, fires, and the intensity of cattle graze have also been highlighted (Hartman & Danin, 2010; Tieszen, 1991).

Stable isotopes of carbon are fixed in terrestrial ecosystems through plants, which take up atmospheric carbon during photosynthesis. There are three photosynthetic pathways:  $C_3$ ,  $C_4$ , and CAM. The first two have contrasting  $\delta^{13}C$  values that allow them to be differentiated, whereas the CAM's register intermediate values. These differences are transferred to the following trophic levels through isotopic enrichment.  $C_3$  is the most frequent photosynthetic pathway in terrestrial environments. Most trees, shrubs, and grasses belong to this photosynthetic pattern. Within the  $C_4$  plants, we must mention corn. In America, particularly, the stable isotopes of carbon in human skeletal remains have allowed to analyse the process of production and domestication of corn (Vogel & van der Merwe, 1977). The Patagonian region is dominated by plants with  $C_3$  photosynthetic pathways, and  $C_4$  are very few. Marine bicarbonates are the primary source of carbon in the marine environment, which means that marine trophic chains have isotopic parameters different to those mentioned for the terrestrial environment and have overlap with the distribution ranges of  $C_4$  and CAM plants (Chisholm, Nelson, & Schwarcz, 1982; Laffoon, Hoogland, Davies, & Hofman, 2016). However, this equifinality problem is solved by the application, in combination with  $\delta^{13}C$ , of the stable isotopes of nitrogen (Coltrain, Tackney, & O'Rourke, 2016; Laffoon et al., 2016) and, to a lesser extent, sulfur (Nehlich, 2015).

For the marine environment, it has been highlighted that the organisms have higher values than those of the terrestrial environment, so the  $\delta^{15}N$  would be a good indicator of the use of marine resources by human populations in the past. The processes influencing the stable nitrogen isotopic compositions in biological systems are complex (Szpak, Millaire, White, & Longstaffe, 2012a). Traditionally,

variation in  $\delta^{15}N$  values of bone collagen and other tissues has been interpreted within the contexts of marine versus terrestrial resource (Coltrain et al., 2016; Craig, Bondioli, Fattore, Higham, & Hedges, 2013), consumption animal versus plant protein (Schoeninger, 1995), and consumption and the relative timing of nursing and weaning (Tessone, García Guraieb, Goñi, & Panarello, 2015). Recently, investigations demonstrated that organic fertilizers, specifically those derived from animal waste, can cause large enrichments in  $\delta^{15}N$  of plant tissues (Szpak et al., 2012a & 2012b; Szpak, Longstaffe, Millaire, & White, 2014).

Likewise, in the terrestrial environment, several studies evaluated the isotopic variations of nitrogen in plant and animal species at broad spatial scales, based on sampling and transects with climatic–environmental differences (Ambrose, 1991; Hartman, 2011; Heaton, 1987; Murphy & Bowman, 2006; among others). In the archeological field, the discussion related to the effect of aridity and precipitation on animal and plant species is highlighted (for a synthesis, see Murphy & Bowman, 2006; Hartman, 2011). Finally, it is important to note that, in the coastal area, the effect of the marine spray is highlighted, which raises the values of plants and terrestrial fauna in the vicinity of the littoral space (Heaton, 1987; Richards, Fuller, & Molleson, 2006).

In this way, the combination of both stable isotopes can be used to study the relative importance of marine proteins for hunter-gatherers on the Patagonian coast in late Holocene (Barberena, 2002; Gómez Otero, 2007).

## 1.2 | Study area: Landscape and food resources

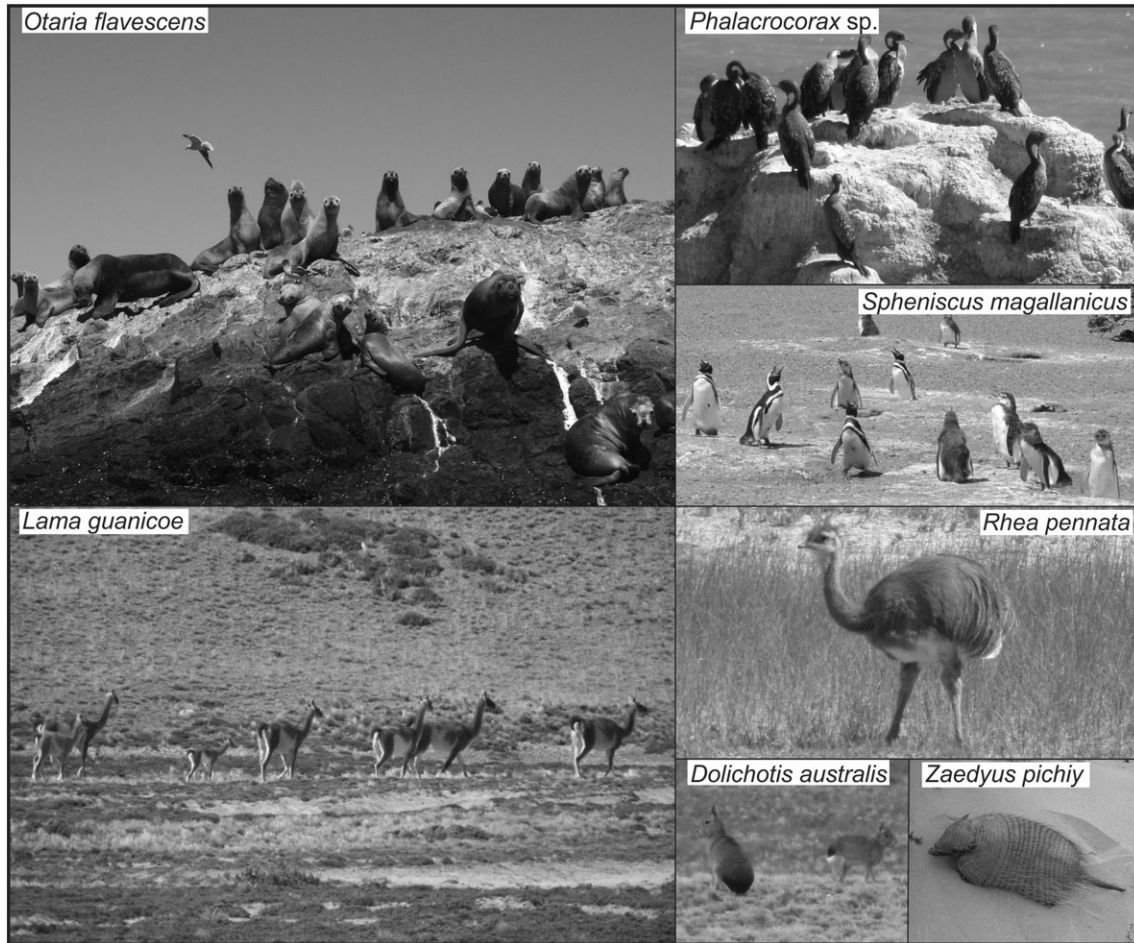
The NCSC corresponds to the territory of the Patagonian Atlantic coast located between the limit of the provinces of Chubut and Santa Cruz, to the north and Bahía Laura locality, to the south; along approximately 420 km (Figure 1). The climate is arid to semi-arid with average temperatures between 17 and 4 °C. Rain is concentrated in winter months with an average of 200 mm per year. Wind blows from the west, generating evapotranspiration, which results in extreme dryness (Soto & Vázquez, 2000). Currently, the locality is characterized by the presence of high shrub steppes and thickets. Among the terrestrial faunal resources in the study area are the guanaco (*Lama guanicoe*), choique (*Rhea pennata*), mara (*Dolichotis australis*), two species of Dasypodidae (*Zaedyus pichiy* and *Chaetophractus villosus*), and canids, among others. The marine fauna is varied and includes diverse species of mollusks (*Nacella magellanica* and *Mytilus edulis*), fish, and birds that form extensive colonies such as Magellanic penguins (*Spheniscus magellanicus*), albatross (*Thalassarche melanophrys*), and cormorants (*Phalacrocorax* sp.), and there are also large mammals, mainly represented by sea lions (*Arctocephalus australis* and *Otaria flavescens*; Figure 2).

## 1.3 | Modes of burials in the NCSC

The studies carried out in the NCSC allowed to identify six modalities of human burials (Table 1 and Figure 3).

### 1.3.1 | Burials in dune

A total of 12 burials in dune was registered, which correspond to primary burials, both individual and multiple, found in aeolian mantles



**FIGURE 2** Fauna present on the northern coast of Santa Cruz province. Photographs taken by the authors

without stone structures or other associated materials. In general, its identification occurred as a consequence of the process of deflation of the dunes, which generates the exposure of the skeletal remains.

### 1.3.2 | Burials in pit

This type of burial was found only in Bahía Lángara archaeological locality in the coast of San Jorge gulf (Figure 1). This type of inhumation is characterized by the presence of primary burials, both single and multiple (Zilio & Hammond, 2017).

### 1.3.3 | Burials with flagstone cover

So far, only two contexts of this type, called Bahía Lángara 2 and Carsa 1, have been identified (Zilio, 2017). Both contexts correspond to individual and primary burials. In addition, they are similar because the individuals were buried in a subsurface manner, and with a cover of few flat rocks that would not have been used as spatial markers because they did not protrude above the surface.

### 1.3.4 | Ring burial

In Punta Medanosa, a structure conformed by ignimbritic rocks, denominated Shag burial, was identified. This is located 150 m away from the modern shoreline. The plan morphology allowed to define an annular structure of approximately 9.6 m by 9.2 m formed by rocks, which protrude slightly on the surface (Zilio, 2017).

### 1.3.5 | Burial in cave

The only human remains from a cave context correspond to those found in Cueva del Negro shell midden (Zubimendi et al., 2015). Three isolated human bone elements were found in this site. One of the hemimandibles has six lines of black paint in a transverse direction on the outer face of the mandibular branch. The presence of human skeletal remains with evidence of painting raises the possible existence of mortuary practices associated with secondary burials.

### 1.3.6 | Chenques

The type of burial most represented in the NCSC are the chenques. These are burials, both individual and multiple, which have, as a distinctive feature, a rock cover forming a mound, which makes structures visible, sometimes at great distances.

## 2 | MATERIALS

### 2.1 | Faunal remains

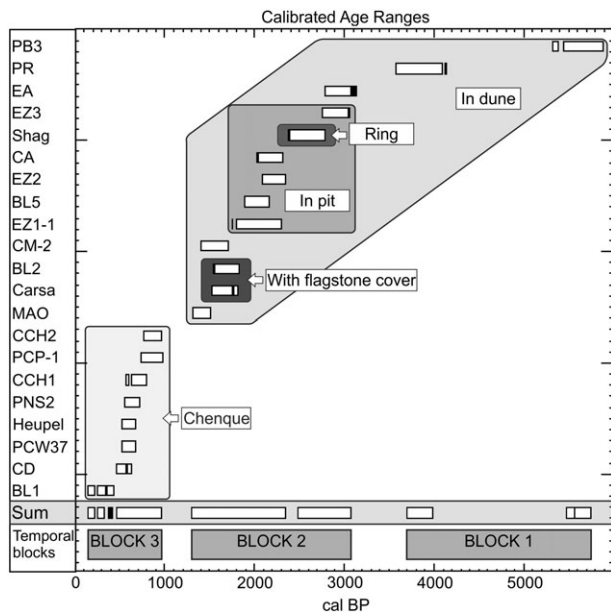
The selection of the taxa potentially consumed by humans was based mainly on the species represented in the highest frequencies in the archaeofaunistic assemblages in the study area (Hammond, 2015; Moreno, 2008). A total of 56 faunal bone samples from the following taxa were analysed: pinnipeds (*A. australis* and *O. flavescens*), seabirds

**TABLE 1** Chronology and isotopic values of human burials on the NCSC

Burial	Burial type	Sex	Age	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C/N	Lab code	$^{14}\text{C}$ age BP	Code	Mixed atmospheric/marine calibration (2 $\sigma$ )	Estimated % marine carbon	References
PCP-1	Chenque	M	Young adult	-16.1	15.5	3.1	MSR401	1,110 ± 60	LP2695	974-739	30	Zilio et al., 2014
EZ1-1	In Pit	M	Young adult	-15.4	14.6	3.2	MSR270	2,210 ± 100	LP2443	2,306-1,759	41	
EZ2	In Pit	M	Young adult	-18.0	13.0	3.0	MSR271	2,280 ± 60	LP2461	2,352-2,093	1	
EZ3	In Pit	I	Adult indet.	-17.7	12.6	3.4	AIE35407	2,850 ± 60	LP3044	3,058-2,763	7	Zilio & Hammond, 2017
CA	In Pit	F?	Young adult	-13.8	17.8	3.3	MSR298	2,400 ± 50	LP2689	2,309-2,030	65	Zilio et al., 2014
BL5	In Pit	M	Senile adult	-14.4	17.2	3.2	MSR402	2,270 ± 50	LP2705	2,157-1,891	56	
BL1	Chenque	F?	Young adult	-16.0	15.3	3.1	MSR299	390 ± 40	LP2713	437-146	32	
Heupel-1	Chenque	M	Middle adult	-15.2	16.2	3.2	AIE35389	810 ± 60	LP2393	668-519	43	
CM-2	In dune	F?	Middle adult	-15.2	-	3.2	MSR403	1,820 ± 60	LP2692	1,703-1,405	43	
CD	Chenque	M	Middle adult	-14.9	17.4	3.2	EILAB195947	720 ± 50	LP2668	628-459	48	Moreno, Zangrando, Tessone, Castro, & Panarello, 2011
BL2	With flagstone cover	F	Young adult	-	-	-	-	1,820 ± 60	LP2700	1,835-1,545*	-	Zilio et al., 2014
Carsa	With flagstone cover	M	Young adult	-17.9	12.9	3.2	EILAB195956	1,780 ± 60	LP2088	1,818-1,522	3	Moreno et al., 2011
PNS2	Chenque	M	Adult indet.	-15.8	16.4	3.0	MSR407	840 ± 60	LP2558	719-547	35	Zilio, 2017
PCO37	Chenque	I	Adult indet.	-16.1	16.5	3.2	MSR408	790 ± 60	LP2523	679-528	31	
CN	In cave	I	Adult indet.	-11.0	22.2	3.2	MSR404	-	-	-	-	
PN2	Chenque	I	Adult indet.	-18.0	12.4	3.2	EILAB195949	-	-	-	-	Moreno et al., 2011
PN3	Chenque	I	Adult indet.	-14.8	17.3	3.1	EILAB195952	-	-	-	-	
MAO	In dune	M	Senile adult	-16.6	15.6	3.2	MSR405	1,620 ± 50	LP2551	1,515-1,308	23	Zilio, 2017
PR	In dune	M	Adult indet.	-18.0	13.5	3.2	AIE35311	3,600 ± 100	LP3039	4,143-3,580	2	
PB1	In dune	I	Adult indet.	-18.0	13.2	3.3	AIE35313	-	-	-	-	
PB3	In dune	M	Young adult	-17.1	14.8	3.2	AIE35309	4,970 ± 100	LP3034	5,888-5,328	15	Zilio, 2017
PB5	In dune	I	Adult indet.	-11.9	20.0	3.2	AIE35312	-	-	-	-	
PMB180	Chenque	I	Adult indet.	-16.7	15.7	3.2	AIE35316	-	-	-	-	
PMB202	Chenque	I	Adult indet.	-13.3	19.9	3.2	AIE35310	-	-	-	-	
EA	In dune	I	Adult indet.	-17.6	14.2	3.2	MSR409	2,890 ± 60	LP2747	3,140-2,780	8	
Shag	Ring	I	Adult indet.	-16.7	15.1	3.2	MSR406	2,670 ± 70	LP2755	2,793-2,381	21	
PM12	Chenque	I	Adult indet.	-14.1	18.4	3.2	EILAB195950	-	-	-	-	Moreno et al., 2011
PM3	Chenque	I	Adult indet.	-16.5	16.0	3.2	EILAB195951	-	-	-	-	
PMB	Chenque	I	Adult indet.	-12.1	17.4	3.1	EILAB195953	-	-	-	-	
PMB14	Chenque	I	Adult indet.	-15.7	16.9	3.2	EILAB195954	-	-	-	-	
CCH2	Chenque	I	Adult indet.	-16.1	15.4	3.2	AIE35314	1,120 ± 50	LP3046	965-768	31	Zilio, 2017
CCH13P	Chenque	I	Adult indet.	-14.1	17.7	3.3	AIE35411	-	-	-	-	
CCH31P	Chenque	I	Adult indet.	-14.3	18.1	3.3	AIE35406	-	-	-	-	
CCH40P	Chenque	I	Adult indet.	-10.4	23.4	3.3	AIE35390	-	-	-	-	
CCH1	Chenque	M	Middle adult	-16.3	15.0	3.2	EILAB195948	890 ± 60	LP2778	792-564	27	Moreno et al., 2011
CC10	Chenque	I	Adult indet.	-14.9	17.1	3.2	EILAB195955	-	-	-	-	

Note. References: PCP = Puerto Caleta Paula; EZ = El Zanjón; CA = Cañadón Algarrobo; BL = Bahía Lángara; CM = Cantera Morales; CD = Cañadón Duraznillo; PNS = Punta Norte Sur; PCO = Playa Castillo Oeste; CN = Cueva del Negro; PN = Punta Norte; MAO = Médano Alto Oeste; PR = Punta Ramos; PB = Punta Buque; PMB = Punta Medanos Baliza; EA = El Amanecer; PM = Punta Medanos; CCH = Campo de Chenques; CC = Cabo Chenque. Calibrations were performed with Mixed marine SoHem curve using CALIB 7.0.4.

\*This calibration was made with SHCal13 curve.



**FIGURE 3** Distribution of calibrated dates and sum of probabilities of human remains from the northern coast of Santa Cruz province. For references, see Table 1

(*Phalacrocorax* sp., *Thalassarche melanophrys* and *Spheniscus magellanicus*), fish (indeterminate fish), Dasypodidae (*Chaetophractus villosus* and *Z. pichiy*), terrestrial birds (*R. pennata*), and artiodactils (*L. guanicoe*; Table 2).

## 2.2 | Human samples

There are values of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  available for 34 adult individuals recovered from the NCSC. The bone remains, on which the isotope determinations were made, come mainly from surface collections of skeletal parts exposed as a result of ransack, or by the alteration of natural agents (PNS2, PCO37, CN, PN2, PN3, MAO, PR, PB1, PB3, PB5, PMB180, PMB202, EA, Shag, PM12, PM3, PMB, CCH2, CCH13P, CCHP31P, CCH40P, and CC10; Table 1).

The available information for these materials is little, because the bone assemblages are represented by scarce human remains and, even in some cases, by a single bone element. For each burial, a bone sample was taken for the analysis of stable isotopes, so in this way, the possibility of taking more than one sample per individual was eliminated. The rest of the analysed samples comes from archaeological rescues (EZ2, Heupel-1, CD, Carsa, and CCH1) and bone remains handed over to the "Museo del Hombre y su Entorno" of Caleta Olivia city by local villagers (PCP-1, EZ1-1, EZ3, CA, BL5, and BL1; Table 1).

In all the analysed samples, the type of burial in which the body was buried was recognized (Table 1). Because the samples come mainly from fragmented and incomplete assemblages, determinations of sex, age, and number of individuals present by burial are not available for all cases (Table 1).

Of the 34 individuals for which stable isotope values are available, in 19 of them, radiocarbon datings were performed (Table 1). For the temporal analysis of the stable isotopes, the samples dated were grouped in three chronological blocks according to the calibration and probability sum of their dates (Figure 3 and Table 1). Temporal

Block 1 (TB1), with a range of ages between 5,742 and 3,650 years cal. BP, includes two samples: PR and PB3. These two are burials en dunes. Temporal Block 2 (TB2) has ages between 3,076 and 1,305 years cal. BP. This consists of nine samples and a variety of burial practices: burials in dunes, in pit, in ring, and with flagstone cover. The TB1 and TB2 correspond temporally with the ILH in the human dynamics model. Finally, the Temporal Block 3 (TB3) with a greater number of samples ( $N = 20$ ) is dated between 1,049 and 280 years cal. BP. This temporal block is represented only by the mode of burial in chenque and corresponds to the FLH (Zilio, 2017).

## 3 | METHODS

### 3.1 | Stables isotopes

Stable isotope analyses of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , based on the processing of the organic fraction (collagen) in skeletal remains, were performed in two laboratories.

Collagen extraction took place in the archaeological laboratory of the Museo de Historia Natural of San Rafael (code MSR). Visually, the specimens exhibited excellent preservation, without signs of thermal alteration or advanced weathering. Approximately 1 g of bone material was taken from each specimen, cleaned, and demineralized in 0.6 N HCL at 4 °C. After demineralization, the collagen pseudomorphs were rinsed repeatedly in distilled water and then treated with 5% KOH to remove humic acids and other base-soluble contaminants (Coltrain et al., 2004). The extracted collagen pseudomorph was once again rinsed to neutrality, then lyophilized and weighed to obtain the yield of collagen. Approximately 100 mg of lyophilized collagen was gelatinized by heating for 24 hr in 5 ml of acidified water (pH 3) at 120 °C. The soluble and insoluble phases were separated by filtration with 10-mm PTFE membrane filter (Millipore), and the soluble phase again lyophilized. The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of this filtered collagen were determined by combustion to produce  $\text{CO}_2$  and  $\text{N}_2$  and passing it through a Finnigan Delta Plus XP mass spectrometer connected to a Costech Elemental Analyzer (EA) 1108 at University of Utah (SIRFER).

The remaining human and all the zooarchaeological samples were processed and measured at the Instituto de Geocronología y Geología Isotópica (code AIE, UBA-CONICET). Bone fragments were cleaned with abrasive elements and ultrasonic baths. Approximately 0.3 g of each sample was repeatedly soaked in very dilute HCl (0.5%) every 24–48 hr. Then it was rinsed with deionised water and treated with NaOH (sodium hydroxide 0.125%) for 20 hr (Sealy, 1986). The collagen extracted was finally dried at 40 °C during 24 hr. The isotopic analysis of collagen was performed with a Carlo Erba EA1108 Elemental Analyzer (CHN), connected to a continuous flow Thermo Scientific Delta V Advantage mass spectrometer through a Thermo Scientific ConFlo IV interface.

The conservation status of isotopic signal was evaluated by elemental analysis C/N (De Niro, 1985). The results are expressed as the ratio of the heavier isotope to the lighter isotope and reported as Delta ( $\delta$ ) values in parts per thousand (‰) relative to internationally accepted standards for carbon (VPDB) and nitrogen (AIR) (Schwarcz & Schoeninger, 1991).

**TABLE 2**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for archaeological faunal samples for the construction of the isotopic ecology

Taxon	Common name	Archaeological site	Lab code	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C/N
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Puesto Baliza 2	AIE36579	-13.9	19.2	3.2
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Cueva del Negro	AIE36589	-13.3	14.8	3.2
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Cueva del Negro	AIE36573	-13.3	17.5	3.3
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Los Albatros	AIE36563	-13.7	20.5	3.3
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Cueva del Negro	AIE36574	-12.3	16.2	3.3
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Cueva del Negro	AIE36587	-12.2	15.8	3.4
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Médano 1	AIE36576	-11.4	16.1	3.3
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Cabo Blanco 1	AIE36585	-11.5	15.8	3.3
<i>Spheniscus magellanicus</i>	Magellanic Penguin	Cueva del Negro	AIE36561	-13.8	15.6	3.3
<i>Thalassarche melanophrys</i>	Albatross	Los Albatros	AIE37813	-12.9	17.9	3.3
<i>Thalassarche melanophrys</i>	Albatross	Los Albatros	AIE37814	-14.0	18.9	3.3
<i>Thalassarche melanophrys</i>	Albatross	Cueva del Negro	AIE37815	-15.2	16.7	3.3
<i>Thalassarche melanophrys</i>	Albatross	Cueva del Negro	AIE37816	-12.2	20.7	3.3
<i>Thalassarche melanophrys</i>	Albatross	Cueva del Negro	AIE37818	-16.2	16.6	3.2
<i>Thalassarche melanophrys</i>	Albatross	Cueva del Negro	AIE37819	-13.6	17.4	3.2
<i>Thalassarche melanophrys</i>	Albatross	Playa del Negro	AIE37822	-13.2	18.8	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Cueva del Negro	AIE37823	-10.8	20.0	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Cueva del Negro	AIE37824	-12.3	23.7	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Los Albatros	AIE37825	-11.2	19.7	3.3
<i>Phalacrocorax</i> sp.	Cormorant	UNPA	AIE37826	-11.9	20.9	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Punta Buque 1	AIE37827	-10.3	20.9	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Las Hormigas	AIE37828	-11.1	20.1	3.2
<i>Phalacrocorax</i> sp.	Cormorant	Cabo Blanco 1	AIE37829	-12.1	19.6	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Puesto Baliza 2	AIE37830	-13.4	17.6	3.4
<i>Phalacrocorax</i> sp.	Cormorant	UNPA	AIE37831	-10.1	20.3	3.3
<i>Phalacrocorax</i> sp.	Cormorant	Los Albatros	AIE37832	-10.9	19.5	3.3
Indeterminate fish	Fish	Cabo Blanco 1	AIE36614	-12.0	17.6	3.3
Pinnipeds	Sea lion	UNPA	AIE36570	-12.9	20.2	3.3
Pinnipeds	Sea lion	Médano 1	AIE36556	-14.0	21.3	3.4
Pinnipeds	Sea lion	Puesto Baliza 2	AIE36564	-12.2	20.3	3.2
Pinnipeds	Sea lion	Cueva del Negro	AIE36552	-12.6	23.2	3.3
Pinnipeds	Sea lion	Puerto Jenkins 2	AIE36554	-12.0	20.5	3.3
Pinnipeds	Sea lion	Las Hormigas	AIE36575	-12.4	19.3	3.3
Pinnipeds	Sea lion	Playa del Negro	AIE36562	-12.2	18.3	3.3
Pinnipeds	Sea lion	UNPA	AIE37808	-12.0	23.1	3.2
Pinnipeds	Sea lion	Punta Buque 1	AIE37809	-11.4	21.0	3.2
Pinnipeds	Sea lion	Cueva del Negro	AIE37810	-12.1	23.0	3.2
Pinnipeds	Sea lion	Cabo Blanco 1	AIE37811	-12.9	22.9	3.3
Pinnipeds	Sea lion	UNPA	AIE37812	-13.5	23.3	3.4
<i>Chaetophractus villosus</i>	Peludo	UNPA	AIE36622	-19.2	9.9	3.2
<i>Chaetophractus villosus</i>	Peludo	UNPA	AIE36621	-18.6	11.8	3.2
<i>Chaetophractus villosus</i>	Peludo	Punta Buque 1	AIE36616	-18.7	8.5	3.3
<i>Zaedyus pichiy</i>	Piche	Los Albatros	AIE36620	-19.6	11.5	3.3
<i>Zaedyus pichiy</i>	Piche	Punta Buque 1	AIE36619	-19.7	9.2	3.2
<i>Zaedyus pichiy</i>	Piche	UNPA	AIE36618	-19.6	8.7	3.4
<i>Zaedyus pichiy</i>	Piche	Las Hormigas	AIE36617	-19.3	7.5	3.3
<i>Lama guanicoe</i>	Guanaco	Puesto Baliza 2	AIE36613	-19.8	9.7	3.4
<i>Lama guanicoe</i>	Guanaco	UNPA	AIE36612	-19.5	8.2	3.3
<i>Lama guanicoe</i>	Guanaco	UNPA	AIE36601	-20.3	7.5	3.4
<i>Lama guanicoe</i>	Guanaco	Playa del Negro	AIE36602	-19.5	9.1	3.4
<i>Lama guanicoe</i>	Guanaco	UNPA	AIE36603	-19.9	6.7	3.4

(Continues)

TABLE 2 (Continued)

Taxon	Common name	Archaeological site	Lab code	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C/N
<i>Lama guanicoe</i>	Guanaco	112	AIE36604	-19.3	8.5	3.4
<i>Lama guanicoe</i>	Guanaco	Los Albatros	AIE36606	-19.6	8.3	3.3
<i>Lama guanicoe</i>	Guanaco	Médano 1	AIE36607	-19.1	10.1	3.4
<i>Lama guanicoe</i>	Guanaco	Cabo Blanco 1	AIE36608	-19.1	8.8	3.3
<i>Rhea pennata</i>	Ñandú	UNPA	AIE36615	-21.2	4.4	3.3

For the palaeodietary interpretation, a figure was made where isotope ecology and the estimated diet of the individuals are presented. For this purpose, the isotopic enrichment values established by Bocherens and Drucker (2003) of collagen from the consumer to collagen of the prey are considered. Likewise, the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of human diets were assumed to be 1‰ and 4‰ lower, respectively, than measured bone collagen values. In relation to the statistical analysis, to compare differences between two species/groups due to the small and different sample sizes, we used the nonparametric Mann-Whitney *U* test. Significance was assumed at  $p \leq .05$  (Somerville, Sugiyama, Manzanilla, & Schoeninger, 2016).

### 3.2 | Radiocarbon dates

Conventional radiocarbon dates on fully terrestrial materials, those whose only ultimate carbon source is contemporary carbon dioxide in the atmospheric reservoir, can be calibrated directly. However, an additional correction is necessary for dates on materials incorporating any carbon from nonterrestrial sources (Molto, Stewart, & Reimer, 1997). If the dated material represents a life in which both terrestrial and marine carbon supported the organism, the relative proportions must be estimated. This is the case when dates come from the bone collagen of humans who ate variable amounts of terrestrial and marine protein during their lives.

The terrestrial calibration curve SHCal13 accounts for the variation in atmospheric production of  $^{14}\text{C}$  in the Southern hemispheres. The Marine13 calibration curve accounts for the variation in atmospheric  $^{14}\text{C}$  and the global marine reservoir effect  $R(t)$ . The surface layer of the world's oceans consists of both contemporary carbon and older  $^{14}\text{C}$  depleted waters brought up from the deep ocean through upwelling. The average  $^{14}\text{C}$  age of the world's ocean surface layers is  $405 \pm 22$  years (Dewar & Pfeiffer, 2010). In addition to  $R(t)$ , each region has its own deviation, or local marine reservoir effect ( $\Delta R$ ), based on local mixing of currents and sources of upwelling (Stuiver & Braziunas, 1993). The calibration of  $^{14}\text{C}$  dates may have a substantial impact on interpretations of the past.

Currently, for the northern coast of Santa Cruz, a  $\Delta R$  there is not available. So  $^{14}\text{C}$  dates were calibrated using Calib 7.0.4 with the mixed curves option that mixes the SHCal13 and Marine13 calibration curves using the value of % marine carbon (Hogg et al., 2013; Table 1). Percentage marine diet is calculated from a linear plot of human bone collagen  $\delta^{13}\text{C}$  values between terrestrial and marine diet endmember values. They were generated from considering the values of local resources (Arneborg et al., 1999).

## 4 | RESULTS AND DISCUSSION

The 56 faunal samples analysed in this paper present good preservation conditions. The percentage recovery of collagen was  $15.5\% \pm 4.6\%$ , whereas the C/N ratio has an average of  $3.2 \pm 0.1$ . On the other hand, human samples register an average of the C/N ratio of  $3.2 \pm 0.1$ . In this way, both faunal and human samples show a relationship within the normal range 2.9–3.6 (De Niro & Hastorf, 1985), which allows us to make sure that the isotopic signals obtained are primary.

### 4.1 | Isotopic ecology

In terms of terrestrial proteins, guanacos register an average of  $-19.6\% \pm 0.3\%$  and  $8.5\% \pm 1\%$  for the  $\delta^{13}\text{C}$  y  $\delta^{15}\text{N}$ , respectively. The Dasypodidae have similar values with  $-19.2\% \pm 0.4\%$  for the  $\delta^{13}\text{C}$  and  $9.6\% \pm 1.6\%$  for the  $\delta^{15}\text{N}$ . These last species—*Z. pichiy* and *Chaetopractus villosus*—present the highest values in the  $\delta^{15}\text{N}$  of the terrestrial proteins with a maximum value of 11.8‰ (Table 3). Finally, there is a ñandú value of  $\delta^{13}\text{C}$   $-21.2\%$  and 4.4‰ in  $\delta^{15}\text{N}$  (Table 2).

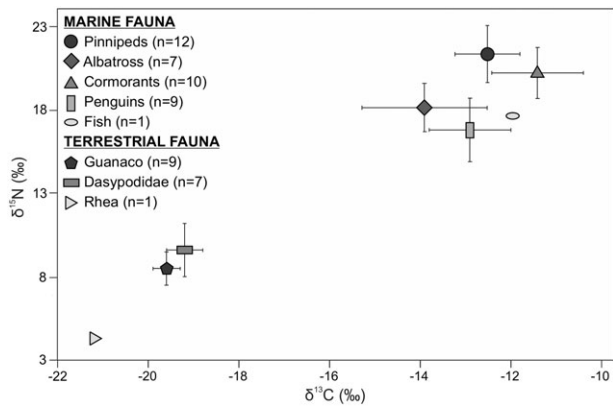
Regarding the marine environment, pinnipeds present an average of  $-12.5\% \pm 0.7\%$  and of  $21.4\% \pm 1.7\%$ , for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively. As for birds, cormorants record the highest values,  $-11.4\% \pm 1\%$  and  $20.2\% \pm 1.5\%$  for  $\delta^{13}\text{C}$  y  $\delta^{15}\text{N}$ , whereas penguins register values of  $-12.9\% \pm 0.9\%$  for  $\delta^{13}\text{C}$  and  $16.8\% \pm 1.9\%$  for  $\delta^{15}\text{N}$ . In turn, the albatrosses registered average values of  $-13.9\% \pm 1.4\%$  and  $18.1\% \pm 1.5\%$  for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  (Table 3). Finally, a sample corresponding to fish recorded in  $\delta^{13}\text{C}$   $-12.0\%$  and for  $\delta^{15}\text{N}$  17.6‰, what allows to relate this specimen with the marine environment (Table 2).

There is a clear separation between marine and terrestrial proteins (Figure 4). As regards terrestrial resources, the separation of the ñandú with respect to the guanacos and the Dasypodidae, which present

TABLE 3 Descriptive statistics of isotopic values for faunal remains from the northern coast of Santa Cruz province

Resources	Isotope	N	Mean	Stand. Dev	Min	Max	
Marine	Pinnipeds	$\delta^{13}\text{C}$	12	-12.5	0.7	-14	-11.4
		$\delta^{15}\text{N}$	12	21.4	1.7	18.3	23.3
	Albatross	$\delta^{13}\text{C}$	7	-13.9	1.4	-16.2	-12.2
		$\delta^{15}\text{N}$	7	18.1	1.5	16.6	20.7
	Cormorants	$\delta^{13}\text{C}$	10	-11.4	1.0	-13.4	-10.1
		$\delta^{15}\text{N}$	10	20.2	1.5	17.6	23.7
	Penguins	$\delta^{13}\text{C}$	9	-12.9	0.9	-13.9	-11.4
		$\delta^{15}\text{N}$	9	16.8	1.9	14.8	20.5
	Terrestrial	Guanaco	$\delta^{13}\text{C}$	9	-19.6	0.3	-20.3
$\delta^{15}\text{N}$			9	8.5	1.0	6.7	10.1
Dasypodidae		$\delta^{13}\text{C}$	7	-19.2	0.4	-19.7	-18.6
		$\delta^{15}\text{N}$	7	9.6	1.6	7.5	11.8





**FIGURE 4** Distribution of faunal values from the northern coast of Santa Cruz province

similar values, is observed. On the other hand, marine resources present major trophic differences. The pinnipeds recorded the highest values with the cormorants, whereas the lowest values were recorded in penguins.

So far, there are few marine isotope ecologies on the Atlantic coast of Patagonia. Although there are many works of stable isotopes in human palaeodiets, we consider important to start studying the isotopic ecologies of the different areas to deepen the interpretations on the subsistence strategies of hunter-gatherers and their spatial and temporal variations. Recently, for the Beagle channel, an extensive database of marine resources has been generated (Kochi et al., 2017). In this sense, the differences between the isotopic values of pinnipeds and cormorants registered in the Beagle Channel and in this research are interesting. In the NCSC, pinnipeds and cormorants could have consumed other resources of higher trophic level than in the Beagle Channel, or the same prey, but with higher isotopic values. However, it is striking that penguins and albatrosses register similar values in both regions. In this way, these differences are a call for attention to the extrapolation of reference isotope values between different research areas.

In articles of marine ecology, differences have been mentioned in the trophic chains of the Atlantic coast of Patagonia, highlighting latitude and primary productivity as the main factors in the structuring of the marine trophic chains in the region (Saporiti et al., 2014).

In the same sense, in the terrestrial environment, the guanacos analysed here register higher values in the  $\delta^{15}\text{N}$  if we compare them with those studied in the inland of the province at similar latitude distant about 400 km from the NCSC, with a mean of 6.1‰ in the  $\delta^{15}\text{N}$ . The differences are statistically significant ( $p \leq .05$ ; Tessone, 2010; Tessone, Rindel, Belardi, Panarello, & Goñi, 2014). A possible cause of the difference would be the influence of the marine spray on the terrestrial trophic chains. This was recorded in different parts of the world (Heaton, 1987) and suggested for continental Patagonia (Gómez Otero, 2007). The data provided here represent strongly supports of this behaviour in the natural distribution of the isotopes of nitrogen. Thus, up to now, the analysed samples would be reflecting the hunting of guanacos in areas near the coast. In the future, it will be necessary to establish how far from the coast the influence of the marine spray on this species is reflected, and the possibility of analysing these variations to study the exploitation areas of the guanaco (coast or inland), and the probability of transporting the carcasses by the hunter-gatherers groups.

## 4.2 | Human palaeodiets

The main characteristic of human samples is the great variability of palaeodiets, in which diets based mainly on terrestrial as well as exclusively on marine proteins are represented. The  $\delta^{13}\text{C}$  varies between  $-18\text{‰}$  and  $-10.4\text{‰}$ , whereas the  $\delta^{15}\text{N}$  between  $12.4\text{‰}$  and  $23.4\text{‰}$ . Three values of  $\delta^{15}\text{N}$  stand out between  $20.0\text{‰}$  and  $23.4\text{‰}$  (Table 1), which represent the highest values of  $\delta^{15}\text{N}$  so far recorded in the Atlantic coast of Patagonia (Barberena, 2002; Borrero et al., 2001; Favier Dubois, Borella, & Tykot, 2009; Gómez Otero, 2007; Guichón, Borrero, Prieto, Cárdenas, & Tykot, 2001; Suby, Guichón, & Zangrando, 2009; Yesner, Figuerero Torres, Guichón, & Borrero, 1991; Zilio, Gordón, Béguelin, & Castro, 2014). These values reflect an exclusive consumption of marine proteins by hunter-gatherers during the Late Holocene. Other contexts where extremely high values of  $\delta^{15}\text{N}$  have also been recorded are the northern coast of Chile (Santana Sagredo, Hubbe, & Uribe, 2016), the southern coast of Peru (Tomczak, 2003), and the coast of Brazil (Colonese et al., 2014), as well as in historic Alaskan Eskimo populations, whose diet consisted mainly of marine mammals, and in the Haida and Tlingit societies of the north-west coast of the United States, which depended fundamentally on fishing salmon (Schoeninger, De Niro, & Tauber, 1983).

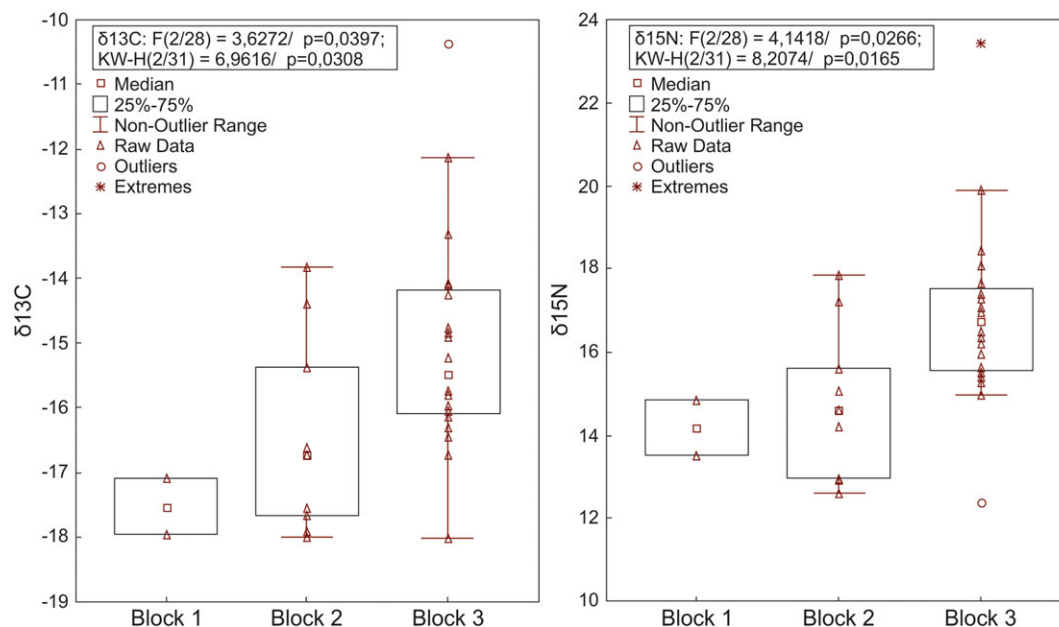
In spatial terms, there are differences in the number of archaeological sites and artefacts between San Jorge gulf and south of the Deseado estuary (Figure 1; Hammond, 2015; Zubimendi et al., 2015; Zilio, 2017). However, when comparing palaeodietas of these two sectors, the differences are not statistically significant (Mann–Whitney  $p < .05$ ). The only difference that appears between these sectors is that the individuals with isotopic values that indicate exclusively marine diets come from archaeological localities to the south of the Deseado estuary.

The temporal analysis reveals a greater emphasis on the consumption of marine proteins during the TB3 (Table 4 and Figure 5). The differences of the medians are 1.3‰ and 2.1‰ between TB2 and TB3 for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively, being the difference in this last isotopic ratio statistically significant (Mann–Whitney  $p < .05$ ). As for TB1, it only has two values, but they are located within the distribution of TB2.

By relating the isotopic ecology with the estimated diet of the individuals, three main aspects can be observed. First is a predominance of mixed diets represented by the consumption of marine and terrestrial proteins in variable proportions. Second, another aspect to be highlighted is that diets based mainly on terrestrial resources are recorded in all temporal blocks, although its predominance in TB2 is clear. Third, for the moment, only in the TB3, there are diets based mostly on marine proteins.

**TABLE 4** Descriptive statistics of isotopic values for human remains and temporal blocks

Temporal block	Block 2		Block 3	
	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
N	9	9	20	20
Mean	-16.4	14.8	-15.1	16.9
Stand. dev	1.5	1.8	1.7	2.1
Min	-18	12.6	-18	12.4
Max	-13.8	17.8	-10.4	23.4



**FIGURE 5** Box plots showing  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  human values from northern coast of Santa Cruz province and the temporal blocks [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

However, there are two individuals associated with burials in cave and in dune, of which absolute chronologies are not available, which register values of  $\delta^{15}\text{N}$  greater than 20.0‰ (Figure 6).

From the results of the human samples, and taking into account isotope ecology and radiocarbon dating, it is possible to infer that human populations in the NCSC used the marine and terrestrial proteins during the Late Holocene. However, from the temporal analysis, it is established that the exploitation of marine resources was greater during the last temporal block associated with the human remains recovered in chenques and dated to the last 1,000 years (Figures 5 and 6).

Associated with the TB3, there is an important record of shell middens in the NCSC, especially to the south of the Deseado estuary (Hammond, 2015). They present a large number of mollusk exoskeletons and marine vertebrate fauna. Also at this moment, the implementation of artefacts oriented to the exploitation of marine resources, such as harpoons (Beretta et al., 2013; Moreno, 2008) and “rompecráneos” for pinniped hunting (Moreno, 2008) is appreciated, as well as grinding tools for the processing of terrestrial vegetables (Ciampagna, 2015), and the emergence of pottery technology (Zubimendi et al., 2015). Also, a slight reduction in the average sizes of mollusk exoskeletons from shell middens of the three species with highest nutritional value during the Late Holocene was recorded. This reduction of the size of exoskeletons was interpreted as a consequence of a process of intensification in the use of malacological resources (Hammond & Zilio, 2016).

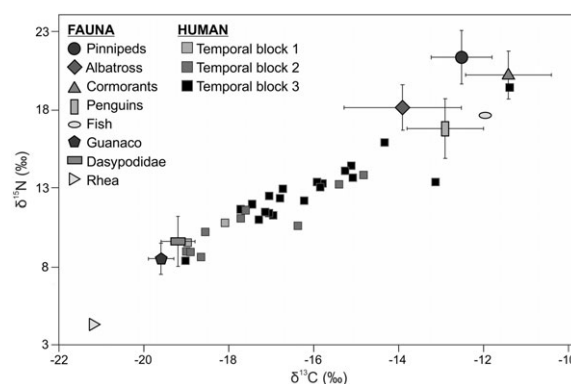
These particularities, associated with TB3, have been associated with modifications in the subsistence and mobility strategies of the hunter-gatherer groups during the FLH. From the isotopic, archaeofaunal, artefactual, and the spacial distribution of the archaeological record, a process of intensification in the exploitation of coastal resources was proposed. This process would have involved the implementation of a diversification strategy (sensu Betts & Friesen, 2004) in

the exploitation of marine and terrestrial resources. There would have been an increase in the diversity or quantity of food species, as well as changes in the organization and strategies for obtaining resources (Zilio, 2017).

## 5 | IMPLICATIONS

The results obtained provide evidence of the increasingly intensive use of marine resources, reaching in some individuals a total dependence on these during the FLH.

One of the contributions of this paper is the creation of a regional isotope ecology. We believe that they are necessary to perform palaeodietary interpretations in human remains. From the isotope ecology, two possible lines of research are revealed that would be interesting to explore from the analysis of the zooarchaeological record. In relation to terrestrial trophic chains, the possibility of differentiating populations of guanacos that inhabit the coast and the inland will allow to discuss



**FIGURE 6** Collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values. Distribution of human (temporal blocks) and faunal values from northern coast of Santa Cruz province

aspects related to the exploitation areas by hunter-gatherers. In relation to the model proposed by Zilio (2017), the isotopic expectation would be different according to the temporal block associated with changes in the mobility of the populations. On the other hand, in relation to the marine trophic chains, the comparative analysis of the isotopic record from the faunal remains of the archaeological sites is showing spatial and temporal variability, which denotes the complexity of the marine environment and the need to continue expanding these samplings.

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