



Living on the coast without depending on coastal resources. Isotopic evidence in Central Chile

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ABSTRACT

Along the Pacific coast of South America, including what is now Chilean territory, the coastal zone has been exploited since the earliest peopling of the continent and marine resources played an important role in the development of pre-Hispanic communities. Analysis of stable isotopes in human remains has confirmed the importance of marine resources in the diet of these populations; however, based on the isotope results presented here, Central Chile appears to be an exception. The analyses of stable isotopes of C, N and O that we have carried out show that occupation of coastal areas did not necessarily imply a diet based on marine resources. Individuals who lived on the coast from the Late Archaic and throughout the Early Ceramic and Late Intermediate periods present varied approaches to subsistence; only in some cases were low trophic level coastal resources the principal component of their diet. We argue that Central Chile is an unusual case in this region, when compared to populations along the rest of the Chilean coast who were highly dependent on marine foods.

1. Introduction

All along the Pacific coast of South America, and especially on the 4000 km of what is now the Chilean coast, marine resources played a preponderant role in the development of the cultural history of the resident populations. The Pacific coast in these latitudes has a highly productive ecosystem due to the presence of the Humboldt Current. This has been exploited since the earliest peopling of South America, as is shown by the very early coastal sites with clear evidence of a subsistence strategy oriented towards marine resources (Sandweiss, 2008). A preponderant role has been attributed to the same ecosystem in the rise of early social complexity on the coast of Peru, thanks to the abundant and predictable supply of resources that it provides (Moseley, 1975).

To the south of Peru, the use of marine resources has been reliably dated to the early peopling of the Southern Cone (Monte Verde site, Dillehay et al., 2008), while early occupation of the coast is documented by the existence of coastal settlements and by big shell middens which provide evidence of the exploitation of marine molluscs, fish, birds and mammals since early times (Llagostera, 1989; Núñez, 1999; Quiroz and Sánchez, 2004; Ramírez et al., 1991; Salazar et al., 2015). These activities extend to historical periods as assessed in ethno-historical and ethnographic records, when groups like the *Changos*, on the Atacama coast (Ballester and Gallardo, 2015) and the marine hunter-

gatherers of the far south (Massone et al., 2016) presented subsistence strategies oriented towards exploitation of coastal resources which continued to be used until recent times.

Analysis of stable isotopes in human remains has confirmed the importance of marine resources in the diet of the populations who lived along the southern Pacific coast of South America (Fig. 1). On the Arid Northern coast of Chile, analyses carried out in Chinchorro populations (Aufderheide et al., 1993; Tieszen et al., 1995) show a marked trend towards the consumption of marine foods of high trophic levels; this trend was maintained throughout the pre-Hispanic era, during the Formative, Middle and Late periods (Andrade et al., 2015, 2016; Aufderheide et al., 1994; Aufderheide and Santoro, 1999; King et al., 2018; Roberts et al., 2013). In this zone we also see that marine resources played an important role in the diet of populations living inland (Tarapacá, Quillagua and the middle course of the Loa river), consistent with the vast regional integration network then in existence (Pestle et al., 2015a, 2015b; Petruzzelli et al., 2012; Santana-Sagredo et al., 2012, 2015, 2016; Torres-Rouff et al., 2012).

Further south, in the Semi-arid North, a set of human remains with one of the earliest datings in South America, recovered from the Los Rieles site a few km south of Los Vilos, presents very high values of $\delta^{15}\text{N}$, suggesting a marine diet (Jackson et al., 2012). This is consistent with the inferences which can be drawn from the records associated with the Huentelauquén Complex, which indicate a coastal orientation

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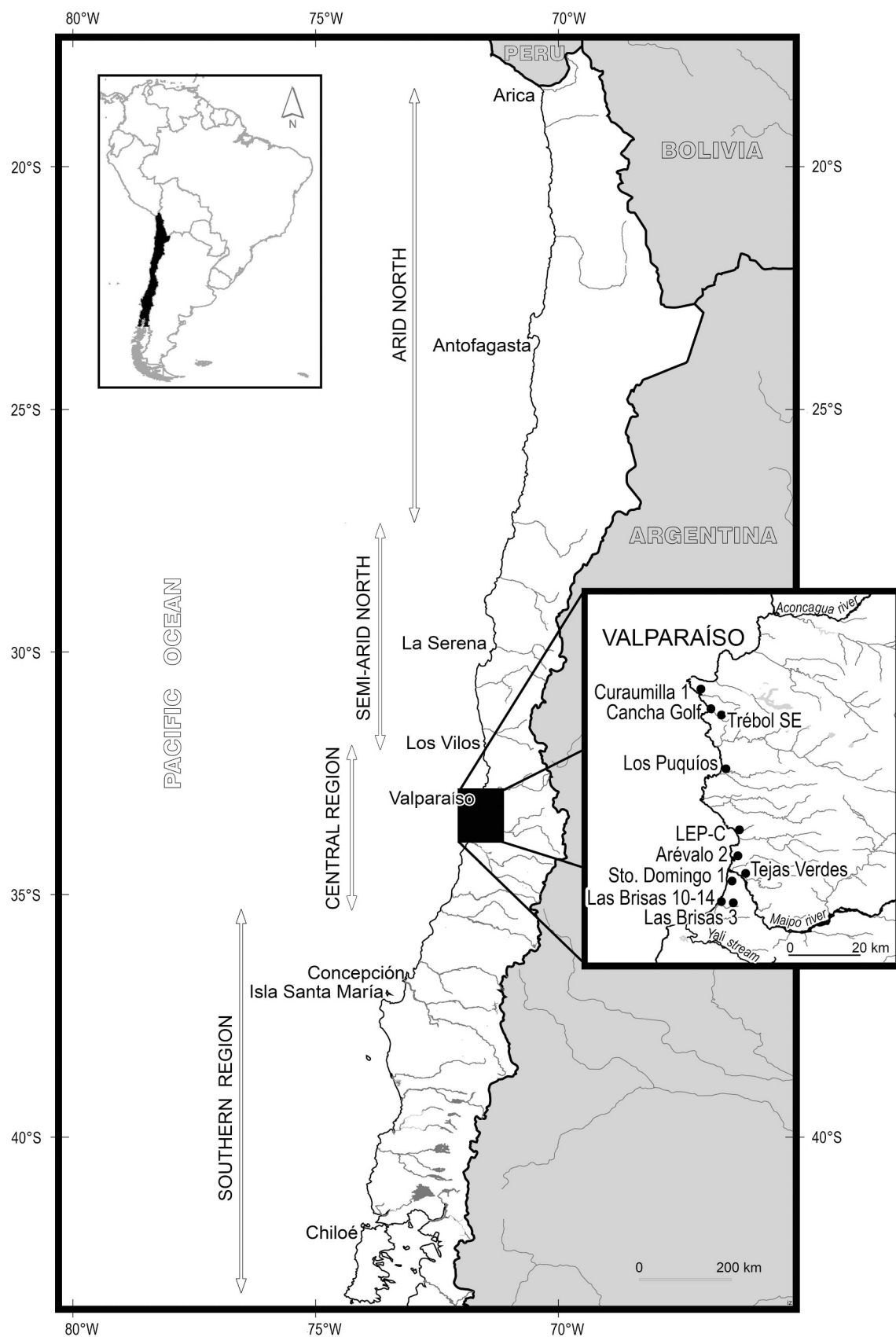


Fig. 1. Map showing the geographic regions in Chile and the archaeological sites in the Central region discussed in the text.

Table 1

NISP percentages from zooarchaeological data in coastal sites in Central Chile. Data compiled from Falabella and Planella (1991) for site LEP-C; Planella and Falabella (1987) for AVLO-2; Rivas and González (2008) for LB-3; Falabella and Planella (1979) for TV1; Vargas (2003) for LB-10-14.

	Period ^a	Cultural group	marine Mammals %	Birds %	Fish %	Total marine protein %	Camelid %	Other inland fauna %	Total inland protein %	Lagoon fauna %
LEP-C	LAP	Archaic	51,1	2,9	32,3	86,3	0,5	9,4	9,9	3,9
LEP-C	ECP	Llolleo	0,7	53,5	27,6	81,8	0,4	11,0	11,4	6,8
AVLO-2	ECP	Bato	34,5	7,2	2,0	43,7	26,8	4,3	31,1	0,1
LB-3	ECP	Bato	0,6	10,7	7,1	18,3	55,6	32,8	88,4	0,4
TV1	LIP	Aconcagua	0,4	48,8	19,0	68,2	18,7	9,6	28,3	4,0
LB-10-14	LIP	Aconcagua	0,5	10,7	35,0	46,2	48,7	4,0	52,7	1,1

^a LAP, Late Archaic period; ECP, Early Ceramic period; LIP, Late Intermediate period.

in the subsistence of these first occupants of the area (Jackson et al., 2011). The trend towards marine-based subsistence is maintained in coastal sites at least until the Late Intermediate period (Alfonso-Durruty et al., 2017; Becker et al., 2015).

Towards the south of our study area (Central Chile), isotope analyses are very scarce. Nevertheless, the results of the only 5 individuals analysed, all originating from Santa María Island in Concepción Bay and dated to the first millennium CE, show very high $\delta^{15}\text{N}$ values, suggesting that their diet was based on marine resources, principally of a high trophic level (Massone et al., 2011). Further south again, in Chiloé and the Chonos Archipelago, the isotope values agree with a marine hunter-gatherer way of life, as supported by both the material and the ethnographic records (Reyes et al., 2015).

In this panorama, Central Chile – particularly the area around the mouth of the Maipo river – presents an exception. The stable isotope analyses that we have been carrying out in the region for the last ten years have shown a trend which contradicts that of the occupations on the rest of the Pacific coast, ruling out “marine specialisation” for this area (Falabella et al., 2007, 2008; Sanhueza and Falabella, 2010). In this work we present new data from individuals previously analysed, as well as new analyses of bones and teeth. These, together with existing information and data published recently for the Aconcagua Valley, located immediately north of our study area (Swift et al., 2017), will enable us to present a more complete panorama of this particular situation.

2. Pre-Hispanic occupations along the coast of Central Chile

There is a long tradition in Central Chile of human access to and use of the coast, supported by the dates of the Curaumilla-1 shell midden (from 7500 BCE) and offerings of Pacific Ocean gastropods (*Concholepas concholepas*) in the Andes Range (Piuquenes Cave from 10076 to 9373 BCE) (Cornejo et al., 2016; Ramírez et al., 1991; Stehberg et al., 2005). Archaeological research has documented sites scattered all along the coast between the Aconcagua river and the Yali stream, on dunes, terraces, rocky outcrops, around lakes and river or stream mouths, and on low hills less than 5 km from the sea (Berdichewsky, 1964). Most of them are relatively shallow, low-density sites, associated with pottery sherds, while a few are up to 2 to 4 m deep, reported as “pre-ceramic”. In most of the latter there have been no surface collections or excavations to prove that they are anthropic. Unfortunately many of these shell middens were affected early on by exploitation of the shells for lime, and subsequently for urban construction; there are few recent archaeological investigations in which the resources used are documented.

Occupation of the coast where ceramic technology appeared at an early date (Curaumilla-1, 860 BCE; Arévalo-2, ca. 300 BCE) continued during later periods. In fact the occupations of the Early Ceramic period

(ECP) (ca. 0–1000/1200 CE) and the Late Intermediate period (LIP) (1000–1450 CE) are also widely documented along the coast (Avalos et al., 2010; Avalos et al., 2007; Carmona et al., 2001; Ciprés Consultores, 2003; Falabella and Planella, 1991; Planella and Falabella, 1987; Ramírez et al., 1991; Rivas and González, 2008; Rivas and Ocampo, 1996, 1997). These periods are distinguished from the Archaic not only by the appearance of pottery, but also because they are associated with an increasingly horticultural way of life more dependent on maize, which in turn has been associated with greater sedentarism (Falabella et al., 2016a).

In sites with a sequence of human occupations from the Archaic to the ECP, such as Curaumilla-1 and LEP-C, a change in the archaeofauna has been assessed from one period to the next. During the Archaic, abundant remains of marine mammals are recorded, with scarce fish remains and low diversity of molluscs, the specimens found being very large. During the ECP on the other hand, there is a scarcity of marine mammals, an increase in land mammals, few fish remains and a diversity of molluscs of decreasing sizes (Jerardino et al., 1992; Falabella and Planella, 1991). In the ECP and LIP, for which more information is available, notable diversity is found in the discarded food remains, of both vertebrates and invertebrates (Table 1). We have no MNI data of shells and bone remains which would allow quantitative integration of the information from these different food sources for the sites studied, and where information is available the sampling units are not comparable. Thus we have quantification and taxonomic identification of molluscs on the one hand and bone remains on the other, but we have no way of integrating this information or combining it with data for other food sources such as plants.

A striking feature, in comparison with coastal sites in the north and south of Chile, is the relatively low depth and low density of the sites and the scarce presence of tools related with the extraction of marine resources. In some sites, such as LEP-C, the most frequent remains are mollusc shells from species which live on sandy or rocky bottoms, together with remains of fish which inhabit principally the intertidal rock pools, which can be caught without specialised artefacts (Falabella et al., 1994; Vargas, 1992). In others however, such as Las Brisas 10–14, the shells are associated with marine fish species which are known to have been caught using nets or some kind of hook (*Trachurus symmetricus*, *Cilus gilberti*, *Merluccius gayi*, *Micropogonias furnieri*) (Vargas, 2003). In contrast to this archaeofaunal data, artefacts for sea-hunting and fishing are only occasionally found in the sites studied. Although in some sites this may be related with the scarce archaeological visibility of some fishing techniques like nets, there is a remarkable difference in comparison with the archaeological record in coastal sites in the north and south of Chile (Falabella et al., 2016b).

As is well known, archaeological ecofacts and artefacts present limitations when we seek to understand the type of diet of the residents of these sites. The new isotope evidence provides much more precise

data about what each inhabitant consumed, and opens the way to discovering whether the contextual differences in which the central Chilean coast appears as an anomaly on the southern Pacific coastline are related with consumption habits, and whether these were stable or varied over time.

3. Methods

Archaeology has benefited for years from analysis of the stable isotopes of carbon ($^{12}\text{C}/^{13}\text{C}$) and nitrogen ($^{14}\text{N}/^{15}\text{N}$) to identify diet patterns (DeNiro and Epstein, 1976; Schoeninger et al., 1983; van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). The basic principle is that the carbon and nitrogen isotope composition of human tissues is derived from the foods consumed, and this relation has been tested in multiple experimental studies (Ambrose and Norr, 1993; Katzenberg, 1992; Passey et al., 2005; Tieszen and Fagre, 1993; van der Merwe, 1992). Bone consists of an organic matrix or collagen, at least 75% of which is produced by the protein portion of diet, and a mineral matrix or hydroxyapatite produced by the whole diet including carbohydrates and lipids as well as proteins (Fernandes et al., 2012; Norr, 1995). The $^{16}\text{O}/^{18}\text{O}$ ratio in bone hydroxyapatite and tooth enamel reflects the body's water composition, derived principally from the water drunk and to a lesser degree from the food eaten (Fricke et al., 1995; Longinelli, 1984; Luz and Kolodny, 1985). The human being's continuous need to drink means that the values recorded in bones and teeth should reflect the isotope composition of the drinking water in their environment.

Both the collagen and the apatite in bones are replaced constantly during the individual's life and reflect the isotopic composition of his/her average diet and drinking water over recent years according to age and the turnover rate of the bone analysed (Ambrose, 1993; Hedges et al., 2007; Richards and Hedges, 1999). Tooth enamel on the other hand reflects the period of tooth formation (Wright and Schwarcz, 1998), which in the case of the third molars is between 9 and 12 years; the second molars and premolars are formed approximately between the ages of 3.8 and 6.8 years. Comparing the teeth and the bones of an individual is a way of assessing possible changes in subsistence and residence between childhood and adulthood.

For the main objective of this work – to distinguish the marine and terrestrial components of diet – the nitrogen stable isotope ratios are especially sensitive (see cautionary notes in Makarewicz and Sealy, 2015). On the one hand, $\delta^{15}\text{N}$ values distinguish between different trophic levels, increasing due to fractionation by approximately 3–4‰, and up to around 6‰, in each successive level of the trophic chain (Bocherens, 2000; DeNiro and Epstein, 1981; O'Connell et al., 2012). Because aquatic chains tend to contain more trophic levels than terrestrial ones, the $\delta^{15}\text{N}$ value of diets based on marine products is notably higher (Hedges and Reynard, 2007; Keegan and DeNiro, 1988; Schoeninger et al., 1983; Walker and DeNiro, 1986). On the other hand, nitrates at the base of the marine food chain are enriched relative to nitrates used by terrestrial organisms causing marine resources to have more positive $\delta^{15}\text{N}$ values than terrestrial ones at similar trophic levels (Price et al., 1985). Many variables affect the $\delta^{15}\text{N}$ values (Ambrose, 1991; Makarewicz and Sealy, 2015; Reynard, 2017; Szpak et al., 2012, 2014). On the Chilean coast, some of the recognised N enrichment factors in the Arid North are: the high value found in marine resources, regardless of their trophic level; the “aridity” effect; and the use of manure or guano from sea birds or terrestrial animals as fertilizers in agricultural practices (King et al., 2018; Santana-Sagredo et al., 2015).

Carbon isotopes also distinguish marine from terrestrial ecosystems because seawater bicarbonate is 7‰ more positive than atmospheric CO_2 , increasing the $\delta^{13}\text{C}$ value of marine diet consumers – although

there is a great deal of overlap between organisms in the two environments (Chisholm et al., 1983; Price et al., 1985; Schoeninger and DeNiro, 1984). Carbon isotope ratios are most useful in distinguishing C_3 (low values) from C_4 (high values) plant photosynthetic pathways. When maize, an important C_4 staple food for horticultural and agricultural groups in Chile, is added to the diet, $\delta^{13}\text{C}$ values also increase significantly, blurring the distinctive difference in carbon isotopes between marine and terrestrial foods.

In Central Chile, oxygen isotope ratios vary from the sea to the Andes mountain range. Rain water along the coast has a $\delta^{18}\text{O}_{\text{SMOW}}$ value of around –3 to –4‰. This value diminishes progressively further inland, due to evaporation, lower temperature and increasing altitude, generating significant differences between the coast and inland locations (Moser et al., 1972; Sánchez-Murillo et al., 2018).

The analyses were carried out in the Laboratory for Archaeological Science at the University of South Florida (USF) or in the Center for Applied Isotope Studies at the University of Georgia (CAIS/UGAMS). Each laboratory applied its own protocols for obtaining and analysing collagen and apatite, which were not necessarily identical (see Tykot (2004) for USF and Cherkinsky et al. (2010) for CAIS/UGAMS). This situation does not present serious problems in the case of collagen, to judge by the results of an inter-laboratory study which showed that the differences between the laboratories in the analysis of stable isotopes of bone collagen were of a small magnitude. In the case of apatite, on the other hand, variation was found in the results of analysis which could be confused with biological differences; it is recommended that data of this kind obtained from different laboratories should be viewed with great caution (Pestle et al., 2014).

The present analysis contains only those samples which presented adequate collagen preservation (C:N between 2.9 and 3.6 in the samples analysed by CAIS/UGAMS and/or complete pseudomorphs with bone collagen content higher than 1% in the USF samples). Results are expressed using the delta (δ) notation. Standards for ^{13}C and ^{15}N were the Vienna Pee Dee Belemnite (VPDB) standard and atmospheric nitrogen (AIR) respectively.

4. Results and discussion

4.1. Isotope data of pre-Hispanic coastal people in Central Chile

The samples that we analysed from archaeological sites on the coast of Central Chile (Fig. 1) were extracted from bones and molars of adult individuals, of both sexes, covering a period of some 2500 years and belonging to four clearly differentiated cultural contexts (Archaic, Bato, Llolleo and Aconcagua) distributed in three time periods (Late Archaic, Early Ceramic and Late Intermediate periods). The results appear grouped by cultural group in Table 2.

If the samples from coastal and inland zones in the Central Region (Falabella et al., 2007; present publication) are pooled, the isotope data for bone collagen show indisputably that those individuals who lived and were buried on the coast can be clearly distinguished from those from the interior, both by the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values which indicate the origin of the proteins consumed (Fig. 2) and by the $\delta^{18}\text{O}$ related with the water that they drank (Fig. 3). On the one hand there is no doubt that marine fauna formed part of the diet in these coastal sites, yet when their importance is assessed against the isotope baseline values for marine resources in this area we must conclude that they are only complementary and/or for the most part of a low trophic level, since the individuals present very low $\delta^{15}\text{N}$ values for a diet based mainly on marine resources. And on the other, it seems clear that the individuals analysed lived on or very near the coast for at least a large part of the year because the $\delta^{18}\text{O}$ values are those expected for people drinking

Table 2
Isotopic values for the coastal samples from Central Chile, grouped by cultural context.

	Site Ind. #/tooth	Sex	Age BP (cal age 2 sigmas)	LAB-ID	$\delta^{13}\text{C}_{\text{col}}$ VPDB ‰	$\delta^{15}\text{N}$ AIR ‰	LAB-ID	$\delta^{13}\text{C}_{\text{ap}}$ VPDB ‰	$\delta^{18}\text{O}_{\text{ap}}$ VPDB ‰	LAB-ID	$\delta^{13}\text{C}_{\text{en}}$ VPDB ‰	$\delta^{18}\text{O}_{\text{en}}$ VPDB ‰	Data first published
ARCHAIC	LEP-C 1	M	2800 ± 25 BP (cal. 835–410 BCE)	UGAMS 33,356	−19,1	10,7	USF 8117	−11,5	−4,1				This publication
	LEP-C 3/M3	F	2020 ± 26 AP (cal. 60–471 CE)	UGAMS 33,357	−19,9	7,4	USF 8118	−11,2	−3,8	USF 8118	−13,7	−4,5	This publication
	LEP-C 7	M		USF 10,054	−17,9	11,7	USF 10060	−11,8	−2,4				Sanhueza and Falabella (2010)
	LEP-C 18	F		USF 10,055	−17,6	13,1							Sanhueza and Falabella (2010)
	N total = 4			Mean	−18,6	10,7		−11,5	−3,4				
BATO	AVLO-2 1	Fp		SD	1,1	2,4		0,3	0,9				
	C. Golf-1 2/M3	M		USF 8065	−17,8	11,7	USF 8138	−10,4	−4,1				Falabella et al. (2007)
	C. Golf-1 4	F		USF 8057	−19,0	9,0	USF 8130	−12,1	−4,5	USF 8173	−12,6	−3,2	Falabella et al. (2007)
	C. Golf-1 5	M	1405 ± 47 BP (cal 550–690 CE)	USF 8059	−17,5	11,3	USF 8131	−9,7	−3,4				Falabella et al. (2007)
	C. Golf-1 6	M		USF 8060	−17,4	11,2	USF 8132	−9,7	−3,1				Falabella et al. (2007)
	Trébol SE 7	F		USF 8061	−16,6	9,4	USF 8133	−8,3	−3,5				Falabella et al. (2007)
	Trébol SE 9	Mp		USF 8062	−17,4	9,8	USF 8134	−11,3	−3,0				Falabella et al. (2007)
	Trébol SE 12	F		USF 8063	−19,9	7,1	USF 8135	−11,5	−3,5				Falabella et al. (2007)
	Trébol SE 16	M		USF 8064	−18,7	8,2	USF 8136	−13,6	−2,2				Falabella et al. (2007)
	Trébol SE 15/M3	F	1350 ± 25 BP (cal 664–767 CE)	UGAMS 29856	−17,7	10,9	USF 8137	−11,1	−3,2				Falabella et al. (2007)
	N total = 10			Mean	−18,1	9,8	UGAMS 29856	−14,7	−4,7	UGAMS 29857	−12,9	−4,3	This publication
				SD	0,1	1,5		−11,2	−3,5				
LLOLLEO	LEP-C 9/M2	F	1040 ± 27 BP (cal 1100–1398 CE)	UGAMS 33358	−15,1	10,1	UGAMS 33358	−10,9	−5,4	UGAMS 33364	−10,5	−4,1	This publication
	LEP-C 11/M3	F	1070 ± 28 AP (cal 1046–1332 CE)	UGAMS 33359	−14,4	11,4	UGAMS 33359	−10,4	−5,6	UGAMS 33365	−6,7	−2,9	This publication
	LEP-C 17/M3	M		USF 8070	−13,5	12,6	USF 8143	−8,7	−2,6	USF 8177	−8,4	−2,1	Falabella et al. (2007)
	LEP-C 19/M3	F		USF 8071	−14,8	11,3	USF 8144	−10,0	−2,9	USF 8178	−9,7	−3,4	Falabella et al. (2007)
	LEP-C 22/M2	M	1010 ± 29 BP (cal 1129–1422 CE)	UGAMS 33360	−16,8	9,9	UGAMS 33360	−11,8	−4,3	UGAMS 33366	−11,1	−3,1	This publication
	L. Puquios 2	F		USF 8075	−16,2	12,3	USF 8148	−10,1	−2,5				Falabella et al. (2007)
	TV-1 12/PM2	M	1070 ± 25 BP (cal 981–1045 CE)	UGAMS 29848	−15,6	10,5	UGAMS 29848	−10,6	−5,9	UGAMS 29849	−8,7	−8,7	This publication
	TV-3 9/M3	F	1090 ± 25 BP (cal 970–1030 CE)	UGAMS 29850	−15,3	10,5	UGAMS 29850	−10,6	−8,6	UGAMS 29851	−8,5	−5,2	This publication
	TV-4 19/2	Fp	1085 ± 33 BP (cal 890–1020 CE)	USF 8073	−15,6	10,5	USF 8146	−10,8	−4,6				Falabella et al. (2007)
	TV-5 6/6	M		USF 8074	−14,7	7,7	USF 8147	−8,9	−4,4				Falabella et al. (2007)
ACONCAGUA	N total = 10			Mean	−15,2	10,7		−10,3	−4,7				
				SD	0,9	1,4		0,9	1,9				
	L.B. 10–14 5	M	cal 1297–1699 CE (associated date)	USF 8018	−13,6	8,4	USF 8091	−6,7	−3,7				Falabella et al. (2007)
	L.B. 10–14 7	F	cal 1295–1526 CE (associated date)	USF 8019	−14,3	8,5	USF 8092	−6,3	−4,3				Falabella et al. (2007)
	L.B. 10–14 15/M3	M		USF 8021	−12,4	11,2	USF 8094	−6,2	−4,5	USF 8164	−9,5	−9,5	Falabella et al. (2007)

(continued on next page)

Table 2 (continued)

Site Ind. #/tooth	Sex	Age BP (cal age 2 sigmas)	LAB-ID	$\delta^{13}\text{C}_{\text{col}}$ VPDB ‰	$\delta^{15}\text{N}$ AIR ‰	LAB-ID	$\delta^{13}\text{C}_{\text{ap}}$ VPDB ‰	$\delta^{18}\text{O}_{\text{ap}}$ VPDB ‰	LAB-ID	$\delta^{13}\text{C}_{\text{en}}$ VPDB ‰	$\delta^{18}\text{O}_{\text{en}}$ VPDB ‰	Data first published
L.B. 10–14 17/M3	F		USF 8022	−12,3	10,3	USF 8095	−7,7	−3,9	USF 8165	−5,2	−4,7	Falabella et al. (2007)
L.B. 10–14 24	F		USF 8023	−17,3	14,3	USF 8096	−12,7	−4,2				Falabella et al. (2007)
L.B. 10–14 13	M		USF 8020	−13,5	8,1	USF 8093	−7,5	−5,1				Falabella et al. (2007)
S. Dgo-1 1	M		USF 8025	−10,7	11,6	USF 8098	−5,2	−4,2				Falabella et al. (2007)
TV-5 8/1/M3	F		USF 8024	−13,2	8,2	USF 8097	−7,6	−4,8	USF 8166	−4,1	−5,2	Falabella et al. (2007)
N total = 8			Mean	−13,4	10,1		−7,5	−4,3				
			SD	1,9	2,2		2,3	0,5				

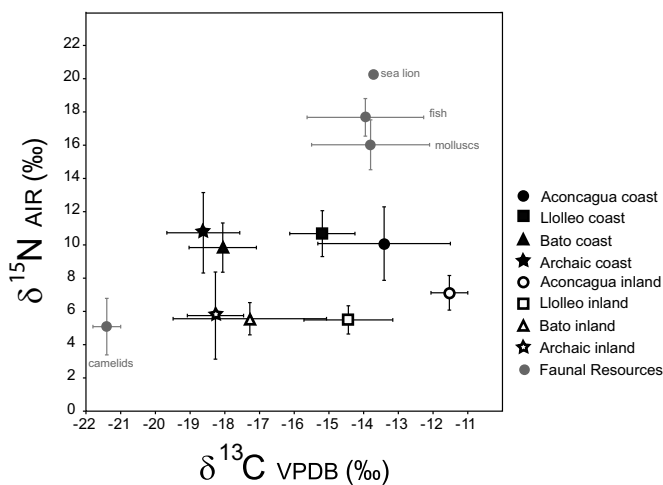


Fig. 2. Bivariate plot of mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and one standard deviation error bars.

water from this environment. Furthermore, the information derived from their teeth suggests that most of them also lived on the coast during their childhood. From this we conclude that their life cycles were spent on or very close to the coast.

Our isotope results are grouped in a range of approximately $\delta^{15}\text{N}$ 9‰ to 13‰ for all the periods, with a few outliers (Table 2, Fig. 4). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the collagen, related with protein consumption, are not what we expected from the kind of food waste and the percentages of bone remains of marine and land vertebrates in the sites from which the samples were taken (Table 1). These values change in the different cultural settings.

The samples from the Archaic context have the widest range of $\delta^{15}\text{N}$ values (7.4‰ to 13.1‰) and the smallest range of $\delta^{13}\text{C}$ values (−17.6‰ to −19.9‰). Of the four samples from the LEP-C site, one presents values appropriate to a diet based on C_3 plants and terrestrial proteins (UGAMS 33357); another (UGAMS 33356) is on the borderline of the $\delta^{15}\text{N}$ value for people who consume some marine foods, but as the $\delta^{13}\text{C}$ values are low, we believe that his diet was also principally terrestrial. These individuals, to judge by their $\delta^{18}\text{O}$ values, lived on or close to the coast but had a food tradition appropriate to inland hunter-gatherers, in which marine proteins, if consumed at all, must have been so low as to remain invisible in the isotope readings. The $\delta^{18}\text{O}$ value in the tooth enamel of one of them supports the idea that they lived on the coast throughout their lives. The other two fall into the range of all the coastal individuals from the ECP and LIP. According to the dates of the Archaic layers of the site (cal 2267–1445 BCE and cal 943–192 BCE) and those of two of the individuals analysed, this occupation occurred around the end of the Archaic IV period and the beginning of the ECP. This is a transitional moment which might explain the variation in the

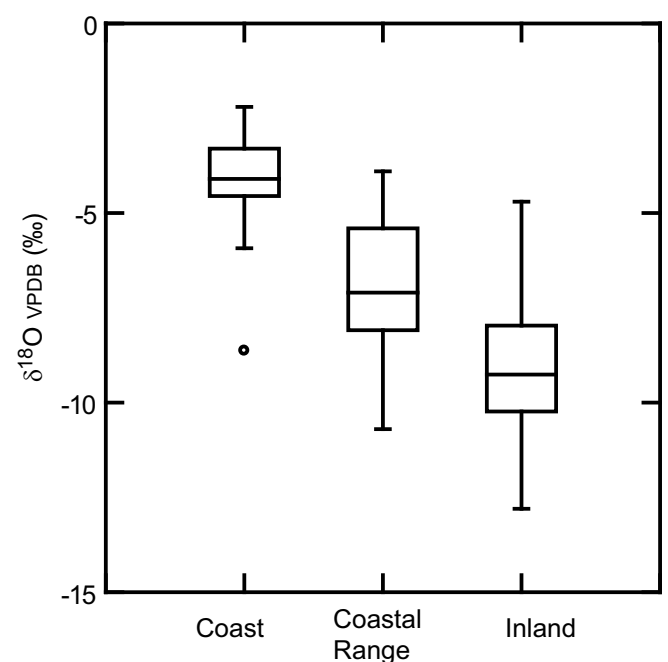


Fig. 3. Boxplot comparison of $\delta^{18}\text{O}$ values for available human bone samples from the Coast, Coastal Range and Inland in Central Chile.

isotope values. In any case, the high percentage of marine mammals in the Archaic layers of this site contradicts the isotope values obtained and raises a problem of interpretation which we cannot clarify with the few individuals analysed.

The Bato samples from the ECP also show wide dispersal of $\delta^{15}\text{N}$ (7.1‰ to 11.7‰) and $\delta^{13}\text{C}$ (−19.9‰ to −16.6‰) values, indicating high individual variation in the consumption of both marine proteins and other types of resources. Two or three individuals appear to have consumed diets with no marine foods and no C_4 plants. In two of them, the enamel analysis indicates that they lived on the coast during childhood, but consumed a diet poor in marine resources. The others ($\delta^{15}\text{N}$ 9.5‰ to 11.7‰) must have eaten a few marine products from a low trophic level, in some cases also including maize (high $\delta^{13}\text{C}$ values). As in general the sites contain more remains of molluscs than of marine vertebrates, we think that the $\delta^{15}\text{N}$ values reflect the consumption of invertebrates from lower down the food web. Arévalo-2 is the only site with abundant remains of marine mammals in the shell middens, from which we expected a higher $\delta^{15}\text{N}$ value.

The case of Lilloo – also from the ECP – is different. This group contained only one male individual who showed no indications of marine resource consumption ($\delta^{15}\text{N}$ 7.7‰), from a site on the terrace of the Maipo river, close to its mouth. Considering that the $\delta^{18}\text{O}$ value

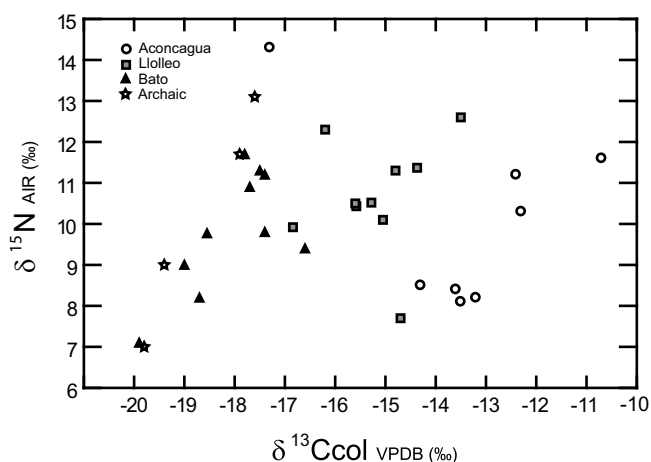


Fig. 4. Bivariate plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ obtained from bone collagen of coastal individuals from Central Chile coded by cultural context.

(-4.4‰) corresponds to coastal or near-coastal water, he must have lived in this environment, but for some reason ate a different diet to the other individuals of this cultural context. The other samples from Lilloe present a range for $\delta^{15}\text{N}$ (9.4‰ to 13.1‰) characteristic of the coastal individuals in this study, with wide variations in $\delta^{13}\text{C}$ which reflect both the variability of the types of resource consumed and the unequal contributions of maize (C_4 plant) – extensively documented in the diet of these populations (Falabella et al., 2008; Planella et al., 2014). In all cases except one (UGAMS 29849), they present $\delta^{18}\text{O}$ values which support the idea that they lived on the coast since childhood; one of them (UGAMS 33365) is unusual in that she presents a very high $\delta^{13}\text{C}$ value (-6.7‰) in the apatite of dental tissue, but we are not able to determine whether this is due to consumption of maize-rich food or marine products. Another peculiarity between the individuals of this group is the case of a woman, who although she is buried on the coast and lived there as a child, must have moved inland at some time as indicated by the lower $\delta^{18}\text{O}$ value (-8.6‰) in her bone.

The Aconcagua group from the LIP is most particular. One individual (USF 8023) presented very high $\delta^{15}\text{N}$ values (proteins from aquatic trophic chains) and low $\delta^{13}\text{C}$ values. According to the literature, this could indicate contributions of fresh water fauna, however two specimens of lacustrine edible species obtained from coastal archaeological sites of Central Chile present low $\delta^{15}\text{N}$ values (Tykot et al., 2009). The samples in this set fall into two isotope groups: four individuals (2 females and 2 males) with $\delta^{15}\text{N}$ values between 8.1‰ and 8.5‰ and $\delta^{13}\text{C}$ values between -13.2‰ and -14.3‰ ; and three others with $\delta^{15}\text{N}$ values of 10.3‰ to 11.6‰ and $\delta^{13}\text{C}$ values of -10.7‰ to -12.4‰ . This suggests two different marine resource consumption patterns occurring even among the inhabitants of the same site (Las Brisas 10–14). It should be noted that the differences between the carbon values in the collagen of these two sets appear to be the product of consumption of marine resources, and not of greater consumption of C_4 plants by the group with higher values, since both groups present a fairly similar range of values in their apatite ($\delta^{13}\text{Cap}$ -5.2‰ to -7.7‰ and $\delta^{13}\text{Cap}$ -6.3‰ to -7.6‰ respectively), showing that they had similar consumption of lipids and carbohydrates (Fig. 5). Our data show that this difference cannot be based on a gender-differentiated diet. There is also no evidence in the Aconcagua population of marked differences attributable to status or power which might be related with this difference in diet. One possible explanation of the lower consumption of marine foods by some of the Aconcagua individuals is that they practiced mobility between the coast and the neighbouring valleys of the Coastal Range, as a result of which their carbon and nitrogen isotope ratios readings match those of the individuals living in that environment (Falabella et al., 2007).

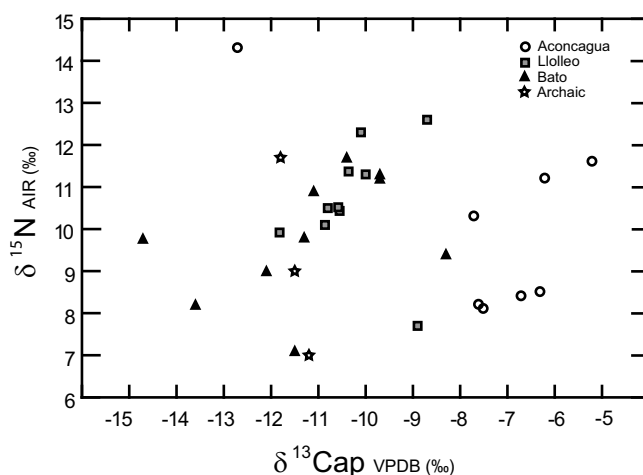


Fig. 5. Bivariate plot of coastal samples from Central Chile coded by cultural context. Note that $\delta^{13}\text{C}$ apatite values of the Aconcagua samples are similar for individuals with high and low $\delta^{15}\text{N}$ values.

Alternatively, it might be due to the different activities of people living in a coastal community, i.e. some dedicated to horticulture, others collecting molluscs and fishing. These hypotheses need to be worked out in new investigations.

Furthermore, the $\delta^{18}\text{O}$ values of rainwater in the Coastal Range valleys, as analysed by Moser et al. (1972), differ by -1.5‰ compared to that from the coast, which might explain why two of these individuals have slightly lower $\delta^{18}\text{O}$ values; this needs to be explored further. It is notable that this pattern (individuals with more or less consumption of marine foods) is repeated in the recent Aconcagua samples from the Las Brisas 10–14 site analysed by Swift et al. (2017). Moreover, the Aconcagua samples are the most carbon-enriched of our sample set, demonstrating the importance of maize in their diet (Falabella et al., 2008; Planella et al., 2014).

4.2. Central Chile: an anomaly on the South Pacific coast of South America

The isotope data of the coastal populations of Central Chile are very different from those of other parts of the country (Fig. 6). The mean values, grouped by cultural periods, show that throughout the whole time sequence the samples of this study present systematically lower $\delta^{15}\text{N}$ values, which may be interpreted as indicating lower consumption of marine resources. At no time do the values come close even to those of the coast of the Semi-arid North, which are slightly lower than those of the Arid North and the South of the country. This striking difference is not due to the baseline values in the local food webs. If the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data available for Arica in the Arid Northern region (Tieszen et al., 1995), La Serena in the Semi-arid North (Alfonso-Durruty et al., 2017) and Central Chile (Falabella et al., 2007; Tykot et al., 2009) are compared, they show quite similar values which do not explain the distances between the carbon and nitrogen isotope values among the pre-Hispanic populations of Chile (Table 3).

Every ecosystem has its own biota, with particular species, food chains, productivity and ecological relations. When the results for Central Chile are compared within the context of the south-eastern Pacific coast, it must be remembered that the characteristics of one environment are not necessarily the same in another; they may be influenced by the characteristics of each location, the geomorphology of the coast and the possibility of inhabiting the littoral zone depending on the marine resources and the proximity to different microenvironments.

Between Arica and Chiloé (18.4°S to 41.43°S), the coast is one geomorphological unit of coastal plains where there are no major oceanographical-physical barriers and the characteristics and distribution of marine species since before the human peopling of this territory

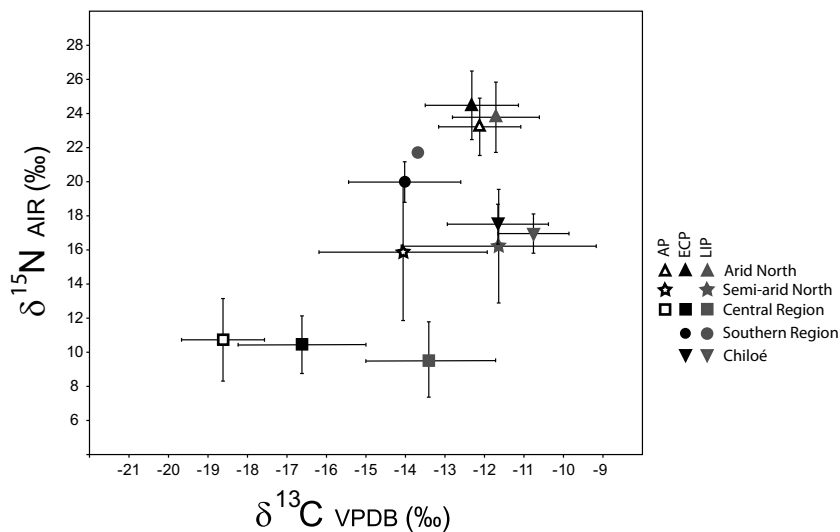


Fig. 6. Bivariate plot of $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ as means and one standard deviation bars for individuals with published isotopic analyses in the coastal regions of Chile grouped by period (AP = Archaic, ECP = Early Ceramic/Formative, LIP = Late Intermediate) and geographic region. Data for Arid North compiled from Andrade et al. (2015), Ballester and Clarot, (2014), Díaz-Zorita et al. (2016), King et al. (2018), Pestle et al. (2015a), Roberts et al. (2013), Santana-Sagredo et al. (2012); Semi-arid North from Alfonso-Durruty et al. (2017), Jackson et al. (2012); Central Chile from data in this study and from Swift et al. (2017); Southern Region from Massone et al. (2011); Chiloé/Chonos Archipelago from Reyes et al. (2015).

Table 3

Averaged stable isotope data for marine faunal resources from Chilean coastal regions (1 SD in parentheses). Data compiled from Tieszen et al. (1995: 441) (Arid North); Alfonso-Durruty et al. (2017: 154) (Semi-arid North); Tykot et al. (2009: 163) (Central Region).

Region	Fish		Invertebrates		Other vertebrates	
	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$
Arid North	-14,0 (1,8)	19,2 (1,4)	-13,3 (1,8)	17,9 (2,4)	-14,3 (0,8)	18,0 (1,2)
Semi-arid North	-15,3	15			-16,4	17,3
Central Region	-14,0 (1,7)	17,7 (1,1)	-13,8 (1,7)	16,0 (1,5)	-13,7	20,2

were similar to today's, with variations which depended on tolerance to environmental variables (Camus, 2001).

The whole coast consists of extensive beaches, coves and rocky outcrops which give access to a great variety of resources, with no major differences between north and south. A common factor is the influence of the Humboldt Current, a mass of water with low temperature and salinity harbouring a varied and abundant marine biota. The most important phenomenon associated with this current are the upwellings of nutrient-rich water, responsible for the high primary productivity of the south-eastern Pacific (Thiel et al., 2007). This is a fairly ubiquitous phenomenon, especially between Arica and Antofagasta and from La Serena to Chiloé, with an important focus off the coast of Valparaíso in Central Chile. In comparative terms therefore, our study area is just as rich in marine resources as all the others. It is true that these upwellings occur all year round in the Arid North, whereas from La Serena southwards they are seasonal, taking the form of a phytoplankton bloom and an increase in zooplankton and bacterioplankton in spring-summer (Escribano and Castro, 2004). However, if this variable were enough to condition the intensity of marine exploitation and consumption, we would expect a similar effect in samples from the Semi-arid North and the South of the country, which is not the case.

The climatic conditions and the land biogeography present clear differences. From 18.4°S to 27°S, there is a desert zone which is extremely arid all year round, with very limited watercourses at the mouths of which the coastal population settled. From 27°S to 39°S there is a succession of bio-climatic regions, with a xerophytic zone and east-west valleys in the Semi-arid North; then a Mediterranean zone with a broad central valley in the Central Region. Further south, from 39°S to 44°S, the main difference is that the precipitation is higher, and occurs all year round.

It has been proposed that marine resources were necessary for the populations of the Arid North, in a framework of complementarity and risk reduction imposed by the extreme environmental conditions (Pestle

et al., 2015a). Something analogous is proposed for the Semi-arid North, where it is suggested that coastal occupation during the Mid-Holocene acted as a buffer zone in an east-west migration circuit, as a response to adverse environmental conditions (Méndez and Jackson, 2006). Following this line of argument, it has recently been proposed that the abundance of inland resources in Central Chile would have offered little incentive to intensify marine exploitation (Roberts et al., 2013). We take a different view. We believe that the answers to where people live and what and how they eat are decided by cultural practices and long-lived culinary traditions. People do not necessarily exploit what is closest to hand or easiest to obtain, but what is culturally approved and tested and for which particular tastes and symbolic associations have developed. Most of the literature on food habits points in this direction (Bourdieu, 1998; Contreras and Gracia, 2005; Goody, 2000; Hastorf, 2017; Smith, 2006; Sutton, 2010). Besides, Central Chile is not a unique case. Many years ago, S. Hallam (1987) noted, for the central west coast of Australia, that “coastal does not equal littoral”. In more recent times, Carmichael et al. (2014) used almost the same words “coastal but not littoral” to deconstruct the idea that the Nazca culture, on the southern coast of Peru, was a coastal culture; and Salazar-García et al. (2018) speak of “to seafood or not to seafood?” to highlight differences in marine exploitation in the western Mediterranean. The results that we have presented help to break down a priori prejudices on cultural practices which assume a direct relation between available resources and diet.

5. Conclusions

Stable isotope analyses are here to stay in archaeology. Together with radiogenic isotopes and complementary techniques such as measuring isotope ratios of single amino acids, they are helping to present a more real and accurate panorama of the diets of populations of the past. In Central Chile, the data show that occupation of coastal areas did not necessarily imply a diet based on marine resources. Even if they lived

on the coast, individuals dated to the Late Archaic as well as the Early Ceramic and Late Intermediate periods present variations in their diet, which only in some cases incorporated low trophic level coastal resources. This makes Central Chile an unusual area in the context of occupations along the whole Chilean coast, where a high dependence on marine resources is generally found, and suggests the importance of considering cultural factors in the differences in the dietary preferences of the populations, as well as their persistence over time.

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