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SUBSISTENCE CONTINUITY LINKED TO CONSUMPTION OF MARINE PROTEIN IN THE FORMATIVE PERIOD IN THE INTERFLUVIC COAST OF NORTHERN CHILE: RE-ASSESSING CONTACTS WITH AGROPASTORAL GROUPS FROM HIGHLANDS

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ABSTRACT. From material culture evidence dating as early as 7500 cal BC, it has been established that populations from the interfluvic coast in northern Chile adapted to a maritime economic livelihood. During the 2nd millennium BC, local populations began to experience major social changes arising mainly from an increase in contacts with agropastoral populations from the highlands of the Andes. New radiocarbon data and stable isotope ($\delta^{15}N_{col}$, $\delta^{13}C_{col}$, and $\delta^{13}C_{ap}$) analyses of human bone remains from interfluvic coastal individuals were obtained. The data showed that these individuals, at the time of contact with highland populations, maintained a mode of subsistence relying principally on marine protein. This suggests that, although instances of social change may have arisen, the livelihoods linked to the consumption of marine resources would have remained constant, demonstrating a high degree of resistance in changing local lifestyles.

INTRODUCTION

The interfluvic coast of Chile is located in the northern area of the country (19°35′S, 70°13′W; 29°01′S, 71°25′W). This area is characterized by a lack of waterways, the only exception being the Loa River (Llagostera 2005) and occasional water springs. Despite these harsh environmental conditions, the presence of human settlements has a long-standing record linked to a continuous exploitation of available marine resources by groups adopting a subsistence strategy based on hunting and gathering (Salazar et al. 2015). Furthermore, mining exploitation in the area has been practiced in continuity from prehistoric to contemporary times (Salazar et al. 2011).

Recent studies (Nuñez et al. 2006; Gallardo 2009; Nuñez and Santoro 2011) suggest that during the 2nd millennium BC, populations from the interfluvic coast experienced significant social changes. Indicative of these are the adoption of innovative fishing techniques, development of metallurgy, introduction of foreign pottery, production and processing of surplus marine resources such as dry fish and bird guano, and changes in forms of settlement pattern (Nuñez and Santoro 2011). It has been hypothesized that modifications in social structure correspond to an increased contact with agropastoral populations from the highlands of the Andes.

Under this hypothesis, it becomes relevant to investigate if changes to the social structure and possible contacts between coastal and highland populations resulted also in modifications of subsistence strategies adopted by interfluvic coast populations. This research question can be addressed through stable isotope analysis of human remains (DeNiro and Epstein 1976; Van der Merwe and Vogel 1978, 1983; Tauber 1981; Schoeninger et al. 1983; Richards et al. 2003; Lee-Thorp 2008). Unfortunately, the presence of human remains in the region is scarce and many burial contexts have been looted (Andrade et al. 2014). Nonetheless, it was possible to recover six relatively well-preserved human skeletons for radiocarbon and stable isotope analysis from the Taltal area located in Antofagasta Province. These provide the first human isotope results obtained for this study area.

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ARCHAIC AND FORMATIVE PERIODS OF THE COAST OF TALTAL

The earliest human occupation in the Taltal area occurred during the Archaic period, dating as early as 12,000 cal BP (Salazar et al. 2011). From previous research at Taltal, an occupational sequence has been proposed for this period (Salazar et al. 2015), defining a total of six distinct occupational phases, which extend from 12,000 to 3500 cal BP. In general, the first of the six occupation phases, dating between 12,000 and 10,000 cal BP, is characterized by an economy based on coastal hunting and gathering, and the exploitation of iron oxide (Salazar et al. 2011). The end of this period is marked by an abandonment of the area that lasted 1500 yr.

Between 8500 and 3500 cal BP, the interfluvic coast was permanently occupied (Salazar et al. 2015). However, during this period there were some modifications in settlement patterns, burial techniques, and technology. Nonetheless, predominance in the exploitation of marine resources was maintained. The zooarchaeological evidence supports this chronology, showing a large presence in the archaeological record of fish, shellfish, and marine mammals (Olguín et al. 2014). However, fish remains are the most abundant, and in particular fish bones of *Trachurus murphyi* (jack mackerel/jurel). This species is frequently present in different Archaic sites and along the chronological sequence (Olguín 2011; Rebolledo 2014). Other well-represented fish species are *Thyrsites atun* (snoek/sierra), *Genypterus* sp. (cuks-eel/congrio), and *Cilus gilbert* (corvine/corvina).

The archaeological period traditionally known as the Formative period dates from 3500 to 1500 cal BP, and has been characterized in the Andean region by three fundamental aspects: the emergence of architecture, change in subsistence strategies and the emergence of small-scale agriculture, and pottery production (Aldunate et al. 1986; Santoro 2000; Sinclair 2004; Nuñez and Santoro 2011).

Despite these findings, no archaeological materials related to architecture or agriculture have been found in the Taltal study area in Formative archaeological contexts. Pottery was present, although most of it was imported (Varela 2009). The presence of foreign items, both in coastal and inland areas, in addition to the presence of transit sites in intermediate areas, supports the existence of foreign contacts (Pimentel et al. 2006, 2011). However, bioarchaeological studies carried out in recent years show no differentiation in terms of subsistence strategies followed by populations from Archaic and Formative periods (Andrade et al. 2014), reaffirming the idea proposed by Salazar et al. (2015) that in Taltal the Formative period was not represented in its classical definition.

MATERIAL AND METHODS

Femur and tibia bone samples were taken from the remains of six adult individuals from Taltal sites dating to the Later Archaic and Formative periods (Table 1). Bone samples were analyzed at the Center for Applied Isotopes Studies (University of Georgia, USA). ^{14}C and stable isotopes ($\delta^{15}N_{col}$ and $\delta^{13}C_{col}$) were measured in bone collagen and bone bioapatite ($\delta^{13}C_{ap}$), following the methodology proposed by Cherkinsky (2009).

Bayesian Diet Reconstruction Using FRUITS

The Bayesian mixing model FRUITS (beta 2.0) was used to provide quantitative dietary estimates (Fernandes et al. 2014). The approach adopted here is very similar to that described in two previous cases studies (Fernandes 2015; Fernandes et al. 2015). These case studies provided highly accurate dietary estimates, established from the comparison of observed and measured dietary contributions. Briefly, the FRUITS model compares human isotope values ($\delta^{15}N_{col}$, $\delta^{13}C_{col}$, and $\delta^{13}C_{ap}$) with reference animal and plant food isotope values for the region (Pestle et al. 2015). Four food groups were defined (C_3 plants, C_4 plants, terrestrial animals, and marine animals) and isotopic offsets between reference (e.g. collagen) and edible fractions (protein, lipids, carbohydrates), plus macronutrient compositions were established following Fernandes (2015) and Fernandes et al. (2015). The previous references also describe employed diet-to-tissue isotopic offsets. In the case of collagen carbon, a routed model was employed that accounts for the dietary contributions from lipids and carbohydrates towards bone collagen (Fernandes et al. 2012). For the different model parameters, including for isotopic values in individual consumers, conservative uncertainties were taken as the reference. Finally, to constrain model estimates a purely physiological prior was introduced limiting protein intake to acceptable levels between 10 and 35% of total calories (Otten et al. 2006). The default FRUITS model is given as online supplementary material (Supplementary file 1) and the robustness of generated estimates was tested by varying default parameter values (Supplementary file 2).

The estimates generated by FRUITS for marine carbon contributions to bone collagen were used to correct human bone collagen ^{14}C dates for marine dietary ^{14}C reservoir effects. These estimates differ from protein contribution estimates given the use of routed model for bone collagen (Fernandes et al. 2012). The correction was based on a local marine ^{14}C reservoir effect of 626 ± 98 yr (Ortlieb et al. 2011). Corrected human ^{14}C dates were calibrated using the SHCal13 calibration curve (Hogg et al. 2013) and the OxCal v 4.2 calibration software (Bronk Ramsey 2009).

Sample Pretreatment and Radiocarbon and Stable Isotope Measurements

Bone samples were mechanically cleaned using a wire brush and washed in an ultrasonic bath. After cleaning, the dried bone was gently crushed to small fragments. The crushed bone was treated with diluted 1N acetic acid to remove surface absorbed and secondary carbonates. Periodic evacuation insured that evolved carbon dioxide was removed from the interior of the sample fragments, and that fresh acid was allowed to reach even the interior microsurfaces. The chemically cleaned sample was then reacted under vacuum with 1N HCI to dissolve the bone mineral and release CO_2 from bioapatite. Organic bone residues were filtered, rinsed with deionized water, and heated at 80°C for 6 hr under slightly acidic conditions (pH = 3) to dissolve collagen and leave humic substances in the precipitate. The collagen solution was filtered to isolate pure collagen and dried out. Isotopic measurements were carried out using a dual-inlet Finnigan MAT252 mass spectrometer and a Delta V elemental analyzer mass spectrometer. Isotope measurements are expressed in δ notation relative to standards Vienna Pee Dee Belemnite (V-PDB) and AIR (Cherkinsky 2009). Bone bioapatite carbon isotope values ($\delta^{13}C_{ap}$) and bone collagen isotope values ($\delta^{15}N_{col}$ and $\delta^{13}C_{col}$) were measured with a precision better than 0.1‰ and 0.2‰, respectively. ^{14}C measurements of human bone collagen were done using a 0.5MeV Pelletron accelerator mass spectrometer and followed previously described combustion, graphitization, and measurement steps (Cherkinsky 2009).

Literature Data

Previously published bone isotope data from different populations, chronologies, and geographical areas of northern Chile (see Figure 1) were taken for comparison with the results presented here. Detailed information on retrieved literature data is given in Table 2.

RESULTS AND DISCUSSION

Results from stable isotope analyses are given in Table 3. Bone collagen atomic C/N ratios ranged between 3.2 and 3.4, indicating a good preservation status of the collagen (DeNiro 1985; Ambrose 1990). ^{14}C measurements corrected for human dietary ^{14}C reservoir effects and calibrated (cal BP, 2σ) are shown in Table 1. These results assign the San Lorenzo 1 sample to the Archaic period, whereas three other bone samples (Punta Cañas Norte, San Lorenzo 3, and Quebrada Rincon) are clearly assigned within the Formative period. The calibrated ^{14}C result for Caleta Buena assigns this sample to the later stage of the Formative period. Finally, the ^{14}C result for Zapatero indicates that the sample likely dates to a post-Formative period.

Table 1 Radiocarbon dates and contextual data, sex and age of individuals included in the Taltal sample.

Site	Site type	Burial type	Looted?	Sex	Age (yr)	Lab code	^{14}C date (yr BP)	Collagen marine carbon (%)	Reservoir-corrected ^{14}C date (yr BP)	cal BP (2σ)
San Lorenzo 1	Rockshelter	Primary, individual	No	Female	25–30	15976	4030 ± 25	40 ± 6	3780 ± 141	3726–4569
Punta Cañas Norte	Rockshelter	Secondary, multiple	Yes	unknown	>20	15974	3100 ± 25	29 ± 6	2918 ± 112	2797–3358
San Lorenzo 3	Rockshelter	Secondary, multiple	Yes	Female	25–30	15977	2550 ± 25	42 ± 6	2287 ± 146	1991–2735
Quebrada Rincon	Open sky	Primary, individual	No	Female	35–40	17941	1940 ± 20	22 ± 5	1802 ± 88	1536–1925
Caleta Buena	Rockshelter	Primary, individual	Yes	Female	25–30	15973	1570 ± 25	49 ± 6	1263 ± 164	803–1525
Zapatero	Rockshelter	Primary, individual	Yes	unknown	>20	15978	1280 ± 25	46 ± 6	992 ± 156	670–1258

Table 2 Period and locations of previously published human isotopic measurements compared in this study.

Area	Location	Chronology	Site	Mean $\delta^{15}N_{col}$ (‰)	Mean $\delta^{13}C_{col}$ (‰)	Reference
Northern Chile	Coast	Archaic	Camarones 9	24.1 ± 0.4	–10.6 ± 0.2	Tieszen et al. 1995
			Chinchorro	23 ± 0.4	–11.9 ± 0.2	Tieszen et al. 1995
			Playa Miller 7	28.7 ± 3.5	–18.4 ± 0.1	Poulson et al. 2013
			Quiani 7	31 ± 2.1	–19.1 ± 1.2	Poulson et al. 2013
	Coast	Formative	Alto Ramirez	15.5 ± 0.4	–13.5 ± 0.8	Tieszen et al. 1995
			Caleta Vitor 3	24.3 ± 1	–12.8 ± 0.8	Roberts et al. 2013
	Valley	Formative	Az-75	17.6 ± 2.2	–14.1 ± 0.6	Aufderheide et al. 2002
			Az-71	18.6 ± 3.6	–17.1 ± 4.6	Petruzelli et al. 2012
Antofagasta	Coast	Archaic	Copaca 1	24.1 ± 0.6	–12.2 ± 0.4	Andrade and Castro 2015
	Coast	Formative	El Vertedero	24 ± 0.8	–12.6 ± 0.3	Ballester and Clarot 2014
			ENAEX	26.4 ± 1.2	–12.8 ± 1.2	Ballester and Clarot 2014
			Punta Blanca	25 ± 0.5	–12.3 ± 0.2	Ballester and Clarot 2014
			TGN1	26.5 ± 1.4	–12.5 ± 1.5	Ballester and Clarot 2014
			Gualaguala 01	24.3 ± 1.4	–17.7 ± 0.6	Pestle et al. 2015
			Gualaguala 04	23.7 ± 1	–17.7 ± 0.8	Pestle et al. 2015
			Michilla02	24.7 ± 1.3	–16.6 ± 0.6	Pestle et al. 2015
	Valley	Formative	San Salvador	12.5 ± 2.3	–16.8 ± 0.9	Pestle et al. 2015
	Highland	Formative	Chorrillos	12.7 ± 2.8	–19.5 ± 1.3	Pestle et al. 2015
			RanL	11.3 ± 0.1	–19.6 ± 0.2	Pestle et al. 2015
			Calar	10.3 ± 0.4	–15.9 ± 0.6	Pestle et al. 2015
			Topater	11 ± 1.3	–18.3 ± 0.7	Pestle et al. 2015
Atacama	Coast	Archaic	Punta Totoralillo	20.5 ± 3.9	–16.2 ± 4.8	Pacheco and Gómez 2013

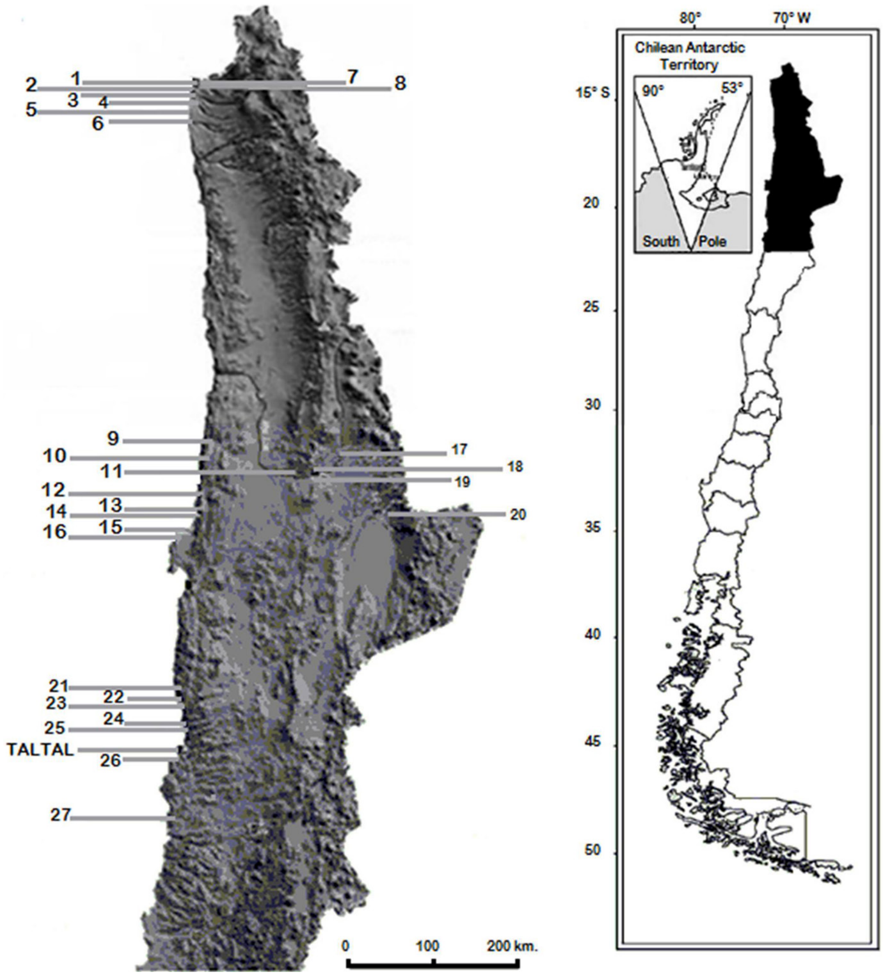

Figure 1 Locations of sites compared in this research: (1) Chinchorro; (2) Alto Ramírez; (3) Playa Miller 7; (4) Quiani 7; (5) Caleta Vitor 3; (6) Camarones 9; (7) AZ-75; (8) AZ-71; (9) Punta Blanca; (10) Copaca 1; (11) San Salvador; (12) Michilla 2; (13) Gualaguala 1; (14) Gualaguala 4; (15) TGN1; (16) ENAEX; (17) RanL273; (18) Chorrillos; (19) Topater; (20) Calar; (21) Punta Cañas Norte; (22) Zapatero; (23) Quebrada Rincón; (24) San Lorenzo 1; (25) San Lorenzo 3; (26) Caleta Buena; (27) Punta Totoralillo.

Table 3 Isotopic data for individuals from the Taltal study area.

Individual	$\delta^{13}C_{ap}$ (‰)	$\delta^{13}C_{col}$ (‰)	$\delta^{15}N_{col}$ (‰)	C/N
San Lorenzo 1	–8.4	–11.4	21.8	3.3
Punta Cañas Norte	–7.6	–10.5	19.6	3.3
San Lorenzo 3	–8.1	–11.4	22.4	3.2
Quebrada Rincon	–8.8	–12.1	18.3	3.4
Caleta Buena	–8.4	–11.4	23.8	3.2
Zapatero	–9.1	–12.0	23.1	3.2
Average	**–8.4 ± 0.5**	**–11.4 ± 0.6**	**21.7 ± 2.1**	**3.2 ± 0.1**

In general terms, isotopic values for the Taltal individuals define a well-constrained group, with relatively small isotopic differences among individuals. Human bone collagen isotope averages (δ^{15}N = 21.7 ± 2.1‰; δ^{13}C = –11.4 ± 0.6‰) suggest a diet relying heavily on marine protein (Katzenberg 2008; Pestle et al. 2015). This is illustrated in Figure 2, where isotopic values for the Taltal humans are plotted together with average isotopic values for archaeological and modern food resources from the Antofagasta region (Pestle et al. 2015).

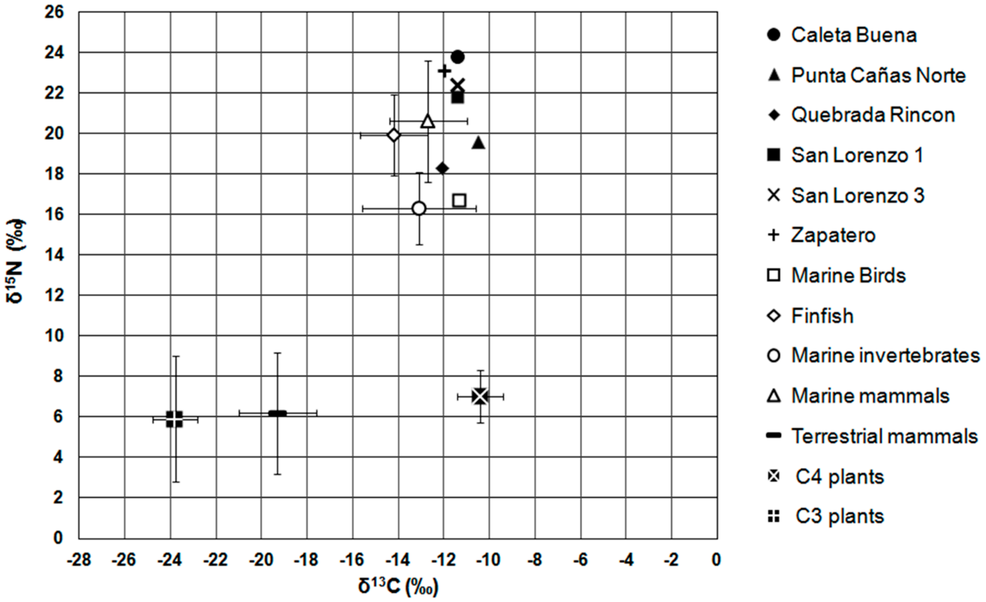

Figure 2 Taltal human isotope data plotted together with floral and faunal isotope data from Pestle et al. (2015)

The FRUITS Bayesian mixing model was used to provide quantitative dietary estimates (Table 4). To check the robustness of generated estimates, a sensitivity test was performed by varying model parameters values towards the default model (Supplementary file 2). These results demonstrated that generated estimates were always within a 1σ range of those generated by the default model and thus highly robust. Default model estimates showed for all individuals, with the exception of Quebrada Rincon, that the contribution from marine protein was predominant and typically represented ~60 to 70% of protein calorie contributions (Table 4). The levels of protein intake, for all individuals, represented ~25 to 30% of total macronutrient intake. This corresponds to a level of protein intake typical of a hunter-gatherer lifestyle based on aquatic food resources (Cordain et al. 2000). However, model estimates also showed that plant foods represented ~50% of total dietary calories. Thus, C_3 (e.g. *Chenopodium quinoa*) and C_4 plants were major carbohydrate sources, while proteins were chiefly obtained from a marine source.

To further validate the dietary estimates generated by FRUITS, the multivariate model proposed by Froehle et al. (2012) was also employed. This model uses cluster analysis and discriminant function analysis of human isotope data ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$, and $\delta^{13}C_{ap}$) to define reference cluster values associated with known dietary preferences (Figure 3). The calculated discriminant function value, for the human Taltal isotopic average, is located in the vicinity of Cluster 3 (Figure 3), as defined by Froehle et al. (2012), which indicates equal dietary contributions from non-protein C_3 and C_4 plant foods and a predominance of marine protein. This is in excellent agreement with the dietary estimates generated by FRUITS (Table 4).

Table 4 Dietary estimates generated by FRUITS for Taltal individuals.[a]

	Total calorie contributions (cal %)				Protein contributions (cal %)				
Individual	C_3 plants	C_4 plants	T. animals	Marine foods	C_3 plants	C_4 plants	T. animals	Marine foods	Protein (cal %)
San Lorenzo 1	27 ± 9	24 ± 9	20 ± 13	28 ± 6	9 ± 5	9 ± 5	20 ± 11	62 ± 7	30 ± 4
Punta Cañas Norte	20 ± 10	30 ± 11	31 ± 17	20 ± 5	8 ± 6	13 ± 7	32 ± 14	47 ± 7	26 ± 6
San Lorenzo 3	27 ± 8	26 ± 8	17 ± 11	30 ± 6	9 ± 4	9 ± 4	16 ± 10	65 ± 6	30 ± 4
Quebrada Rincon	28 ± 12	17 ± 11	40 ± 20	15 ± 4	12 ± 8	8 ± 7	43 ± 17	37 ± 7	26 ± 6
Caleta Buena	28 ± 7	26 ± 7	11 ± 8	35 ± 5	9 ± 3	8 ± 3	10 ± 7	73 ± 6	30 ± 4
Zapatero	34 ± 8	20 ± 8	14 ± 10	33 ± 6	11 ± 4	7 ± 4	13 ± 9	69 ± 6	30 ± 4

a. T. animals = Terrestrial animals.

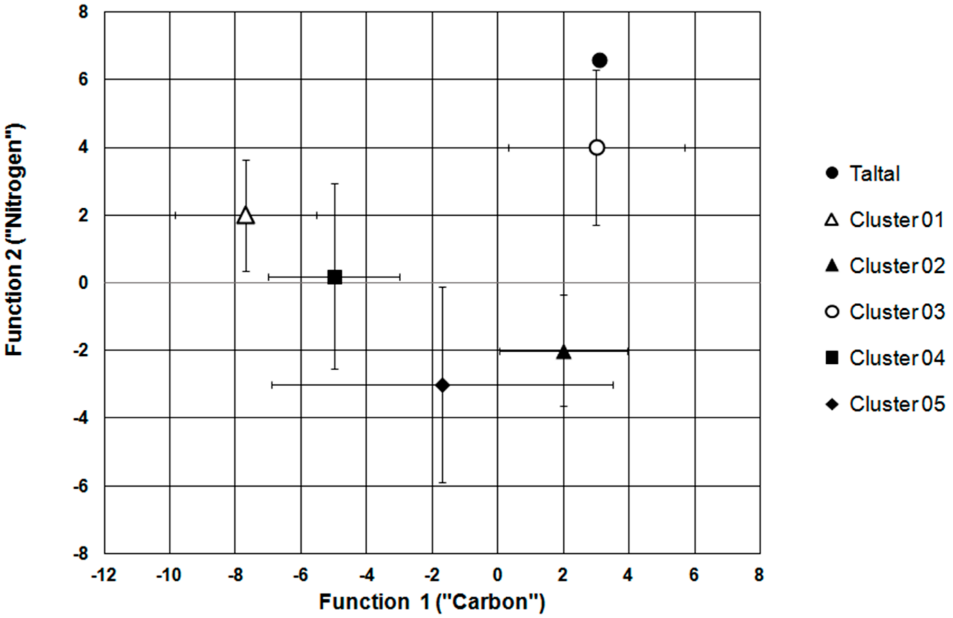

Figure 3 Taltal sample's data plotted against the multivariate carbon and nitrogen stable isotopes model from Froehle et al. (2012).

COMPARISON WITH LITERATURE DATA

The novel isotopic results presented here were compared with human isotopic data from archaeological sites in northern Chile dating to the Archaic and Formative periods (Table 2 and Figure 4). Collected isotope data show similar collagen values for populations from the Archaic and Formative periods in coastal areas, all of them with collagen $\delta^{15}N$ values of ~20‰ (Figure 4). These values are considerably higher than those observed in valley and highlands areas of Antofagasta during the Formative period. Thus, the collected isotope data suggest a degree of continuity in the dietary habits of coastal populations. This is in agreement with the hypothesis of a continuum in the exploitation and consumption of marine resources from the Archaic to the Formative periods. This occurred despite contacts with highland populations and the potential introduction of domesticated plants into the coastal desert of Taltal.

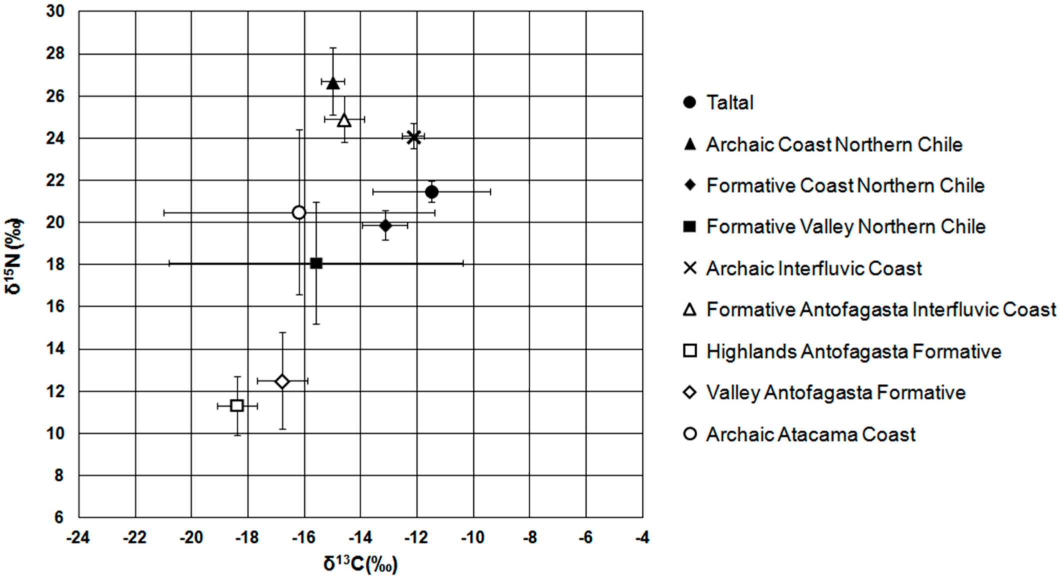

Figure 4 Average human bone collagen isotopic values for Taltal individuals compared with other human data sets dating to the Archaic and Formative periods in northern Chile.

CONCLUDING REMARKS AND FUTURE PERSPECTIVES

Newly collected human isotopic data combined with previously published results clearly suggest that there was a continuity in subsistence strategies followed at Taltal, and that there were no major modifications during the so-called Formative period. This is inferred from an estimated large protein intake originating principally from marine foods. However, estimated dietary contributions from C_3 and C_4 plants allow for possible contacts with inland populations. In this regard, new tooth isotopic analyses ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) could aid in assessing mobility patterns linking the highlands and Taltal. It is also possible that there were population movements along coastal areas, as proposed by Gallardo et al. (2012).

This small study demonstrated the potential that stable isotope analysis has in the interpretation of the dietary habits and lifestyles of past Taltal inhabitants. Future research will aim at expanding the data presented here, through the use of other isotopic proxies to assess mobility, a characterization of the local food isotopic baseline, and, when available, the inclusion of new skeletal material.

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REFERENCES

Aldunate C, Berenguer J, Castro V, Cornejo L, Martínez JL, Sinclaire C. 1986. Cronología y asentamiento en el Región del Loa Superior. *Chungara* 16–17:333–46.

Ambrose S. 1990. Preparation and characterization of bone and tooth collagen for stable carbon and nitrogen isotope analysis. *Journal of Archaeological Science* 17(4):431–51.

Andrade P, Castro V. 2015. Reconstrucción del modo de vida de endividuos del arcaico de la costa arreica del Norte de Chile: una aproximación bioarqueológica desde el sitio Copaca 1. *Chungara*. In press.

Andrade P, Salazar D, Urrea J, Castro V. 2014. Modos de vida de los cazadores-recolectores de la costa arreica del norte grande de Chile: una aproximación bioarqueológica a las poblaciones prehistórica de Taltal. *Chungara* 46(3):467–91.

Aufderheide AC, Aturaliya S, Focacci G. 2002. Enfermedades pulmonares de una muestra de población del cementerio AZ-75, Valle de Azapa, Norte de Chile. *Chungara* 34(2):253–63.

Ballester B, Clarot A. 2014. *La Gente de los Túmulos de Tierra. Estudio, Conservación y Difusión de Colecciones Arqueológicas de la Comuna de Mejillones*. Antofagasta: Ilustre Municipalidad de Mejillones.

Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–60.

Cherkinsky A. 2009. Can we get a good radiocarbon age from "bad bone"? Determining the reliability of radiocarbon age from bioapatite. *Radiocarbon* 51(2):647–55.

Cordain L, Miller JB, Eaton SB, Mann N, Holt SH, Speth JD. 2000. Plant-animal subsistence ratios and macronutrient energy estimations in worldwide hunter-gatherer diets. *The American Journal of Clinical Nutrition* 71(3):682–92.

DeNiro MJ. 1985. Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317(6040):806–9.

DeNiro MJ, Epstein S. 1976. You are what you eat (plus a few permil): the carbon isotope cycle in food chains. *Geological Society of America Abstracts with Programs* 8:834–5.

Fernandes R. 2015. A simple(r) model to predict the source of dietary carbon in individual consumers. *Archaeometry*. DOI: 10.1111/arcm.12193.

Fernandes R, Nadeau M-J, Grootes P. 2012. Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. *Archaeological and Anthropological Sciences* 4(4):291–301.

Fernandes R, Millard A, Brabec M, Nadeau M-J, Grootes P. 2014. Food Reconstruction Using Isotopic Transferred Signals (FRUITS): a Bayesian model for diet reconstruction. *PLoS ONE* 9(2):e87436.

Fernandes R, Grootes P, Nadeau M-J, Nehlich O. 2015. Quantitative diet reconstruction of a Neolithic population using a Bayesian mixing model (FRUITS): the case study of Ostorf (Germany). *American Journal of Physical Anthropology* 158(2):325–40.

Froehle AW, Kellner CM, Schoeninger MJ. 2012. Multivariate carbon and nitrogen stable isotope model for the reconstruction of prehistoric human diet. *American Journal of Physical Anthropology* 147(3):352–69.

Gallardo F. 2009. Social interaction and rock art styles in the Atacama Desert (Northern Chile). *Antiquity* 83(321):619–33.

Gallardo F, Cabello G, Pimentel G, Sepúlveda M, Cornejo L. 2012. Flujos de información visual, interacción social y pinturas rupestres en el desierto de Atacama (Norte de Chile). *Estudios Atacameños* 43:35–52.

Hogg AG, Hua Q, Blackwell PG, Niu M, Buck CE, Guilderson TP, Heaton TJ, Palmer JG, Reimer PJ, Reimer RW, Turney CSM, Zimmerman SRH. 2013. SHCal13 Southern Hemisphere calibration, 0–50,000 cal BP. *Radiocarbon* 55(4):1889–903.

Katzenberg M. 2008. Stable isotope analysis: a tool for studying past diet, demography and life history. In: Katzenberg K, Saunders S, editors. *Biological Anthropology of the Human Skeleton*. Hoboken: Wiley. p 413–42.

Lee-Thorp JA. 2008. On isotopes and old bones. *Archaeometry* 50(6):925–50.

Llagostera A. 2005. Culturas costeras precolombinas en el norte chileno: secuencia y subsistencia de las poblaciones arcaicas. In: Figueroa E, editor. *Biodiversidad Marina: Valoración, Uso, Perspectivas ¿Hacia dónde va Chile?* Santiago: Editorial Universitaria. p 107–48.

Núñez L, Santoro C. 2011. El tránsito arcaico-formativo en la Circumpuna y Valles Occidentales del Centro Sur Andino: hacia los cambios "neolíticos." *Chungara* 43(1):487–530.

Núñez L, Cartajena I, Carrasco C, de Souza P, Grosjean M. 2006. Emergencia de comunidades pastoralistas formativas en la Puna de Atacama. *Estudios Atacameños* 32:93–117.

Olguín L. 2011. Historia de un conchal: procesos de formación y secuencia ocupacional del sitio arqueológico Agua Dulce, costa arreica del Desierto de Atacama, comuna de Taltal, región de Antofagasta [PhD dissertation]. Santiago: Universidad de Chile. 181 p.

Olguín L, Salazar D, Jackson D. 2014. Tempranas evidencias de navegación y caza de pesca de especies oceánicas en la costa Pacífica de Sudamérica (Taltal, ~7000 años cal. A.P.). *Chungara* 46(2):177–92.

Ortlieb L, Vargas G, Saliège J-F. 2011. Marine radiocarbon reservoir effect along the northern Chile–southern Peru coast (14–24°S) throughout the Holocene. *Quaternary Research* 75(1):91–103.

Otten J, Pitzi HI, Meyers L. 2006. *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: National Academies Press.

Pacheco A, Gómez P. 2013. Análisis bioantropológico de los individuos recuperados de la Concentración 80. In: Aswakear Consultores, editor. *Informe final salvataje Concentración 80, Sitio 1, Puerto Punta Totoralillo*. Report on file at Laboratorio de Antropología Física de la Universidad de Chile, Santiago.

Pestle W, Torres-Rouff C, Gallardo F, Ballester B, Clarot A. 2015. Mobility and exchange among marine hunter-gatherer and agropastoralist communities in the formative period Atacama desert. *Current Anthropology* 56(1):121–33.

Petruzzelli B, Roberts A, Pate D, Santoro C, Maddern T, Carter C, Westaway M. 2012. Stable carbon and nitrogen isotopic analysis of skeletal remains from

Azapa 71 and Pica 8, northern Chile: an assessment of human diet and landscape use in the Late Holocene. *Journal of the Anthropological Society of South Australia* 35:52–80.

Pimentel G, Rees C, de Souza P, Ayala P. 2006. Estrategias de movilidad del periodo formativo en la depresión intermedia, Desierto de Atacama. *Actas XVII Congreso de Arqueología Chilena*. Valdivia: Sociedad Chilena de Arqueología, Universidad Austral, Ediciones Kultrún. p 1353–64.

Pimentel G, Rees C, de Souza P, Arancibia L. 2011. Viajeros costeros y caravaneros. Dos estrategias de movilidad en el periodo Formativo del Desierto de Atacama, Chile. In: Nuñez L, Nielsen A, editors. *En Ruta. Arqueología, Historia y Etnografía del Tráfico Sur Andino*. Grupo Encuentro Editorial. Argentina. p 43–82.

Poulson SR, Kuzminsky S, Scott G, Standen V, Arriaza B, Muñoz I, Dorio L. 2013. Paleodiet in northern Chile through the Holocene: extremely heavy δ^{15}N values in dental calculus suggest a guano-derived signature? *Journal of Archaeological Science* 40(12):4576–85.

Rebolledo S. 2014. Arcaico medio en la costa arreica: estrategias de caza y pesca costero-marítima en el sitio Zapatero [PhD dissertation] Santiago: Universidad de Chile. 130 p.

Richards MP, Schulting RJ, Hedges REM. 2003. Archaeology: sharp shift in diet at onset of Neolithic. *Nature* 425(6956):366.

Roberts A, Pate D, Petruzzeli B, Carter C, Westaway M, Santoro C, Swift J, Maddern T, Jacobsen G, Bertuch F. 2013. Retention of hunter-gatherer economies among maritime foragers from Caleta Vitor, northern Chile, during the late Holocene: evidence from stable carbon and nitrogen isotopic analysis of skeletal remains. *Journal of Achaeological Science* 40(5):2360–72.

Salazar D, Jackson D, Guendon J, Salinas H, Morata D, Figueroa V, Manriquez G, Castro V. 2011. Early evidence (ca. 12000 BP) for iron oxide mining of the Pacific coast of South America. *Current Anthropology* 52(3):463–75.

Salazar D, Figueroa V, Andrade P, Salinas H, Power X, Rebolledo S, Parra S, Orellana H, Urrea J. 2015. Cronología y organización económica de las poblaciones arcaicas de la costa de Taltal. *Estudios Atacameños* 50:7–46.

Santoro C. 2000. El Formativo en la región de valles occidentales del área centro surandina (sur Perú-norte de Chile). In: Lederberger-Crespo P, editor. *Formativo Sudamericano*. Quito: Ediciones bya-Ayala. p 243–54.

Schoeninger MJ., DeNiro MJ, Tauber H. 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220(4604):1381–3.

Sinclair C. 2004. Prehistoria del Periodo Formativo en la Cuenca Alta del Rio Salado (Región del Loa Superior). *Chungara*, Volumen Especial:619–39.

Tauber H. 1981. ^{13}C evidence for dietary habits of prehistoric man in Denmark. *Nature* 292(5821):332–3.

Tieszen LL, Iversen E, Matzner S. 1995. Dietary reconstruction based on carbon, nitrogen, and sulfur stable isotopes in the Atacama Desert, northern Chile. In: Aufderheide AC, Martin CR, editors. *World Congress on Mummy Studies*. Tenerife: Museo Arqueológico y Etnográfico de Tenerife, Organismo Autónomo de Museos y Centros. p 427–41.

Van der Merwe NJ, Vogel JC. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in woodland North America. *Nature* 276(5690):815–6.

Van der Merwe NJ, Vogel JC. 1983. Recent carbon isotope research and its implications for African archaeology. *African Archaeological Review* 1(1):33–56.

Varela V. 2009. La cerámica arqueológica de Taltal. *Taltalia* 2:118–29.