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BRIEF COMMUNICATION

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An isotopic study of dietary diversity in formative period Ancachi/Quillagua, Atacama Desert, northern Chile

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Abstract

Objectives: To characterize the paleodiet of individuals from Formative Period (1500 B.C.–A.D. 400) Atacama Desert sites of Ancachi and Quillagua as a means of understanding the dietary and cultural impacts of regional systems of exchange.

Materials and methods: Thirty-one bone samples recovered from the cemetery of Ancachi (02QU175) and in/around the nearby town of Quillagua were the subject of carbon and nitrogen stable isotope analysis of bone collagen and hydroxyapatite and multisource mixture modeling (FRUITS, food reconstruction using isotopic transferred signals) of paleodiet. These individuals were compared with nearly 200 other Formative Period individuals from throughout the region to identify differences in dietary behaviors.

Results: 80.6% (25/31) of the samples yielded sufficient well-preserved collagen and were included in the multisource mixture model. The FRUITS model, which compared individuals with a robust database of available foods from the region, identified a wide diversity of diets in the Ancachi/Quillagua area (including both coastal and interior individuals), and, most notably, thirteen individuals who consumed an average of 11.2 ± 1.9% terrestrial animals, 19.8 ± 1.9% legumes, and 22.5 ± 3.1% marine fauna, a balanced pattern of protein consumption distinct from both the coastal and inland individuals in our larger regional sample.

Conclusions: The combination of stable isotope analysis and multisource mixture modeling permitted the characterization of dietary behavior of 25 individuals from nodal sites in the Atacama Desert, thus enhancing our understanding of the economic and social relationships that bound together Formative Period sites, populations, and individuals in this hyperarid region.

KEYWORDS
Atacama Desert, Formative Period, Southern Andes, stable isotope analysis, paleodiet

1 | INTRODUCTION

The Atacama Desert is located in northern Chile and southern Peru, between ca. 18 and 30° South. The Atacama is the world's driest desert, with less than 1 mm/year falling in the study area (Houston, 2006), and the region's aridity seems to have been a persistent feature for millennia (Moreno, Santoro, & Latorre, 2009). A recent paleoclimatic study suggests that aridity equal to, if not exceeding, that seen in the present prevailed throughout the Holocene, with the exception of a somewhat wetter period between 1000 and 2000 years ago

(Maldonado, de Porra, Zamora, Rivadeneira, & Abarzúa, 2016). In order to survive these arid conditions, ancient peoples strategically chose settlement locations on the Pacific coast, at oases, in deep *quebradas* on the western slope of the Andes, and along the Loa River, the region's only persistent river course (Castro, Berenguer, Gallardo, Llagostera, & Salazar, 2016). To supply material needs and wants, Atacameños (resident of the Atacama Desert) also developed systems of long-distance exchange, through which both essential and luxury goods moved (Pimentel, 2013). Quillagua and Ancachi, the two localities at the heart of this research (Figure 1), are located at a nexus of these trade routes between coastal and inland/highland populations, and a variety of sources support the notion that the Ancachi/Quillagua area has functioned as a frontier zone between groups living to their east, north, and west for much of its inhabited history, from the Formative Period until the 18th century A.D. (Agüero, Ayala, Uribe, Carrasco, & Cases, 2006; Agüero, Uribe, Ayala, Cases, & Carrasco, 2001; Agüero, Uribe, Ayala, & Cases, 1999; Paz Soldán, 1878).

While borders or frontiers such as that seen at Ancachi/Quillagua are often conceived of as limiting the interaction of peoples from surrounding areas, a wealth of social science literature sees them instead as zones of cultural transition between the societies that lie on either side (Barth, 1998, 2000; Newman, 2006; van Dommelen, 1997, 1998; White, 1991). Viewed as such, these frontier zones are judged to facilitate, rather than restrict, cross-cultural pollination. Indeed, people residing in these zones can become engines of cultural innovation and change. As discussed below, the "contact hypothesis," a sociological precept that describes how perceptions and behavior change when groups of people with diverse backgrounds come into close contact, provides a powerful lens for understanding the conditions under which cultural change might occur. In this regard, the inhabitants of Ancachi and Quillagua serve as ideal indicators from which to develop a better understanding of the movement and exchange of resources within the Atacama Desert during the Formative, and the lived consequences of this exchange for their behaviors and lifeways.

The way in which individuals obtain the necessary nutrients to survive is one of the most fascinating aspects of human behavior (Schwarcz & Schoeninger, 1991), and one of the most culturally enmeshed. Indeed, few aspects of human behavior are, simultaneously, as culturally bound and situationally responsive as diet, with the consequence that reconstruction of ancient dietary practices can

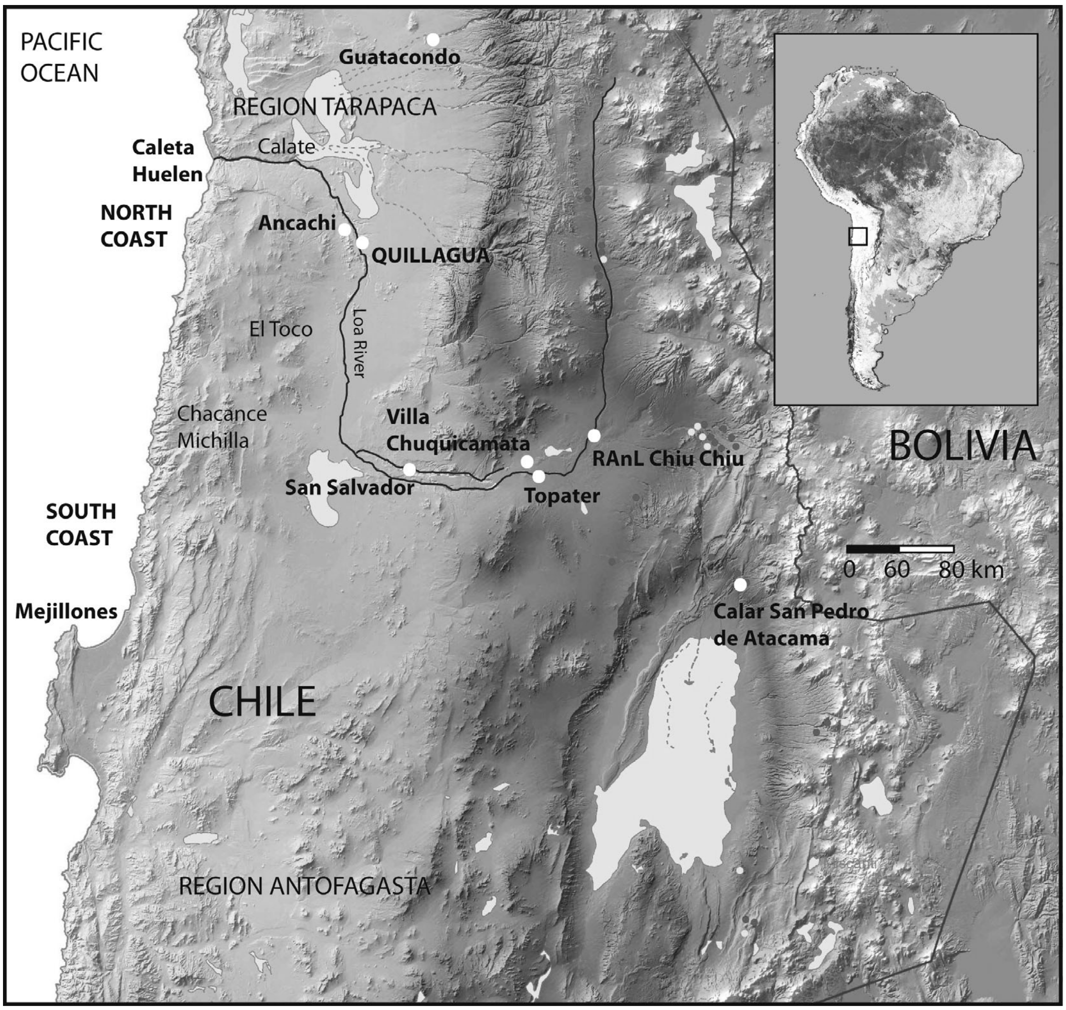

FIGURE 1 Map of study region, with sites mentioned in text noted

offer insights into myriad aspects of ancient life (see, for example, the articles in Twiss, 2007 [ed.]). The most well established technique for reconstructing individual-level ancient human diet is stable isotope analysis, which provides high-fidelity data on long-term (decadal) individual consumption patterns (Lee-Thorp, 2008). Stable isotope analysis has been part of the archeologist's toolkit since the last quarter of the 20th century, and it has been proven to provide researchers with an accurate method for estimating the dietary composition of past people, assuming a series of preconditions are met.

When combined with multisource mixture modeling (Fernandes, Millard, Barabec, Nadeau, & Grootes, 2014), one can use stable isotope analysis to develop quantitative and probabilistic estimates of the lived behavior (diet) of members of past societies. In the present case, these techniques allow us to characterize individual-level diet at Ancachi/Quillagua and identify those persons who appear to have been behaving (consuming) in ways not seen elsewhere among their contemporaries or in the broader region. Through this process of estimating ancient diet, we contend that we can, in effect, measure the effects of interaction patterns in these individuals, and thus gauge the presence and effects of ancient frontiers in the archeological record.

2 | MATERIALS AND METHODS

Cortical bone samples (~1 g) were obtained from 31 individuals from Formative Period burials in the tumulus cemetery of Ancachi and from pit/shaft tombs near the modern town of Quillagua (Agüero et al., 1999; Agüero & Uribe, 2015; Gallardo et al., 1993; Latcham, 1933). For these purposes, we consider the two sites, which sit ~10 km apart, jointly. The present work adds 19 individuals to a previously published sample of 12 individuals from Ancachi/Quillagua (Pestle, Torres-Rouff, Gallardo Ibanez, Andrea Cabello, & Smith, 2019). Ultimately, we consider both the internal variability and structure of the paleodiet of these individuals and then position them against a larger regional sample of nearly 200 previously analyzed individuals from the Formative Period (Pestle, 2017; Pestle, Torres-Rouff, Hubbe, Santana, Pimentel, Gallardo, & Knudson, 2015; Pestle, Torres-Rouff, Gallardo, Ballester, & Clarot, 2015).

The extraction of collagen and hydroxyapatite from human bone samples was performed at the Archeological Stable Isotope Laboratory at the University of Miami. Collagen and hydroxyapatite were both extracted from the same bone sample. Each sample was individually ground by hand using a ceramic mortar and pestle. Samples were then separated into size fractions using geological screens. The collagen extraction protocol used was established by Longin (1971) and modified by Pestle (2010). For each bone sample, 0.5 g of the 0.5–1.0 mm fraction was weighed and placed in a 50 ml centrifuge tube. The samples were demineralized in 30 ml of 0.2 M HCL on a spinning rotator for 24 hr. Samples were then rinsed to neutral pH through a process of centrifugation, decanting, and the addition of 30 ml of distilled water. Humic removal was accomplished by adding 30 ml of 0.0625 M NaOH to each sample for 20 hr. After this time elapsed, the samples were again rinsed to neutral pH. The remaining collagen was then gelatinized in 10^{-3} M HCL at 90°C and filtered using single-use Millipore Steriflip® vacuum filters, condensed, frozen, and freeze-dried. Start and end weights were recorded and used to calculate collagen yield (wt%) for each sample.

Hydroxyapatite extraction followed a protocol established in Lee-Thorp (1989) and Krueger (1991) and modified by Pestle (2010). Approximately 0.1 g of the 0.125–0.25 mm fraction was placed in a 50 ml centrifuge tube. After weighing, each sample underwent a 24 hr oxidation of organics using 30 ml of 50% bleach. The bleach treatment was then repeated for an additional 24 hr period for a total of 48 hr of treatment. Samples then were rinsed to neutral pH. The final step in the protocol involved the samples undergoing an acid treatment for the removal of labile carbonates. This was accomplished by the addition of 30 ml of 0.1 M acetic acid to each centrifuge tube for a total of 4 hr with a 5 min vacuum treatment at the 2 hr mark. After the acid treatment, each sample was rinsed again to neutral pH before being placed in a 50°C oven overnight. Start and end weights were recorded for all hydroxyapatite samples and used to calculate the weight percent hydroxyapatite yield.

Collagen and hydroxyapatite isotopic analysis was performed in the Marine Geology and Geophysics Stable Isotope Laboratory and the Rosenstiel School of Marine and Atmospheric Science at the University of Miami. Collagen samples were packed into tin capsules and analyzed using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20–20 isotope ratio mass spectrometer (IRMS). This analytical process yields information on elemental carbon and nitrogen composition as well as the stable isotopes of carbon and nitrogen ($\delta^{13}C_{co}$ and $\delta^{15}N_{co}$). Hydroxyapatite samples were analyzed using a Kiel-IV Carbonate Device coupled to a Thermo Finnigan DeltaPlus IRMA, providing the $\delta^{13}C_{ap}$ values. Collagen results were calibrated using acetanilide and glycine, and an optically clear calcite (OCC) standard calibrated to NBS-19 was used for hydroxyapatite. Standards were analyzed in every sample set at the beginning and end of the run, as well as in-between the analyzed samples to ensure instrumental stability. Check samples of all three standards were also run as unknowns in every run to verify measurement accuracy (Szpak, Metcalfe, & Macdonald, 2017). Precision (as determined by replicate analysis of samples included in the present study) averaged 0.1‰ for $\delta^{13}C_{co}$, 0.2‰ for $\delta^{15}N_{co}$, and 0.1‰ for $\delta^{13}C_{ap}$.

With isotopic data in hand, the food reconstruction using isotopic transferred signals (FRUITS) model of Fernandes et al. (2014) was used to quantify individual dietary composition. This multisource mixture modeling technique is one of several developed with the hope of better bounding estimates of food source contribution. Indeed, recent southern Andean attempts (Andrade et al., 2015; Pestle et al., 2019; Pestle, Torres-Rouff, & Hubbe, 2016; Pestle, Torres-Rouff, Hubbe, & Smith, 2017) at modeling have tended to use this, or similar, Bayesian approaches, which accommodate underdetermined systems (those with more than $n + 1$ sources), and also allow for the incorporation of priors (Fernandes et al., 2014; Moore & Semmens, 2008; Parnell, Inger, Bearhop, & Jackson, 2010). These approaches "offer a powerful means to interpret data because they can incorporate prior information, integrate across sources of uncertainty and explicitly compare the strength of support for competing models or parameter values," (Moore & Semmens, 2008: p. 471).

In order to generate consumer (human) data for the model, we first determined the consumer-foodstuff offset (and error) for $\delta^{13}C_{co}$ using the method of Pestle, Hubbe, Smith, & Stevenson, 2015. The offset in $\delta^{13}C_{ap}$ was stipulated as 10.1 ± 0.4‰ (Fernandes, Nadeau, & Grootes, 2012). Finally, for $\delta^{15}N_{co}$, we employed a trophic fractionation value of 3.6 ± 1.2‰, as recommended by several experimental studies of omnivorous animals (Ambrose, 2000; DeNiro & Epstein, 1981; Hare, Fogel, Stafford, Mitchell, & Hoering, 1991; Howland et al., 2003; Sponheimer et al., 2003; Warinner & Tuross, 2009).

Food web isotope values comprised the edible portions of 89 archeological and modern Atacameño plants and animals. The decision to restrict the food web sample to only those generated in the course of our work in the region was due to the isotopic dissimilarity between those samples and other previously published values. Any modern data included in this reference sample had $\delta^{13}C$ values corrected by +1.5‰ to account for recent fossil fuel burning (Keeling, Mook, & Tans, 1979). The $\delta^{13}C$ value of bone samples were adjusted by −1‰ (fish), −1.5‰ (marine mammals), and – 2.0‰ (terrestrial mammals/birds) to account for bone collagen-edible tissue offset. All food web values are provided in Table S1. Macronutrient composition of each food group was determined by reference to the USDA National Nutrient Database for Standard Reference (Agriculture, 2013). Elemental composition (particularly percentage of C) of each foodstuff/macronutrient group was based on formulae provided in Morrison, Dodson, Slater, and Preston (2000). Digestibility was determined following Hopkins (1981). All nitrogen in bone collagen was stipulated as coming from dietary protein, the carbon in hydroxyapatite was stipulated as reflecting all dietary carbon, and the carbon composition of bone collagen was set as reflecting a 3:1 ratio of dietary protein to energy (Fernandes et al., 2012). Carbon isotope offsets between measured bulk food isotope values and the isotopic values of a foodstuff's fats (bulk-6‰) and carbohydrates (bulk+0.5‰) were based on data from Tieszen (1981). The carbon isotope signature of a measured bulk foodstuff's protein was determined using a mass-balance equation, such that a proportional/weighted average of the $\delta^{13}C$ of protein and energy (fats and carbohydrates) would equal the measured $\delta^{13}C$ bulk value (corrected for the concentration of carbon in each macronutrient and foodstuff-appropriate macronutrient concentration).

Final food group isotope, macronutrient, and elemental concentration values used in the FRUITS simulations are presented in Table 1. We divided the available foodstuffs into five groups (C_3 plants, C_4 plants, legumes, terrestrial animals, and marine animals). Consumption of protein was limited to less than 45% of protein as energy (using the FRUITS a priori data option), reflecting the upper limit of possible human protein intake (World Health Organization, 2007). All FRUITS simulations were performed using 10,000 iterations, as recommended by its developers.

TABLE 1 Macronutrient, isotopic, and elemental data for food groups used in FRUITS multisource mixture model

		Macronutrient concentration (%)				%C				Tissue $\delta^{13}C$ (‰)					Tissue $\delta^{15}N$ (‰)	
Food grouping	Group n	Protein	Fat	Carbohydrates	Energy	Protein	Fat	Carbohydrates	Energy	Bulk	Protein	Fat	Carbohydrates	Energy	Bulk	Protein
Terrestrial animals	24	83 ± 12	16 ± 12	1 ± 3	17 ± 12	43 ± 12.7	12 ± 12.1	0 ± 4.2	13 ± 12.7	−16.5 ± 3.8	−14.8 ± 3.8	−22.5 ± 3.8	−16 ± 3.8	−22.3 ± 3.8	9.8 ± 2.4	9.8 ± 2.4
Marine animals	31	74 ± 15	19 ± 16	7 ± 9	26 ± 15	39 ± 15.3	15 ± 16.6	3 ± 9.6	18 ± 15.3	−14.6 ± 2.9	−12.4 ± 2.9	−20.6 ± 2.9	−14.1 ± 2.9	−19.5 ± 2.9	20.9 ± 3.4	20.9 ± 3.4
C_3 plants	17	10 ± 5	5 ± 4	84 ± 7	89 ± 5	5 ± 6.9[a]	4 ± 6.7	37 ± 8.5	41 ± 6.9	−23.7 ± 2.0	−22.3 ± 2.0	−29.7 ± 2.0	−23.2 ± 2.0	−23.8 ± 2.0	8.6 ± 5.4	8.6 ± 5.4
C_4/CAM plants	13	10 ± 5	5 ± 4	84 ± 7	89 ± 5	5 ± 6.9[a]	4 ± 6.7	37 ± 8.5	41 ± 6.9	−11.2 ± 1.6	−9.8 ± 1.6	−17.2 ± 1.6	−10.7 ± 1.6	−11.3 ± 1.6	12 ± 5.6	12 ± 5.6
Legumes	4	24 ± 2	2 ± 1	71 ± 3	72 ± 2	13 ± 5.6[a]	1 ± 5.3	31 ± 5.8	33 ± 5.6	−23.5 ± 1.7	−24.2 ± 1.7	−29.5 ± 1.7	−23.0 ± 1.7	−23.2 ± 1.7	0.7 ± 3.0	0.7 ± 3.0

[a]Assumes 87.4% digestibility of plant protein as compared to animal protein.

3 | RESULTS

Sample preservation quality was determined using both chemical (collagen yield) and elemental (carbon and nitrogen yield, atomic C/N ratio) data. Only well preserved (collagen yield >0.5 wt%, carbon yield >4.5 wt%, nitrogen yield >0.9 wt%, atomic C/N ratio between 2.9–3.6) samples were included in FRUITS calculations. Based on the arid environmental conditions of the region, samples that met these requirements also were assumed to have acceptable hydroxyapatite preservation (the lack of free water making the prospects of dissolution and recrystallization unlikely).

As seen in Table 2, 80.6% (25/31) of the samples yielded sufficient well-preserved collagen to be considered as reflecting biogenic isotope signatures. The average collagen yield for those 25 samples was 13.7 ± 5.3 wt%, carbon yield averaged 40.8 ± 1.9 wt%, the average nitrogen yield was 14.2 ± 1.0 wt%, making the average atomic C/N ratio 3.4 ± 0.1. Elemental values were not recorded for one sample (I-102), but due to its high collagen yield and unremarkable (non-outlying) isotope values, we nonetheless included it in later analysis. Similarly, sample I-101 had a slightly elevated atomic C:N ratio (3.7), but we retained the sample because its carbon and nitrogen yields were within acceptable ranges and it was not an isotopic outlier.

Turning to isotopic results (Table 2), $\delta^{13}C_{co}$ for the 25 well-preserved samples averaged −15.5 ± 0.9‰ (range – 17.1−-13.4‰) and $\delta^{13}C_{ap}$ averaged −11.4 ± 0.8‰ (range – 13.0−-9.8‰), which, when combined, yielded an average $\Delta^{13}C_{ap\text{-}co}$ of 4.2 ± 0.6‰ (range 3.2–5.2‰). $\delta^{15}N_{co}$ averaged 17.3 ± 3.0‰, and possessed an immense range of 10.9–25.8‰. To begin with, then, there is notable isotopic variation within the sample, particularly in $\delta^{15}N_{co}$, suggesting comparable diversity in patterns/sources of protein consumption.

Based on the results of FRUITS modeling (Table 3), C_3 plants were the largest average dietary contributor, providing an average of 37.2 ± 4.4% of calories, with a range of 28.5–46.2%. In comparison, C_4/CAM plants made up an average of only 8.7 ± 1.4% of diet, ranging between 6.2 and 13.0%. Turning to dietary protein, terrestrial animals contributed between 5.2 and 19.8% (average 12.0 ± 2.7%), marine animals 19.5 ± 7.0% (range 7.7–41.3%), and legumes 22.5 ± 6.0% (range 10.8–39.2%). It is the variability of these protein sources, and

TABLE 2 Chemical, elemental, and isotopic data for all Ancachi/Quillagua individuals

Sample	Site	Burial	Collagen yield (%)	%C	%N	Atomic C:N	$d^{13}C_{co}$ (‰)	$d^{15}N_{co}$ (‰)	$d^{13}C_{ap}$ (‰)	$\Delta^{13}C_{ap\text{-}co}$ (‰)
I-99[a]	Ancachi	UR-3	18.4	39.6	13.6	3.4	−14.8	20.4	−11.6	3.2
I-100[a]	Ancachi	UR-3	23.9	43.5	14.9	3.4	−15.1	17.9	−11.4	3.7
I-101[a]	Ancachi	UR-1	14.6	38.6	12.0	3.7	−15.4	18.5	−10.5	4.9
I-102[a]	Ancachi	UR-6	24.5	–	–	–	−15.3	16.9	−11.5	3.8
I-103[a]	Ancachi	UR-2	14.6	39.6	13.4	3.4	−15.4	16.7	−11.8	3.6
I-105[a]	Ancachi	UR-4	20.2	39.8	14.0	3.3	−14.6	16.9	−11.2	3.4
J-84[a]	Quillagua	Museo, caja 3–3	16.0	44.4	15.6	3.3	−15.1	17.7	−11.6	3.5
J-86[a]	Quillagua	Torre 203, Qui.1, museo, exhibido	7.0	41.9	13.6	3.6	−13.4	25.8	−10	3.4
J-92[a]	Quillagua	Torre 203, Qui 02	16.6	44.9	16.3	3.2	−16.5	10.9	−11.5	5.0
J-93[a]	Quillagua	Qui. Res. 2013–1	3.2	38.9	13.4	3.4	−17.1	11.2	−12.1	5.0
L-133	Ancachi	12140, 343, 399	7.8	37.9	13.2	3.3	−16.4	16.8	−11.9	4.5
L-134	Ancachi	12146, 344, 400	5.7	38.1	13.6	3.3	−15.1	17.5	−10.6	4.5
L-135	Ancachi	12065, 340, 401	13.4	41.0	14.6	3.3	−14.7	17.7	−10.7	4.0
L-136	Ancachi	12141, 342, 403	11.1	39.9	14.6	3.2	−17.1	16.0	−13.0	4.1
L-137	Ancachi	12137, 345, 402	16.8	41.1	15.0	3.2	−14.8	20.2	−10.9	3.9
L-138	Ancachi	12139, 347, 398	15.1	41.6	14.7	3.3	−16.0	15.3	−11.4	4.6
L-139	Ancachi	12148, 1899, 403	12.6	40.7	14.8	3.2	−14.6	12.3	−10.1	4.5
L-140	Ancachi	12152, 348, 397	12.9	41.0	14.7	3.2	−15.8	16.7	−12.1	3.8
L-141	Ancachi	ANC16	16.7	40.8	13.6	3.5	−16.0	19.0	−11.7	4.3
L-144	Ancachi	ANC-30-I1	15.1	42.2	15.0	3.3	−15.5	16.4	−11.7	3.9
L-148	Ancachi	ANC12	7.4	39.9	14.1	3.3	−16.0	16.5	−11.2	4.8
L-149	Ancachi	ANC7	8.1	42.2	14.1	3.5	−16.9	16.7	−12.5	4.4
L-150	Ancachi	ANC6-I1	12.9	41.4	14.3	3.4	−16.4	19.4	−12.9	3.5
L-151	Ancachi	ANC13	10.8	37.3	12.7	3.4	−15.4	19.1	−11.2	4.1
L-152	Ancachi	ANC-2-I1	16.4	42.2	15.1	3.3	−15.0	19.6	−9.8	5.2

[a]Individuals were previously published in Pestle et al., 2019.

TABLE 3 Results of FRUITS multisource mixture modeling for Ancachi/Quillagua individuals, mean and *SD* for each source provided

Sample	Site	Burial	Terrestrial animals (%)	*SD* (%)	C_3 plants	*SD* (%)	C_4/CAM plants (%)	*SD* (%)	Legumes (%)	*SD* (%)	Marine animals (%)	*SD* (%)
I-99[a]	Ancachi	UR-3	8.4	7.6	39.6	18.2	7.7	6.4	16.7	13.7	27.6	11.3
I-100[a]	Ancachi	UR-3	12.3	10.3	38.0	18.5	8.7	7.1	20.1	15.2	20.9	10.4
I-101[a]	Ancachi	UR-1	11.0	9.5	36.2	18.4	9.6	7.6	20.0	15.0	23.2	11.1
I-102[a]	Ancachi	UR-6	13.0	10.9	36.8	19.0	8.8	7.2	22.9	16.1	18.5	9.5
I-103[a]	Ancachi	UR-2	13.3	11.0	37.9	19.2	8.3	6.8	23.1	16.7	17.3	9.3
I-105[a]	Ancachi	UR-4	14.0	11.5	34.4	18.3	9.8	7.7	22.5	15.3	19.3	10.0
J-84[a]	Quillagua	Museo, caja 3–3	12.7	10.4	38.5	18.6	8.4	6.9	20.4	15.9	20.0	10.0
J-86[a]	Quillagua	Torre 203, Qui.1, museo, exhibido	5.2	4.6	32.8	14.7	10.0	8.0	10.8	9.4	41.3	11.7
J-92[a]	Quillagua	Torre 203, Qui 02	13.4	10.5	30.8	19.1	9.6	7.4	38.5	18.1	7.7	6.3
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L-135	Ancachi	12065, 340, 401	12.3	9.9	36.5	18.4	10.3	8.1	20.2	15.1	20.8	10.1
L-136	Ancachi	12141, 342, 403	11.7	10.5	45.3	21.3	6.2	5.2	23.1	17.5	13.7	8.5
L-137	Ancachi	12137, 345, 402	9.1	8.6	36.9	17.5	8.7	7.1	17.8	13.8	27.5	11.0
L-138	Ancachi	12139, 347, 398	14.5	11.4	37.1	20.0	8.8	6.9	25.3	17.4	14.4	8.8
L-139	Ancachi	12148, 1899, 403	19.8	12.8	28.5	17.5	13.0	8.9	28.1	15.7	10.7	7.7
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L-141	Ancachi	ANC16	9.4	8.5	42.1	18.6	7.5	6.4	18.5	14.6	22.5	10.7
L-144	Ancachi	ANC-30-I1	13.4	11.1	37.9	19.7	8.2	6.5	24.0	16.9	16.5	9.0
L-148	Ancachi	ANC12	13.3	10.8	37.0	19.1	9.0	7.3	23.4	16.4	17.4	9.5
L-149	Ancachi	ANC7	12.1	11.1	43.3	20.1	7.0	5.8	22.1	16.3	15.6	8.9
L-150	Ancachi	ANC6-I1	8.8	8.6	46.2	18.8	6.4	5.6	17.5	14.9	21.1	10.1
L-151	Ancachi	ANC13	10.0	9.0	38.4	18.6	8.5	7.0	19.6	14.6	23.6	10.5
L-152	Ancachi	ANC-2-I1	10.6	9.5	32.3	17.4	10.3	8.1	19.9	14.7	26.9	11.1

[a]Individuals were previously published in Pestle et al., 2019.

in particular that of the marine faunal source (which shows a greater-than fivefold difference between minimum and maximum modeled contribution), that is most noteworthy.

4 | DISCUSSION

Comparing these results to Formative Period individuals from coastal and interior sites in the Atacama (Figure 2), for whom we used the same FRUITS model, (at least) two distinct dietary regimes are evident among the individuals from Ancachi/Quillagua. On the one hand, certain individuals (e.g., J-86 from Quillagua [41.3 ± 11.7% marine protein]) possess modeled diets consistent with coastal origin, whereas others (e.g., L-139 from Ancachi [10.7 ± 7.7% marine]) would appear to be of interior origin, based on their heavy terrestrial protein reliance. This provides direct testament to the presence in Ancachi/Quillagua of people of presumably nonlocal origin, or at least people who ate in ways consistent with other far-removed locales. It is our contention that these individuals came to be buried in Ancachi/Quillagua as a consequence of their direct personal movement/involvement in systems of regional exchange. Like other Formative Period individuals who we have recovered from alongside trade routes through the Atacama (Knudson, Pestle, Torres-Rouff, & Pimentel, 2012; Pimentel, Ugarte, Blanco, Torres-Rouff, & Pestle, 2017; Torres-Rouff, Pimentel, & Ugarte, 2012), these individuals were agents (travelers, traders) embedded in these region-wide systems of exchange.

A larger number of the Ancachi individuals (52%, 13/25), however, would appear to have consumed a mixed diet (particularly in terms of protein composition/balance) unlike that seen in any other site in the region. These individuals consumed an average of 11.2 ± 1.9% terrestrial animals, 19.8 ± 1.9% legumes, and 22.5 ± 3.1% marine fauna, a balanced pattern of protein consumption that is notably distinct from both the coastal and inland individuals in our larger regional sample. As Ancachi/Quillagua were located at a centralized location between coastal and interior populations, in a border/frontier space, we contend that the unique dietary pattern seen in this population evince the types of interactions and cultural innovation that only (or most

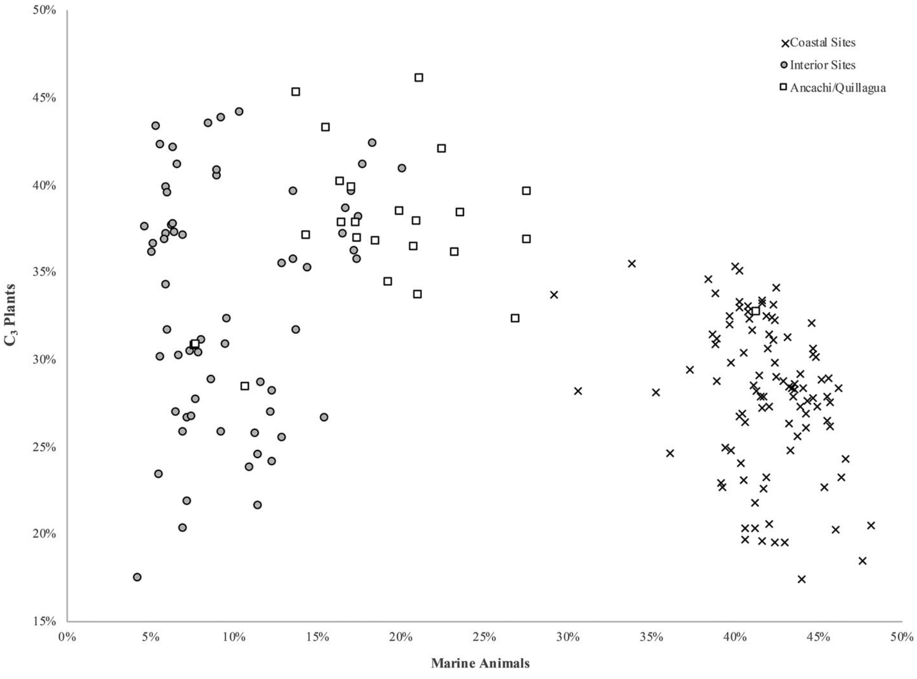

FIGURE 2 FRUITS modeled consumption of marine animals and C3 plants for Ancachi/Quillagua individuals and comparative interior and coastal populations. FRUITS, food reconstruction using isotopic transferred signals

often) occur in such border spaces. Individuals of diverse origin and food culture were coming together at Ancachi/Quillagua, interacting via meaningful economic and social exchanges, and (one of) the products of this interaction was new dietary practices, new cultural forms.

In sociology, the "contact hypothesis" has been employed for over 60 years as means of explaining how attitudes and behaviors can change as a consequence of long-term meaningful (equal-status, non-transactional) interaction between groups of distinct interest/origin. While this notion was originally developed in the context of racial prejudice reduction in the United States of the mid-20th century (Allport, 1954), decades of further study has validated its prediction that under circumstances of prolonged equal-status co-existence and interaction, common experience will shape and sway the opinions and worldview of even the most entrenched actors (Kende, Phalet, Van den Noortgate, Kara, & Fischer, 2018; Mirwaldt, 2010; Pettigrew & Tropp, 2006; Pettigrew, Tropp, Wagner, & Christ, 2011). When these interactions extend beyond the transactional, to the kinds of more profound egalitarian relationships that emerge when diverse individuals interact and coexist for long periods of times while engaged in mutually-beneficial activities, individuals begin to exhibit real social and cultural exchange, and new and hybrid behaviors emerge.

That a form of eating unlike anything else seen in the Loa River Region of the Atacama during the Formative Period would emerge in a space like Ancachi and Quillagua would suggest that beyond simply functioning as economic nodes, these sites acted as locations of social exchange and interculturation. People were not only passing through these spaces in pursuit of material needs, but the positioning of these sites as a nexus or node in the Formative Period's regional exchange network would appear to have facilitated the transculturation of individuals involved, and the emergence of new ways of eating, if not new ways of living. Indeed, the dietary intermediacy presented here mirror findings derived from ceramics and textiles of cultural merging, hybridity, and evolution in the area of Quillagua during the Formative (Agüero et al., 2001, 2006; Agüero & Cases, 2004; Uribe & Ayala, 2004). These processes would likely have been similar/the same that produced, for instance, new regional stylistic conventions and symbolic vocabularies during the Formative (Castro et al., 2016).

5 | CONCLUSIONS

Dietary patterns are fundamental to an individual's identity, and their reconstruction can serve as a powerful tool for understanding past cultural and ethnic differences and identity formation. In the present work, stable isotope analysis and multisource mixture modeling permitted the characterization of dietary behavior of 25 individuals buried in a region thought to be central to a vast regional exchange system. Our results suggest that the diets of these Ancachi/Quillagua individuals were strongly influenced by the kind of exchange systems that surrounded them in life. One possible explanation for the novel dietary patterns we observed is that these systems of economic exchange had fostered meaningful social relationships among different cultural groups. Through these interactions, some of the individuals studied here adopted new cultural lifestyles and behaviors, consuming resources from both coastal and interior cultural patterns, in an entirely new way of living otherwise not seen in the surrounding region. Further analysis of additional human remains recovered from Ancachi/Quillagua cemetery should be performed to validate and develop this notion, but based on the data presented here, it is clear that something novel, and indeed phenomenal, was taking place in this portion of Atacama Desert region more than 2000 years ago.

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