Reports

Mobility and Exchange among Marine Hunter-Gatherer and Agropastoralist Communities in the Formative Period Atacama Desert

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Northern Chile's Atacama Desert is one of the most unforgiving landscapes on the planet; however, a variety of complex risk-mitigation strategies facilitated long-term human occupation of the region. Using a burgeoning corpus of human, floral, and faunal stable carbon and nitrogen isotope data, the present work examines patterns of mobility, exchange, and social interaction in northern Chile's Formative Period (1500 BC–AD 400). While the geographic barriers and harsh climatic conditions of the Atacama Desert, in concert with substantial logistic considerations, established constraints on human diet at the site and local levels, regional dietary variation speaks to frequent and possibly even regular interzonal movements of people and/or foodstuffs. Through isotopic analysis of the remains of 86 individuals, we examine regional patterns of dietary variation in light of recently advanced hypotheses concerning the nature of mobility, exchange, and social interaction in Formative Period northern Chile. These data indicate both systematic regional exchange in foods and other goods and the central role of sites in the Calama oases in facilitating this exchange and movement.

The Formative Period in the Americas is considered an analogue to the European Neolithic, a period in which a profound shift in subsistence strategies engendered equally acute social transformations. In northern Chile's Atacama Desert, the Formative Period (1500 BC–AD 400) saw the emergence of a suite of novel phenomena including sedentism, agriculture, camelid pastoralism, surplus production fostering far-flung exchange networks, and burgeoning cultural and ceremonial complexity (Gallardo 2009; Lumbreras 2006; Núñez et al. 2006; Pimentel 2013). Of particular interest here is the emergence of a network of zonal complementarity (*la red de complementariedad zonal*), which not only served to distribute, and thereby mitigate, economic risk in a marginal environment, but also fostered a previously unseen degree of pan-regional integration (Gallardo, n.d.).

The present work employs stable isotope analysis to examine the human dimension of this network of interzonal exchange. Stable isotope composition, and thus dietary composition, can serve as a proxy for residency and the movement of people and goods. Here, we show that exchange between the coast and interior, and potentially even farther east to the trans-Andean region, was a regular, sustained, and sustaining part of life during the Formative. Through this innovative approach to paleomobility and exchange we seek to identify communities and individuals that were active in this network, the ultimate effects of which were novel and profound. By complementing a more traditional focus on the things that moved with our perspective on the people themselves, we hope to inject a more humanized view into the nature and consequences of interzonal exchange in northern Chile's Formative Period.

Regional Background

The Atacama Desert (fig. 1) is a roughly 100,000 km^2 expanse stretching north from ~30° south latitude to the present border with Peru at ~18° south latitude. It is bounded on the west by the depths of the Pacific Ocean and to the east by the commanding heights of the Andes. While conditions along a north-south axis are relatively homogenous, an east-west transect (fig. 2) reveals considerable topographic and environmental variation. The intense aridity that characterizes the Atacama—"an extreme habitat for life on Earth and . . . an analog for life in dry conditions on Mars" (McKay et al. 2003:393)—has generally dominated the regional climate throughout the temporal span of human occupation (Moreno, Santoro, and Latorre 2008). This pervasive dryness makes life in the region contingent upon successful strategies of risk management. At least part of this strategy included the logistical situation of settlements in the desert's few hos-

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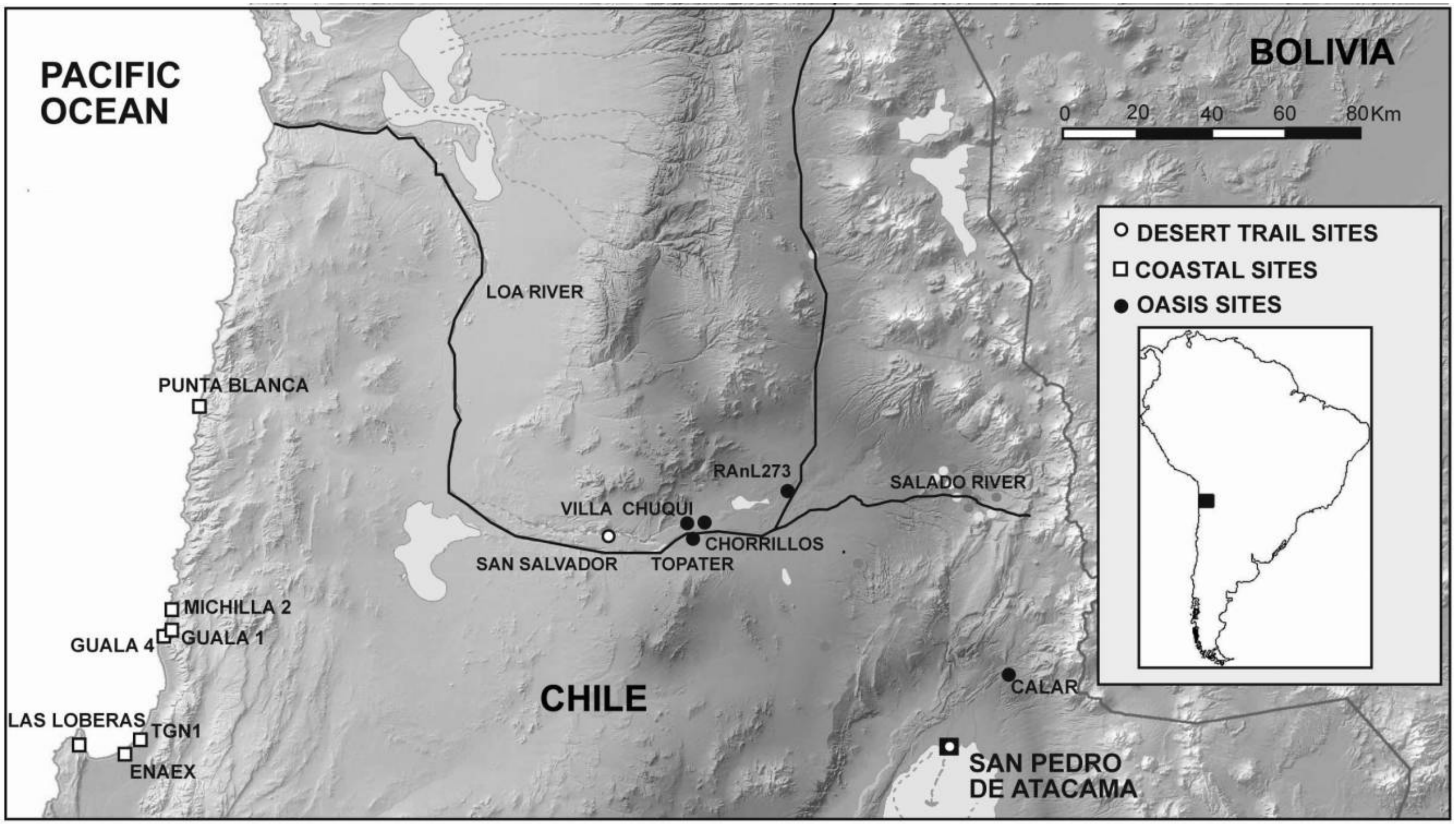

Figure 1. Map of Atacama Desert with location of sites mentioned in text noted.

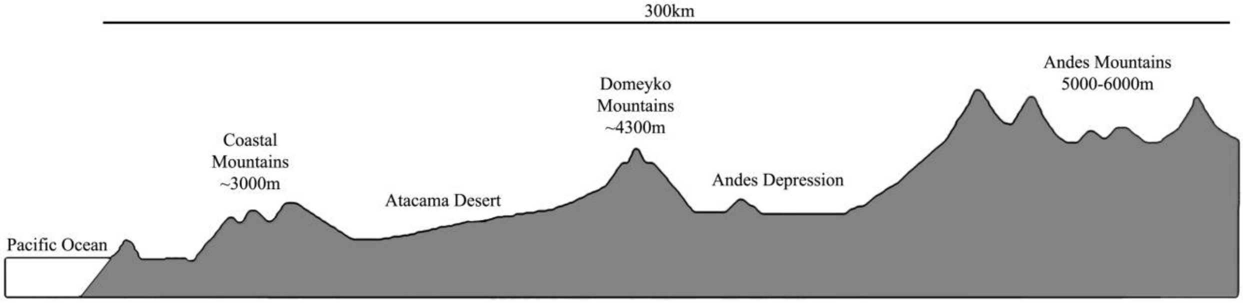

Figure 2. Elevation profile of Atacama Desert (after McKay et al. 2003, fig. 2).

pitable areas, that is, in oases or along river canyons as well as in settlements on the comparatively resource-rich coast (Ballester and Gallardo 2011; Pimentel 2013).

Other means of mitigating these environmental risks have been used over time by different Andean societies. These included zonal complementarity as a means of accessing the varied resources available along the east-west altitudinal and environmental cline. In the earlier Archaic Period (8000 BC–4500 BC), a pattern of seasonal residential mobility allowed the region's inhabitants to avail themselves of patchy and cyclical sources of food and raw material (Aldenderfer 1989; Núñez and Santoro 2011). The domestication of llamas as beasts of burden, the appearance of semipermanent villages, and the long-distance exchange that emerged among Archaic hunter-gatherer groups in the desert of northern Chile (ca. 4500–1500 BC) have been interpreted as early signs of social complexity (Cartajena, Núñez, and Grosjean 2007; de Souza et al. 2010; Mengoni 2008; Núñez and Santoro 2011; Yacobaccio 2004). Much later, in the Inka and Historic Periods (after AD 1400), Murra (1972) observed a form of complementarity, "characterized by direct, central control of vertically stratified resource-producing zones ("vertical archipelagos")" (Aldenderfer 1989:118), providing access to goods that were also obtained by long-distance trade (Gallardo 2013; Hirth and Pillsbury 2013*a*, 2013*b*). Here, we seek to address how people living in the intervening Formative Period approached the necessity for interzonal complementarity through far-flung exchange networks.

The Formative Period

The Formative Period of the oases of northern Chile (traditionally divided into three phases, Early [1500–500 BC], Middle [500 BC–AD 100], and Late [AD 100–400]) witnessed: (*a*) the emergence of large agglomerated residential centers, (*b*) the growth of pastoralism, (*c*) the intensification of gathering and hunting, (*d*) small-scale agriculture, and (*e*) long-distance exchange (Gallardo 2009; Labarca and Gallardo 2012; Lumbreras 2006; Núñez and Santoro 2011; Núñez et al. 2006; Pimentel 2013).

Archaeological localities along the Loa River (Chiu Chiu, Calama, and Quillagua oases) and neighboring coast exhibit stable economies (based on gathering and farming-herding in the interior and, on the coast, on marine hunting and fishing) that fostered increasing population size and nucleation. These increases, supported by steady resource bases, gave rise to a communal social organization manifested not only in the appearance of settled villages (oases) and residential camps (coast), but also in the elaborate and consolidated mortuary practices expressed in the community tombs and cemeteries of the interior (Ballester and Gallardo 2011; González and Westfall 2006; Pollard 1971; Thomas et al. 1995), and the expansive mound cemeteries of the coast (Moragas 1982; Núñez 1971; Spahni 1967).

Burgeoning populations and the production and storage of food surpluses, marine shells, copper ore, textiles, ceramics, and metallurgical craft also stimulated the development of region-wide systems of exchange (Ballester and Gallardo 2011; Cartajena, Núñez, and Grosjean 2007; Gallardo 2009; Labarca and Gallardo 2012; Pimentel 2013). This long-distance trade was facilitated by llama caravans in the desert and sea lion skin vessels on the coast. The recovery of a diverse array of materials including Tarapacá ceramics and textiles, dried marine fish, seashell artifacts, Argentine ceramics, seeds for hallucinogenic snuff (*Anadenanthera* species), pipes, and freshwater gastropod shells at sites in the Atacama oases stand as testament to these connections (Agüero et al. 2006; González and Westfall 2006; Pollard 1971; Thomas et al. 1995; Torres-Rouff et al. 2012).

The presence, at sites in/near modern-day Calama, of exotic goods from the north (Tarapacá), west (Pacific coast), and east (San Pedro de Atacama and northwest Argentina) extremes of this regional long-distance exchange network, demonstrates the nodal importance of these localities.

Stable Isotopes as a Proxy for Paleomobility

Analysis of radiogenic isotopes of strontium ($^{87}Sr/^{86}Sr$) in geological, faunal, and human skeletal and dental samples is the preferred means for reconstructing the movement and migration of prehistoric peoples and has been used with great effectiveness in the Andes and elsewhere (Bentley 2006). Unfortunately, in portions of the Atacama Desert, there does not appear to be sufficient underlying variability in bedrock $^{87}Sr/^{86}Sr$ signatures to derive inferences about smaller scale movement (Knudson and Torres-Rouff 2009; Torres-Rouff and Knudson 2007). Therefore, while strontium isotope analysis is an ideal tool for identifying truly "exotic" individuals, for example, from the Bolivian *altiplano* (e.g., Knudson et al. 2004), at present there is insufficient baseline strontium isotope data to derive conclusions about interzonal movement internal to the Atacama itself.

While geologically homogenous, the Atacama is environmentally diverse, at least along its east-west axis (fig. 2). As a consequence, the types of foods, and in particular the primary sources of animal protein at the ends of the east-west trade networks, are remarkably different. While terrestrial taxa, in particular camelids, dominate the faunal resources in mid- and high-altitude areas of the Atacama (Cartajena, Núñez, and Grosjean 2007), sites proximate to the Pacific coast had easy access to one of the world's most productive marine fisheries (Chavez et al. 2008).

It is this difference in dietary protein that, rather fortuitously, provides a potential means of identifying the origin and patterns of movements not only of materials from these areas, but also of the Atacama's ancient inhabitants. Due to systematic differences in the underlying carbon and nitrogen isotope composition of marine and terrestrial ecosystems, and the disparate lengths of trophic chains in those two environments, fauna from land and sea are isotopically distinct in both their carbon and nitrogen makeup (Bösl, Grupe, and Peters 2006; Chisholm, Nelson, and Schwarcz 1982; Schoeninger and DeNiro 1984; Schoeninger, DeNiro, and Tauber 1983). Systematic isotopic enrichment in $\delta^{13}C$ and $\delta^{15}N$, the stable isotope ratios of carbon and nitrogen, are a hallmark of marine taxa as compared to their terrestrial counterparts. The osseous remains of human consumers who habitually (10–30 years before death) eat one or the other of these protein sources will, in turn, have telltale signatures with which their diet, and by extension their geographic place of origin or long-term residency, can potentially be elucidated (i.e., Knudson et al. 2012).

Methods and Materials

Here, as in any isotopic study of paleodiet, two complementary data sets are needed: one derived from the tissues of consumers, in this case Formative Period humans, and one from a foodweb that represents the range of foods that those consumers may have been eating. Below we briefly present our sampling and laboratory protocols for these data sets.

As displayed in table 1, the 86 archaeological human samples include 40 individuals from five coastal sites, and 46 individuals from four inland sites (greater than 180 km from the coast, measured following the course of the Loa River). The vast majority ($n = 75$) of these data result from new analyses conducted by the authors, although previously published isotopic data on nine individuals from San Salvador (Torres-Rouff, Pestle, and Gallardo 2012) and two individuals from Regimiento Chorillos (González and Westfall 2006) are also included. Radiocarbon dates from human bone or associated materials are available for 74 of these 86 individuals (86%).

All newly acquired skeletal samples were processed prior to isotopic analysis in the laboratory of one of the authors (WJP). Extraction of collagen (the principal protein of bone) followed a modified version (Pestle 2010; Pestle and Colvard 2012) of the protocol first established by Longin (1971). Collagen yield data were collected after extraction and lyophilization to verify preservation of biogenic isotopic signals. Extraction and purification of bone hydroxyapatite (the most abundant mineral in bone) followed the protocol of Lee-Thorp (1989) and Krueger (1991), with modifications described elsewhere (Pestle 2010). Hydroxyapatite yield was recorded subsequent to extraction and lyophilization.

Isotopic analysis of all extracted biomolecular samples was performed at the Colorado Plateau Stable Isotope Laboratory (CPSIL) at Northern Arizona University. Collagen samples were converted to gas via combustion in an Elemental Analyzer (allowing for the generation of atomic C:N ratio) interfaced into the Isotope Ratio Mass Spectrometer (EA-IRMS). Data generated during EA-IRMS of bone collagen included both $\delta^{13}C_{co}$ and $\delta^{15}N_{co}$, isotopic variables that have been shown experimentally to reflect the carbon and nitrogen isotope composition of dietary proteins (Ambrose and Norr 1993; Jim et al. 2007; Kellner and Schoeninger 2007). Hydroxyapatite samples were converted to gaseous form prior to mass spectrometry via acid digestion in a Gas Bench II carbonate inlet system interfaced with the IRMS. This GB-IRMS process produced data on $\delta^{13}C_{ap}$ reflecting the carbon isotope makeup of whole diet, but particularly dietary carbohydrates (Ambrose and Norr 1993). While this process also generated $\delta^{18}O$ data from hydroxyapatite, it was omitted from the present analysis given the complexity of the Andean oxygen isoscape (Knudson 2009) and the lack of comparability of $\delta^{18}O$ results obtained in different laboratories (Pestle, Crowley, and Weirauch 2014)

The foodweb data set ($n = 301$) for comparison with human stable isotope values comprises a mixture of ancient and modern samples, including previously published data from the southern Andes (DeNiro and Hastorf 1985; Miller, Capriles, and Hastorf 2010; Schoeninger and DeNiro 1984; Tieszen and Chapman 1992), as well as data generated in the course of the present work. A summary of the foodweb isotopic data by broad ecological niche is provided in table 2.

Results

Results of the human bone collagen and hydroxyapatite stable isotope analyses are presented in table 1. We now consider these results first in terms of regional patterns and then on a site-by-site basis.

Table 1. Findspot, radiometric, and isotopic data of individuals included in the present sample

Site	Site number	Laboratory code	Atomic C:N	$\delta^{13}C_{co\text{-}PDB}$ (‰)	$\delta^{15}N_{co\text{-}AIR}$ (‰)	$\delta^{13}C_{ap\text{-}PDB}$ (‰)	$\Delta^{13}C_{ap\text{-}co}$ (‰)	^{14}C Laboratory code(s)	Material dated	Uncalibrated ^{14}C date(s)	(Average) calibrated median probability ^{14}C date	Distance from coast (km)
Calar	3055	H-17	3.2	−15.7	10.7	−11.0	4.8	A-14111	Plant	1810 ± 55	112 cal AD	317
Calar	3056	H-18	3.2	−16.9	10.8	−11.2	5.7	A-14111	Plant	1810 ± 55	112 cal AD	317
Calar	3483	H-16	3.3	−15.7	10.1	−10.0	5.8	A-14111	Plant	1810 ± 55	112 cal AD	317
Calar	3041, #213	H-14	3.2	−15.7	9.9	−11.0	4.7	A-14111	Plant	1810 ± 55	112 cal AD	317
Calar	3048, #214	H-15	3.4	−15.5	9.9	−8.9	6.7	A-14111	Plant	1810 ± 55	112 cal AD	317
Chorillos	C14			−20.4	10.7			Beta-205812	Collagen	2590 ± 40	674 cal BC	230
Chorillos	H-16			−18.6	14.7			Beta-205813	Collagen	2550 ± 40	638 cal BC	230
Gualaguala01	06-01	G-17	3.2	−11.8	24.4	−9.3	2.5	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	09-01	G-23	3.2	−10.9	27.1	−7.0	4.0	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	11-01	G-18	3.1	−12.0	24.6	−9.0	3.0	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	14-01	G-14	3.1	−11.9	23.7	−8.7	3.2	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	16-01	G-15	3.2	−11.6	24.1	−6.1	5.4	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	17-01	G-16	3.2	−12.0	25.7	−9.3	2.7	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	C5-01	G-19	3.3	−11.3	24.9	−5.3	6.0	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	F2-01	G-20	3.2	−12.9	22.0	−11.0	1.9	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	H1-01	G-22	3.2	−10.8	22.8	−7.8	3.0	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala01	H6-01	G-21	3.2	−11.3	23.7	−8.8	2.6	Beta-322322/322323	Plant/plant	1760 ± 30, 1710 ± 30	345 cal AD	0
Gualaguala04	03-01	F-116	3.1	−11.3	23.2	−7.7	3.6	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	D3-01	F-115	3.2	−11.3	24.7	−8.5	2.8	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	D5-01	G-1	3.2	−11.2	21.6	−8.5	2.7	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	E5-01	G-3	3.2	−11.0	24.3	−8.1	2.9	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	E5-03	G-8	3.2	−12.3	24.0	−9.4	2.9	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	E5-04	G-7	3.1	−12.6	24.7	−10.5	2.1	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	F5-01	F-113	3.2	−10.7	23.8	−7.8	3.0	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	F5-03	F-114	3.2	−12.2	23.9	−10.0	2.2	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	F6-02	F-112	3.2	−13.2	23.9	−9.7	3.5	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Gualaguala04	G3-01	G-5	3.2	−11.0	22.6	−8.1	3.0	Beta-322285/322286	Plant/plant	1790 ± 30, 1370 ± 30	499 cal AD	0
Michilla02	MCHN-02-01-01	F-104	3.7	−11.1	24.3	−6.2	4.9	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-02-01	F-96	3.2	−13.0	24.6	−10.0	3.0	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-02-02	F-99	3.1	−11.4	23.9	−8.6	2.8	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-05-01	F-109	3.5	−11.4	24.1	−7.2	4.1	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-07-01	F-103	3.1	−11.4	23.6	−6.6	4.8	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-07-01A	F-97	3.3	−11.5	23.7	−7.3	4.2	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-19-01	F-105	3.3	−11.5	23.6	−6.1	5.4	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-20-01	F-106	3.2	−10.8	24.6	−6.4	4.4	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-22-01	F-92	3.2	−11.0	23.1	−8.7	2.2	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-25-01	F-110	3.2	−11.4	23.1	−6.1	5.3	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-31-01	F-94	3.2	−11.7	25.9	−9.2	2.5	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-33-01	F-101	3.3	−12.1	26.7	−7.8	4.2	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-A2-01	F-107	3.2	−11.4	25.8	−8.6	2.8	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	MCHN-02-B2-01	F-95	3.6	−11.9	26.2	−6.5	5.4	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0
Michilla02	T10, MCHN-02-10-01, #306	H-35	3.7	−12.4	27.1	−9.0	3.4	Beta-322287/322288	Plant/plant	1820 ± 30, 1700 ± 30	321 cal AD	0

Table 1 (*Continued*)

Site	Site number	Laboratory code	Atomic C:N	$\delta^{13}C_{co\text{-}PDB}$ (‰)	$\delta^{15}N_{co\text{-}AIR}$ (‰)	$\delta^{13}C_{ap\text{-}PDB}$ (‰)	$\Delta^{13}C_{ap\text{-}co}$ (‰)	^{14}C Laboratory code(s)	Material dated	Uncalibrated ^{14}C date(s)	(Average) calibrated median probability ^{14}C date	Distance from coast (km)
RAnL	2739-0326, #17	G-29	3.1	−19.4	11.1	−13.0	6.4	I-5.400	Wood	2150 ± 95	151 cal BC	250
RAnL	2739-0326, #18	G-30	3.7	−19.7	11.4	−12.8	6.9	I-5.400	Wood	2150 ± 95	151 cal BC	250
RAnL	2739-0329, #16	G-28	3.1	−19.4	11.2	−14.1	5.3	I-5.400	Wood	2150 ± 95	151 cal BC	250
RAnL	#1	F-85	3.2	−19.4	11.3	−14.9	4.6	I-5.400	Wood	2150 ± 95	151 cal BC	250
RAnL	#2	F-86	3.2	−19.7	11.2	−13.6	6.1	I-5.400	Wood	2150 ± 95	151 cal BC	250
RAnL	#3	F-87	3.2	−19.9	11.3	−14.9	5.0	I-5.400	Wood	2150 ± 95	151 cal BC	250
San Salvador	1.1	A-19	3.5	−16.6	11.2	−10.9	5.8	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	1.2	E-109	3.5	−17.4	13.3	−13.3	4.2	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	3.1	A-25	3.5	−18.3	12.9	−10.4	7.9	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	5.1	A-26	3.4	−15.5	14.4	−10.6	4.9	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	5.2	A-27	3.4	−16.2	14.6	−11.3	4.9	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	8.1	A-70	3.2	−17.0	8.3	−9.9	7.1	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	2.2	F-27	3.3	−16.9	15.4	−12.1	4.9	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	10.1	A-29	3.6	−17.4	10.6	−9.7	7.8	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
San Salvador	10.1	A-72	3.5	−15.5	11.6	−9.4	6.1	Beta-247417/247418	Algarrobo/plant	2080 ± 40, 2330 ± 40	51 cal BC	180
Topater	3112, D4, #215	H-19	3.6	−18.7	10.9	−14.8	3.9	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3167-1, 0-7, #362	H-29	3.3	−17.9	11.4	−14.0	3.9	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3167-2, 0-7-C-1, #362	H-26	3.4	−17.1	11.4	−13.9	3.2	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3186, N6, #303	H-23	3.3	−19.4	10.0	−13.9	5.5	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3193-1, K9, #388	H-27	3.7	−18.0	11.8	−14.2	3.8	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3245, H6, #304	H-21	3.3	−19.3	9.6	−14.8	4.5	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3246-1, 0-8-C-2, #442	H-30	3.5	−18.6	10.9	−14.4	4.1	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3246-2, 0-8-C-2, #442	H-28	3.4	−18.1	14.5	−12.9	5.2	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3265, K5, #302	H-22	3.5	−17.7	10.6	−14.2	3.5	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3271, M5, #305	H-20	3.3	−18.5	10.0	−15.0	3.5	Beta-259693/322289	Textile/algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230

Topater	3273-1, J6, #478	H-24	3.3	−18.4	11.0	−14.4	4.0	Beta-259693/322289	Textile/ algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Topater	3273-2, J6, #478	H-25	3.3	−18.0	10.0	−12.8	5.3	Beta-259693/322289	Textile/ algarrobo	2120 ± 30, 2180 ± 40	223 cal BC	230
Villa Chuqui	1-3240-435, #120	G-37	3.1	−16.1	16.3	−11.0	5.1					230
Villa Chuqui	19-3169-364, #126	G-42	3.1	−16.1	16.7	−11.0	5.2					230
Villa Chuqui	19-s/n-507, #117	G-35	3.1	−16.6	11.7	−9.5	7.1					230
Villa Chuqui	2-s/n-505, #125	G-41	3.1	−16.2	15.4	−11.2	5.1					230
Villa Chuqui	24-3113-309, #121	G-38	3.1	−17.1	9.8	−10.2	6.9					230
Villa Chuqui	28-s/n-563, #123	G-39	3.1	−16.1	17.3	−11.9	4.2					230
Villa Chuqui	8-3220-415, #116	G-34	3.1	−16.3	16.6	−10.9	5.4					230
Villa Chuqui	8-s/n-602, #115	G-33	3.1	−16.8	16.7	−10.9	5.9					230
Villa Chuqui	9-3201-396, #124	G-40	3.1	−16.0	17.4	−12.1	3.9					230
Villa Chuqui	C2-3168-363, #113	G-31	3.1	−18.0	6.8	−7.6	10.4					230
Villa Chuqui	C29-3250-446, #114	G-32	3.1	−16.4	9.7	−8.1	8.3					230
Villa Chuqui	s/n-3247-443, #119	G-36	3.1	−15.9	16.5	−11.3	4.6					230
Punta Blanca	Sector sur, C2, T2			−12.4	25.3	−9.3	3.2	Beta-320362	Collagen	2040 ± 30	9 cal BC	0
Punta Blanca	Cuad 14, 15, 19 y 20, Tumba 11			−12.3	25.2	−10.1	2.2	Beta-320361	Collagen	2600 ± 30	747 cal BC	0
ENAEX	Fardo			−13.3	27.9	−9.9	3.4	Beta-335825	Collagen	2060 ± 30	18 cal BC	0
ENAEX	Tumba 5			−12.8	25.0	−10.6	2.2	Beta-335826	Collagen	2480 ± 30	540 cal BC	0
TGN-1	Individual 14			−11.9	27.7			UGAMS-6001	Collagen	2320 ± 25	367 cal BC	0

Note. While some samples were directly dated, others were indirectly dated through the analysis of plant materials from the site at which they were found. In such cases, some sites/samples may have multiple dates (as noted). In some cases, only one date was available for a site, and this result was then used as the date for all burials. In others (those where two sample numbers and two dated material types are provided), multiple dates were obtained, in which case the average calibrated median probability date was used to date all burials. All dated collagen samples were from human (*Homo sapiens*) bone collagen, dated plant and wood materials (for which there is no taxonomic information) were from vegetal materials used in construction of tumuli/burials, and dated algarrobo (*Prosopis flexuosa*) and textile were provided as grave goods.

Table 2. Regional foodweb isotope values (edible portions)

Category	$\delta^{13}C_{co\text{-}PDB}$ (‰)	$\delta^{15}N_{co\text{-}AIR}$ (‰)
Flora:		
C_3 plants	−23.8 ± 1.4	5.9 ± 3.1
C_4 plants	−10.4 ± 1	7 ± 1.3
CAM plants	−11.6 ± 0.5	4.1 ± 1.1
Legumes	−23.2 ± 1.4	1.7 ± 1.3
Marine fauna:		
Birds	−11.3	16.7
Finfish	−14.2 ± 1.5	19.9 ± 2
Invertebrates	−13.1 ± 2.5	16.3 ± 1.8
Mammals	−12.7 ± 1.7	20.6 ± 3
Turtles	−13.4	18.5
Terrestrial fauna:		
Mammals	−19.3 ± 2.9	6.2 ± 1.1

As predicted, on a regional scale, distance from the Pacific coast has a significant influence on several of the measured isotopic variables. Both bivariate correlation analysis and partial correlation analysis (controlling for the possibly confounding effect of the differences in date of the samples) found strong, statistically significant, inverse correlations between $\delta^{13}C_{co}$ ($r = -.90$, $P < .01$, partial $r = -.83$, $P < .01$) and $\delta^{15}N_{co}$ ($r = -.94$, $P < .01$, partial $r = -.90$, $P < .01$) and distance from the coast. This finding (as seen in fig. 3) attests to decreasing reliance on isotopically (^{13}C and ^{15}N) enriched marine protein the farther one lived (or, more accurately, was buried) from the coast. While bivariate correlation analysis also identified statistically significant correlations between distance from the coast and the other two isotopic variables ($\delta^{13}C_{ap}$ and $\Delta^{13}C_{ap\text{-}co}$, or the difference in the carbon isotope signatures of $\delta^{13}C_{co}$ and $\delta^{13}C_{ap}$), once date was controlled for, the resulting correlations lack explanatory power (as demonstrated by low *r*-squared values). The lack of meaningful correlations in these measures suggests little or no difference in carbohydrate consumption along the east-west axis.

Employment of a Bayesian automatic clustering algorithm determined that there were two clusters of cases (individuals) based on the four measured isotopic variables ($\delta^{13}C_{co}$, $\delta^{15}N_{co}$, $\delta^{13}C_{ap}$, and $\Delta^{13}C_{ap\text{-}co}$). As seen in figure 4 and table 3, this cluster analysis partitions the individuals from coastal sites (characterized by enriched $\delta^{13}C_{co}$, $\delta^{15}N_{co}$, and $\delta^{13}C_{ap}$ signatures and smaller $\Delta^{13}C_{ap\text{-}co}$ values) from those from inland sites (characterized by depleted $\delta^{13}C_{co}$, $\delta^{15}N_{co}$, and $\delta^{13}C_{ap}$ signatures and larger $\Delta^{13}C_{ap\text{-}co}$ values). None of the individuals from Cluster 1 (the "inland" cluster) were found in sites less than 180 km from the coast, and none of the Cluster 2 ("coastal") individuals were recovered from sites greater than 1 km from the coast.

The results of this cluster analysis, in concert with the correlation analysis presented above, appear to confirm basic biogeographic predictions regarding the differences between coastal and inland diet. While this prediction holds when these isotopic data are considered on a site-by-site basis (table 4; fig. 5), several intriguing deviations from the regional pattern do present themselves. As above, individuals from coastal sites were found to have possessed enriched $\delta^{13}C_{co}$, $\delta^{15}N_{co}$, and $\delta^{13}C_{ap}$ signatures and smaller $\Delta^{13}C_{ap\text{-}co}$ values, with the converse generally holding true for individuals from inland sites. The differences documented between coastal and interior sites can be taken as a testament to differences in protein consumption at either end of the proposed interzonal exchange networks. What is less apparent, but more intriguing, is that the variance in isotopic values, and particularly $\delta^{13}C_{co}$ and $\delta^{15}N_{co}$, observed among individuals from inland sites is substantially greater than that observed between individuals from coastal sites (a finding that is visible in the comparative dispersal of isotopic values at a given distance from the coast, seen in fig. 3). This finding was foreshadowed in the cluster analysis, since the standard deviation for each isotopic measure was greater in the inland cluster than in the coastal one, and for $\delta^{13}C_{co}$, $\delta^{15}N_{co}$, and $\delta^{13}C_{ap}$, significantly so ($P < .01$, Levene's test for equality of variance). This finding suggests a greater diversity of dietary protein consumption among the individuals in some of the inland sites than between residents of the coastal sites. As discussed below, this is likely the result of the habitual consumption of higher trophic level marine protein by some residents of inland sites like Villa Chuquicamata, Topater, and San Salvador (Torres-Rouff, Pestle, and Gallardo 2012). Similar patterns do not hold at the coastal or far inland sites. That people at the sites near modern-day Calama exhibited more varied protein and carbohydrate in their diets may be a testament to the nodal role of these sites in the region's interzonal exchange network.

Discussion

This investigation highlights the potential of stable carbon and nitrogen analyses as a proxy for paleomobility in certain environments, and also raises interesting points about exchange and lifeways during the Formative Period. Here, we highlight three results of particular significance: (1) the stark difference in coastal and interior patterns of protein consumption, (2) the partial mitigation of this difference by isotopic evidence for the consumption of some marine foods in the deep desert, and (3) a series of tantalizing hints about the long-distance reach of the Atacama's exchange networks.

To begin, these isotopic data highlight the starkly different patterns of protein consumption practiced by individuals residing at either extreme of the Loa River. While individuals inhabiting the coast possess some of the most enriched $\delta^{15}N_{co}$ seen anywhere in the world, a testament to the habitual consumption of marine protein, individuals at the other geographical extreme, such as those from Chiu Chiu, were consuming exclusively terrestrially derived protein. This broader biogeographic pattern is mitigated by the apparent consumption of some marine foods by a subset of individuals who died (and presumably lived) at sites located near the

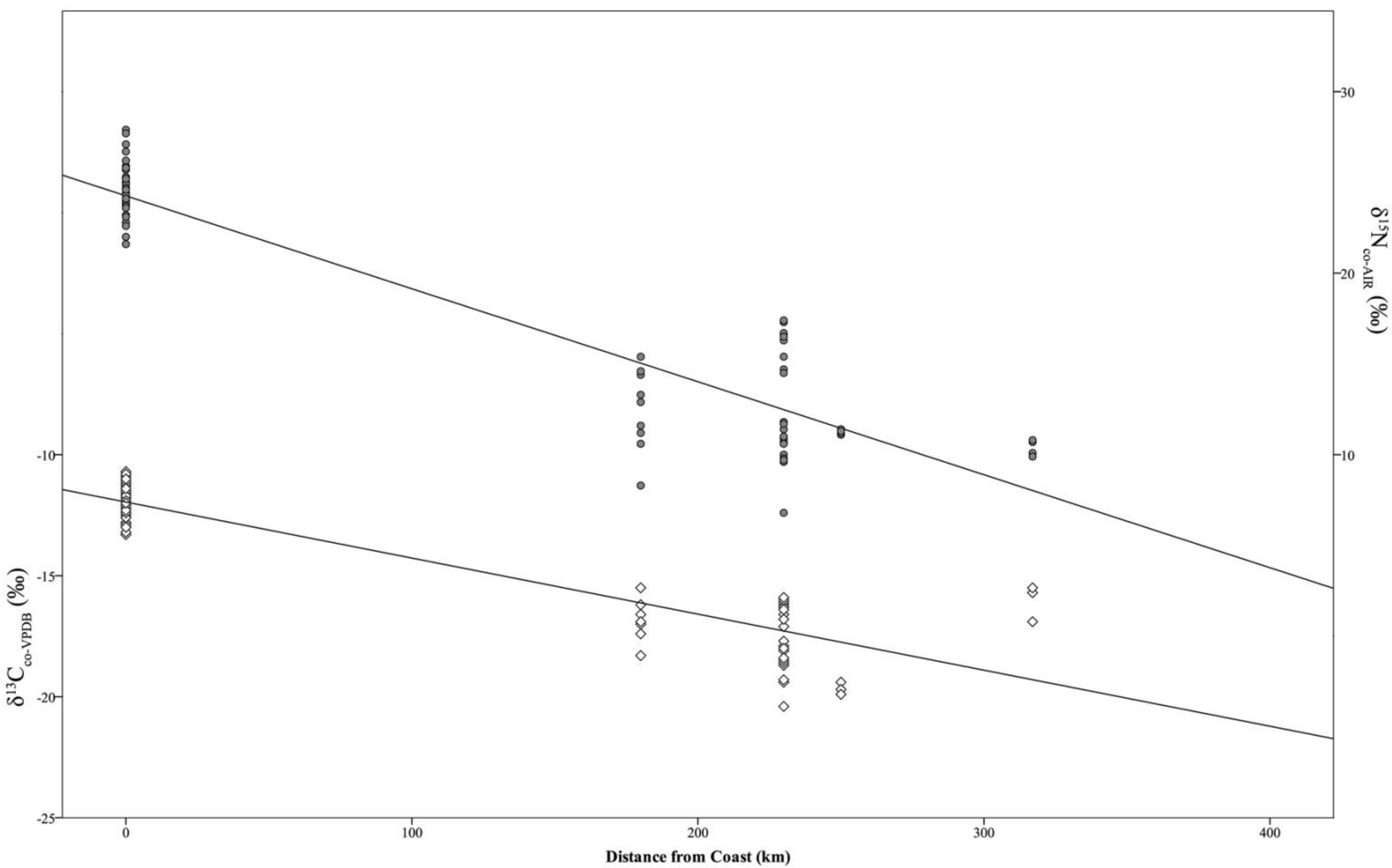

Figure 3. Strong, statistically significant, inverse correlations between collagen isotope variables ($\delta^{13}C_{co}$ in unfilled diamonds, $\delta^{15}N_{co}$ in filled circles) and distance from the coast.

modern-day city of Calama. These individuals appear in figure 5 falling between the coastal and inland extremes of $\delta^{13}C_{co}$ and $\delta^{15}N_{co}$ values. This phenomenon is particularly pronounced at the site of Villa Chuquicamata, where 7 of the 12 (58%) individuals (364, 396, 415, 435, 443, 563, and 602), have $\delta^{15}N_{co}$ values between 16.3‰ and 17.4‰, indicating a protein diet consisting of roughly 50% marine protein. This finding, at a site some 230 km from the ocean, is noteworthy in and of itself.

Table 3. Isotopic values of two clusters: Cluster 1 (inland/oases) and Cluster 2 (coastal)

	Cluster 1	Cluster 2
$\delta^{13}C_{co\text{-}PDB}$ (‰)	-17.5 ± 1.4	-11.8 ± 0.7
$\delta^{15}N_{co\text{-}AIR}$ (‰)	12.2 ± 2.6	24.5 ± 1.5
$\delta^{13}C_{ap\text{-}PDB}$ (‰)	-12.0 ± 2.0	-8.3 ± 1.5
$\Delta^{13}C_{ap\text{-}co}$ (‰)	5.4 ± 1.4	3.4 ± 1.1

Based on the isotopic evidence alone, however, it is impossible to determine whether the diversity of diet at these sites is a consequence of the different residential histories of the individuals buried there (i.e., certain individuals lived some time on the coast and some time in the interior) or of in situ consumption of marine protein resulting from elaborate and well-established trade networks. However, either interpretation raises interesting attendant points. If it is the former, then the Calama sites would seem to be serving a nodal role for population and exchange unlike anything seen at the sites at either terminus of the exchange route, and if it is the latter, then sites on the coast would appear to have been producing a surplus of resources that they were then able to move up-river, highlighting their active participation and agency in patterns of regional exchange. These data also raise the possibility of a spectrum of behavioral patterns between these two extremes.

That the trade/exchange networks of the Atacama may have

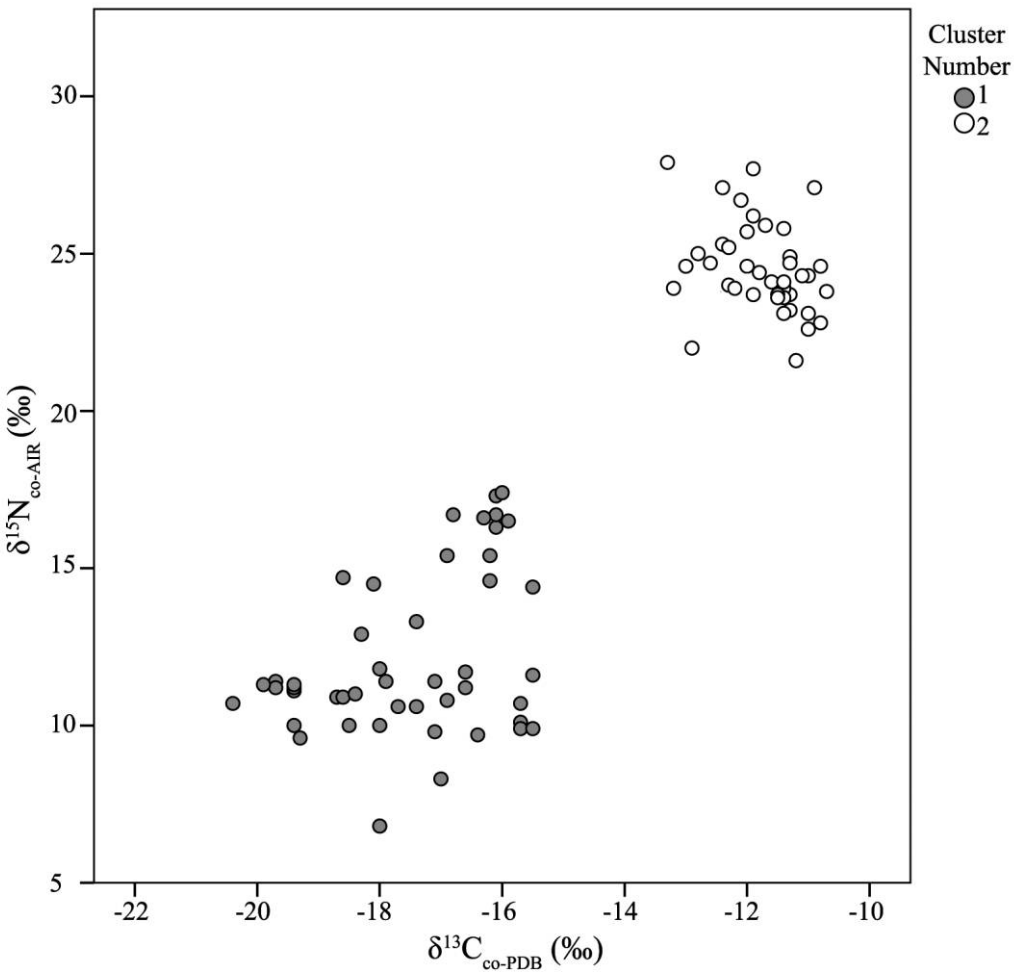

Figure 4. Collagen isotope values ($\delta^{13}C_{co}$ and $\delta^{15}N_{co}$) of individuals included in sample by cluster. Note that none of the individuals from Cluster 1 (the "inland" cluster) individuals were found in sites less than 180 km from the coast, and none of the Cluster 2 ("coastal") individuals were recovered from sites greater than 1 km from the coast.

Table 4. Mean isotopic values by site

Site	$\delta^{13}C_{co\text{-}PDB}$ (‰)	$\delta^{15}N_{co\text{-}AIR}$ (‰)	$\delta^{13}C_{ap\text{-}PDB}$ (‰)	$\Delta^{13}C_{ap\text{-}co}$ (‰)
Interior:				
Calar	-15.9 ± 0.6	10.3 ± 0.4	-10.4 ± 1.0	5.5 ± 0.8
Chorillos	-19.5 ± 1.3	12.7 ± 2.8		
RAnL 273	-19.6 ± 0.2	11.3 ± 0.1	-13.9 ± 0.9	5.7 ± 0.9
San Salvador	-16.8 ± 0.9	12.5 ± 2.3	-10.8 ± 1.2	6.0 ± 1.4
Topater	-18.3 ± 0.7	11.0 ± 1.3	-14.1 ± 0.7	4.2 ± 0.8
Villa Chuqui	-16.5 ± 0.6	14.2 ± 3.7	-10.5 ± 1.4	6.0 ± 1.9
Coastal:				
Gualaguala01	-11.7 ± 0.6	24.3 ± 1.4	-8.2 ± 1.7	3.4 ± 1.3
Gualaguala04	-11.7 ± 0.8	23.7 ± 1.0	-8.8 ± 1.0	2.9 ± 0.5
Michilla02	-11.6 ± 0.6	24.7 ± 1.3	-7.6 ± 1.3	4.0 ± 1.1
Punta Blanca	-12.4 ± 0.1	25.3 ± 0.1	-9.7 ± 0.6	3.2 ± 0.7
ENAEX	-12.7 ± 0.7	26.9 ± 1.6	-10.3 ± 0.5	2.8 ± 0.8

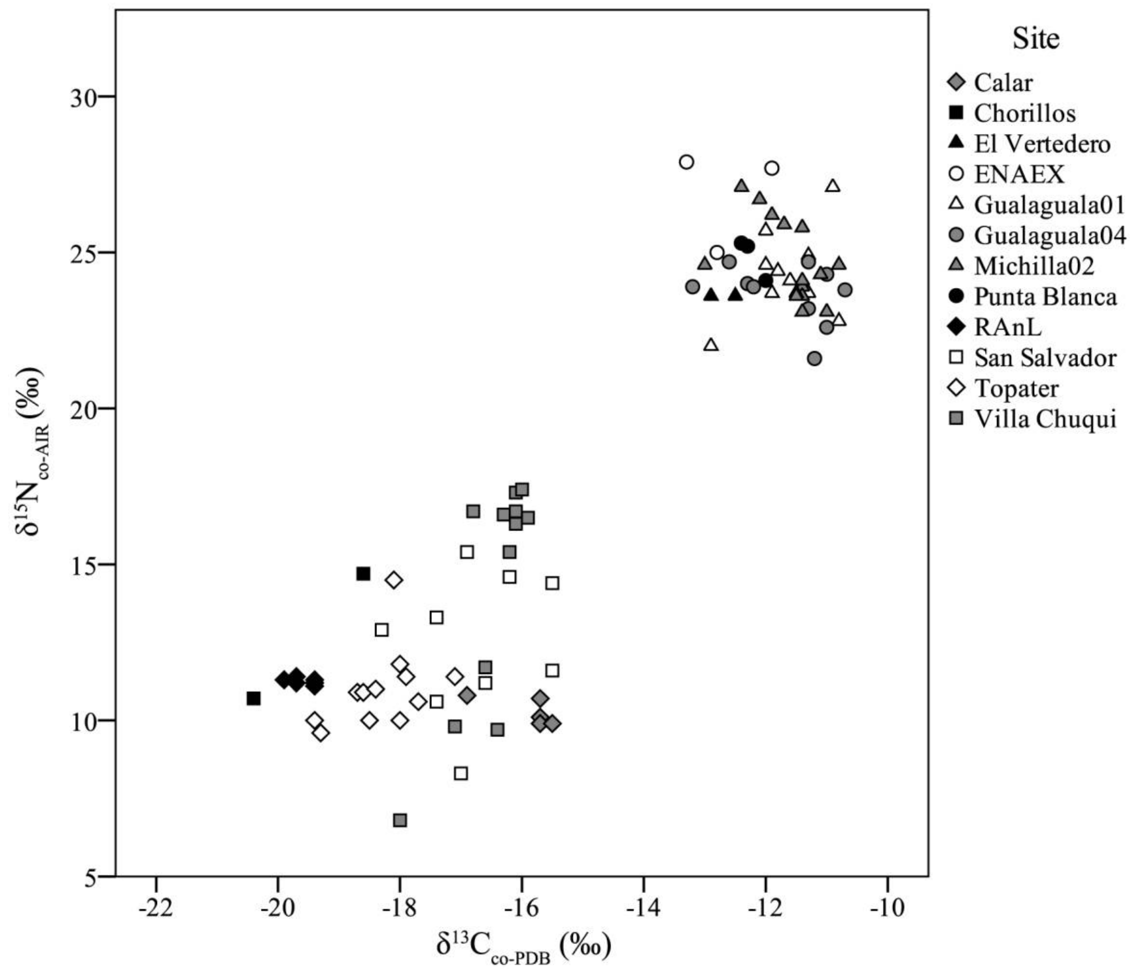

Figure 5. Collagen isotope values ($\delta^{13}C_{co}$ and $\delta^{15}N_{co}$) of individuals included in sample by site.

had broader, even trans-Andean, reach (as suggested by the artifactual evidence) is lent some credence by the isotopic values of Villa Chuquicamata 363. This 16–20-year-old female presents extremely depleted $\delta^{13}C_{co}$ and $\delta^{15}N_{co}$ values (including the most depleted $\delta^{15}N_{co}$ signature of any analyzed individual) and a substantially enriched $\delta^{13}C_{ap}$ signature, which, in turn, produces the largest $\Delta^{13}C_{ap\text{-}co}$ value of any of the individuals under study here. The dietary makeup indicated by these isotopic values, a combination of complete reliance on low trophic level terrestrial protein and heavy focus on C_4 carbohydrates, is atypical of this region. In fact, this particular isotopic combination is more consistent with values seen in contemporaneous individuals from northwest Argentina and central Chile (Gil, Neme, and Tykot 2010; Gil et al. 2006; Sanhueza and Falabella 2010). The presence in Villa Chuquicamata of an individual with such a distinct dietary pattern may have implications for understanding the geographic reach of the Formative Period's interzonal exchange systems and could be complemented by more traditional archaeological data investigating the potential for far-reaching networks in this early period.

Conclusion

Successful, long-term life in the Atacama Desert, in antiquity as today, requires the development of a risk-mitigation strategy to manage the effects of extreme environmental conditions. As highlighted here, during the Formative Period, a network of zonal complementarity served this function. The movement of people and/or foodstuffs up and down the Loa River, as identified here by stable isotope analysis, would appear to have necessitated frequent, long-period movements of individuals and family units. Coastal people, and the products thereof, would appear to have penetrated far into the Atacama, attesting to their active role in the region's prehistory, and contesting models based on Murra's "vertical archipelago" that have been posited for the Formative. Logistically situated and nodal spaces like Topater and Villa Chuquicamata would seem to have been places of interaction for people of diverse origin, from the coast to the Atacama oases, and beyond into northwest Argentina. These findings fly in the face of any notion of the Atacama Desert itself as an empty space and confirm instead the idea of this desert as an active and lived space, in which a system of interzonal exchange would have linked together the economies and societies of diverse peoples (Lazzari 2005; Nielsen 2006; Torres-Rouff, Pestle, and Gallardo 2012; Upham 1992).

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