

Hunting, Gathering, and Fishing on the Coast of the Atacama Desert: Chinchorro Population Mobility Patterns Inferred from Strontium Isotopes

Vivien G. Standen,^{1,*} Calogero M. Santoro,² Bernardo Arriaza,² and Drew Coleman³

¹Departamento de Antropología, Universidad de Tarapacá, Arica, Chile

²Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile

³Department of Geological Sciences, University of North Carolina, Mitchell Hall, Chapel Hill, North Carolina

Correspondence

*Corresponding author; E-mail: vivien.standen@gmail.com

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We discuss how the Chinchorro population of hunter-gatherers and fishermen organized their mobility patterns between the rich marine ecosystems of the Pacific coast and the extreme hyperarid core of the Atacama Desert through the application of strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$). We analyzed tooth enamel samples of 35 individuals from the coast ($n = 28$), inland oasis ($n = 6$), and the Andean highlands ($n = 1$). The Sr isotopic composition of modern and archaeological bone samples from sea mammals and land herbivores were obtained from 10 localities. Coastal human individuals show a similar Sr signal to sea mammals, confirming that the former were born and raised in the littoral zone. These results along with archaeological data suggest that the Chinchorro maintained logistic mobility along the coast. Similarly, a woman buried in the highlands (Patapatane) has a Sr signal closer to marine values, suggesting that some Chinchorro also maintained a logistic mobility linked to the Andean interior. In contrast, the Sr ratios of individuals from the inland oasis (Tiliviche) are intermediate between marine Sr values and those of local fauna. This seems to indicate that, although these Chinchorro individuals were raised in this oasis, they were part of a broad logistic mobility pattern connected with the coast.

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INTRODUCTION

Hunter-gatherers organized their mobility and residence, among other adaptive strategies, differently depending on the environment, population density, and other social and environmental constraints (Johnson, 2014). The ancient Chinchorro people of the coastal Atacama Desert in South America present good opportunities to examine mobility and residence through a historical and cultural paradigm (Sassaman & Holly, 2011). Specifically, we discuss the mobility patterns of the Chinchorro populations through the application of strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$), a powerful methodological tool drawn from analytical chemistry widely used in the study of past populations.

Hunter-gatherer mobility encompasses multidimensional strategies, as it integrates individual or group mobility, ranging from daily, seasonal, to annual movements reaching circuits of larger scale (Kelly, 1983, 1992). The

motivations to move into a territory may have been material, for example, obtaining subsistence resources and/or raw materials (Binford, 1980; Kelly, 1992). Also individuals or groups of individuals moved for social motivations, such as obtaining wives, network exchange, procurement of prestige goods, and to create social alliances for communication and sharing information and knowledge. All of these ensured greater social adaptability. These and other noneconomic causes of mobility, however, are difficult to identify in the archaeological record.

On the basis of Sr analyses and the current archaeological and bioanthropological knowledge of the Chinchorro way of life, we expected that if the Chinchorro people lived permanently along the coast they should have consistent Sr isotopic values at, or near, the composition of seawater. If, however, they maintained regular

movement from the coast to inland enclaves, the Sr isotopic signal would have intermediate values between marine and terrestrial settings.

Here we present new data on the Sr isotopic ratio ($^{87}\text{Sr}/^{86}\text{Sr}$) of 28 Chinchorro individuals from the Pacific coast, six from an interior oasis, and one from a location in the Andean highlands. Based on these analyses, we discuss how the Chinchorro people organized their mobility patterns along the coast as well as between the rich coastal ecosystems and inland enclaves in the extreme hyperarid core of the Atacama Desert. Following Binford's (1980) mobility model, we tested whether the Chinchorro maintained residential mobility where the whole social group moved their base camps, or if they maintained logistical movements where small parties of social groups leave their base camps at the mouths of rivers and spring enclaves along the coast for short periods of time. Our results suggest the Chinchorro people practiced a logistical form of mobility that was tethered to rich coastal ecosystems.

GENERAL BACKGROUND

Chinchorro Hunter-Gatherers and Fishermen

Archaeological Chinchorro sites occur along the Pacific coast in southern Peru and northern Chile and were occupied from *ca.* 9000–3400 ^{14}C yr B.P. Many of these sites contain materials in cultural contexts that originate from distant sources in the Andean highlands. The procurement of these elements implies that Chinchorro groups practiced certain kinds of mobility. Under what mechanisms did the Chinchorro populations supply themselves with animal skins and fiber of camelids, *chinchilla* and *vizcachas*, or with manganese and various lithic raw materials? It is possible that they obtained these materials through interregional exchanges with Andean hunter-gatherers (Núñez, Zlatar, & Núñez, 1975; Núñez & Dillehay, 1979; Santoro & Núñez, 1987; Santoro, 1989; Castillo & Sepúlveda, 2015; Sepúlveda et al., 2013; Tripcevich & Contreras, 2013; Herrera et al., 2015), or directly through travel to the highlands (Schiappacasse & Niemeyer, 1975; Sandweiss et al., 1998; Standen et al., 2004; Sandweiss, 2008; Sandweiss & Rademaker, 2011). Alternatively, it has been suggested that Andean hunter-gatherers came down to the coast to exchange goods with coastal populations (Lynch, 1973). In northern Chile, the distance from the coast to the high Andean plateau, that is, the Puna, does not exceed 120 linear kilometers (Figure 1). In this compressed space, ecological levels range from sea level to 4500 m above sea level (asl). In addition, ravines that connect the coast to the Puna can

be accessed easily and may have been used as natural corridors for the movement of human groups.

Alternatively, a more restricted logistic mobility, between the coast and inland oases like Tiliviche, Aragón, and Conanoxa, 30–40 km from the coast (Figure 1), has been proposed (Núñez & Moragas, 1978). Coastal hunter-gatherers and fishermen may have moved to these enclaves to look for complementary resources such as good lithic raw material, wood, cactus spines, plant food, and reeds (Núñez & Moragas, 1978; Núñez & Hall, 1982; Schiappacasse & Niemeyer, 1984; Standen & Núñez, 1984; Núñez, 1986; Santoro & Núñez, 1987; Santoro, 1989).

Moreover, it has been suggested that Chinchorro people maintained >500 km of longitudinal movement along the coast between the Ilo and Loa Rivers ($17^{\circ}30'$ – 21°S) (Figure 1). The cultural interaction within this territory is inferred from materials that show similar technological, mortuary, and dietary patterns. Coastal groups living at the mouths of rivers and bays shared cultural traits and social practices for social and economic purposes (Wise, 1997; Rasmussen, 1998; Standen, Santoro, & Arriaza, 2004; Arriaza et al., 2008; Marquet et al., 2012; Santoro et al., 2012; Umire, 2013).

The Chinchorro experienced steady population growth that densely occupied geographically circumscribed coastal enclaves, with integrated freshwater sources, and the permanent and abundant richness of the Pacific coast due to marine upwelling linked to the Humboldt Current. Consequently, the area witnessed increased Chinchorro sedentism and social complexity through time (Núñez, Zlatar, & Núñez, 1975; Schiappacasse & Niemeyer, 1984; Núñez & Santoro, 2011; Rasmussen, 1998; Standen, Santoro, & Arriaza, 2004; Arriaza et al., 2008; Núñez, Grosjean, & Cartajena, 2010; Marquet et al., 2012; Santoro et al., 2012). Coastal archaeological sites are typically characterized by broad and deep accumulations of shell middens that have been interpreted to reflect continuous and permanent occupation of the coast. These layered shell midden deposits, some >4 m thick, were derived from accumulation of waste linked to a life dependent almost exclusively on marine resources. The Chinchorro people adapted to a coastal environment and became highly specialized in obtaining a wide range of foods that included fish, mollusks, birds, and marine mammals (Bird, 1943; Standen, Santoro, & Arriaza, 2004). Previous ^{15}N and ^{13}C isotopic analysis of human remains confirm that almost the entire diet (>80%) of coastal populations was derived from marine animal protein (Aufderheide, Muñoz, & Arriaza, 1993; Aufderheide, 1996; Poulson et al., 2013; Roberts et al., 2013).

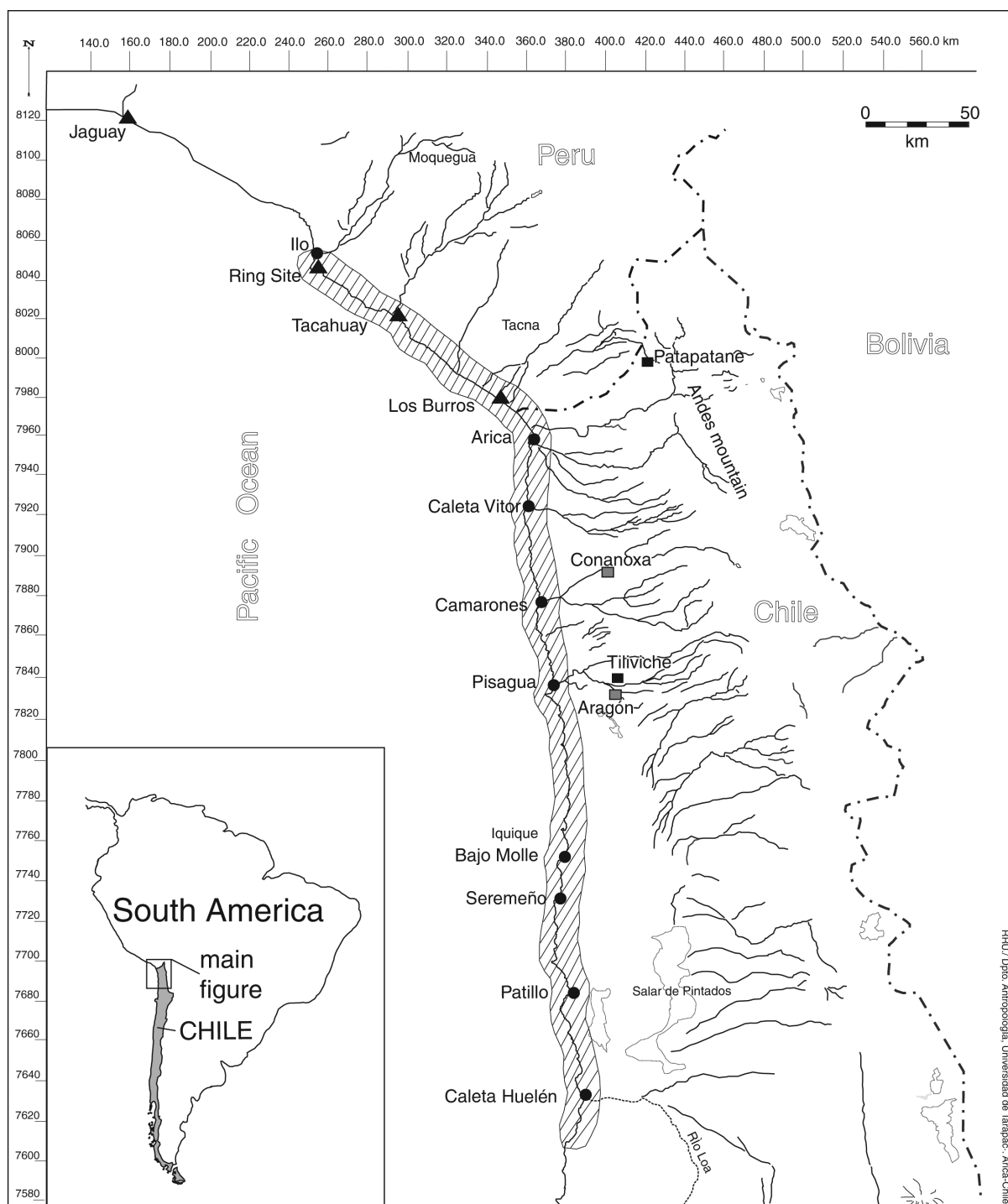


Figure 1 Chinchorro archaeological sites along the coast of northernmost Chile and southern Peru. The hatched area emphasizes the coast where the Chinchorro people lived with archaeological sites marked by circles. Archaic sites without Chinchorro mummies are marked by triangles. The interior sites with and without human remains are marked by black and gray squares, respectively.

Strontium Isotopes and Archaeology

Strontium isotopic analyses have been used to investigate prehistoric residential and mobility patterns (Price

et al., 1994; Price, Manzanilla, & Middleton, 2000; Hodell et al., 2004; Knudson et al., 2005, 2012; Knudson, 2007; Price et al., 2008; Tung & Knudson, 2008; Conlee et al.,

Table I Funerary sites (mummies) in northern Chile sampled for Sr analysis.

Archaeological Site	Samples $n = 35$	Region	Locality	Period	^{14}C yr B.P.
Acha 3	2	Coast	Arica	Early Archaic	$8380 \pm 60 / 8120 \pm 90$
Morro 1	9	Coast	Arica	Middle and Late Archaic	$5434 \pm 59 / 3670 \pm 100$
Morro 1/6	1	Coast	Arica	Late Archaic	$4010 \pm 75 / 3560 \pm 100$
Morro C/T0	1	Coast	Arica	Late Archaic	3730 ± 70
Colon 10	1	Coast	Arica	Middle and Late Archaic	$ca. 5500 / 3590 \pm 30$
Playa Miller 8	5	Coast	Arica	Middle and Late Archaic	$5744 \pm 310 / 4090 \pm 105$
Maestranza CH	2	Coast	Arica	Middle Archaic	$5170 \pm 70 / 5100 \pm 100$
Chinchorro 1	1	Coast	Arica	Middle Archaic	6070 ± 285
Quiani 7B	1	Coast	Arica	Early Formative	3680 ± 100
Camaronas 17	1	Coast	Arica	Middle Archaic	6930 ± 140
Camaronas PN	2	Coast	Camaronas	Middle Archaic	6270 ± 40
Camaronas 15D	1	Coast	Camaronas	Late Archaic	$4010 \pm 75 / 4240 \pm 145$
Camaronas 15C	1	Coast	Camaronas	Early Formative	$ca. 3000$
Tiliviche 2	6	Interior Desert	Tiliviche	Late Archaic	3780 ± 100
Patapatane/E-1	1	Pre-Andean Mountains	Patapatane	Middle Archaic	5910 ± 90

2009; Knudson & Torres-Rouff, 2009) and recently for paleoclimatic reconstructions (Woodward et al., 2015). Strontium is an alkaline earth metal found naturally in the earth's crust. Its isotopic composition ($^{87}\text{Sr}/^{86}\text{Sr}$) differs from one geological region to another on the basis of the age and composition of the rocks (Price et al., 1994). Through the food chain, Sr in rocks and soils passes to water, which is absorbed by plants, which are in turn consumed by herbivores (Aufderheide, 1993; Aufderheide, Muñoz, & Arriaza, 1993; Price et al., 1994; Aufderheide, 1996; Price, Manzanilla, & Middleton, 2000). Similarly, fish, mollusks, and sea mammals absorb Sr found in oceans (Whipkey et al., 2000). When these fauna (terrestrial or marine) are consumed by humans at the end of the food chain, the Sr enters the individuals and its isotopic signature is incorporated into bones and teeth and can be measured (Aufderheide, 1993; Price et al., 1994). Additionally, the isotopic composition of tooth enamel is established early in life and resists modification after death and burial (Price et al., 1994; Price, Manzanilla, & Middleton, 2000). This is not the case with Sr in bones, which may be affected by diagenesis, providing therefore a less reliable understanding of the geological environment the individual inhabited before dying (Price et al., 1994; Knudson, 2007).

The natural ratio of $^{87}\text{Sr}/^{86}\text{Sr}$ in ocean waters is constant across the world, though it varies through time (presently it is 0.709178, Burke et al., 1982). In contrast, this ratio varies in soils, rocks, and water from one geological region to another. Thus, by comparing the $^{87}\text{Sr}/^{86}\text{Sr}$ in the tooth enamel of human groups with reference samples from local fauna, it is possible to infer where the individual/s was/were born and resided during their childhood.

MATERIAL AND METHODS

The Atacama Desert considered in our study includes a vast area of about 19,500 km², whose most characteristic physiographic feature is the 120–150 km distance between the Pacific coast and the Andes. On the coast, the most outstanding habitats are the mouths of 10 valleys containing perennial freshwater, plus some brackish springs, between Ilo (Moquegua Valley) and the Loa River (Figure 1). These are the known coastal geographical boundaries of the Chinchorro social groups.

In our study, we collected teeth from skeletonized and mummified human remains ($n = 35$) dated 8300–3400 ^{14}C yr B.P. from all known Archaic funerary sites in the northernmost region of Chile ($n = 15$) (Table I; Figure 2). Two individuals date to the Early Archaic (~10,000–7000 ^{14}C yr B.P.); 10 date to the Middle Archaic (7000–5000 ^{14}C yr B.P.); 21 date to the Late Archaic (5000–3500 ^{14}C yr B.P.); and two date to the Early Formative (3500–3000 ^{14}C yr B.P.). Sample quantities for each site, locality, and chronological period were based on the number of excavated cemeteries (Table I). Consequently, Archaic cemeteries of Arica formed the majority of samples (Álvarez, 1969; Allison et al., 1984; Standen, 1997; Arriaza et al., 2005; Standen et al., 2014).

There is only one known early cemetery in the inland oasis region (950 m asl) called Tiliviche 2 (Figure 2). This cemetery is located 40 km from the coast at Pisagua (Standen & Núñez, 1984). As no known Chinchorro cemeteries in the Andean plateau exist, we found almost no skeletons to sample in this area. However, one skeleton was found in an isolated burial site at Patapatane Cave, which is located in the Andean foothills at 3750 m asl, 80 km from the coast at Arica (Figure 2) (Standen

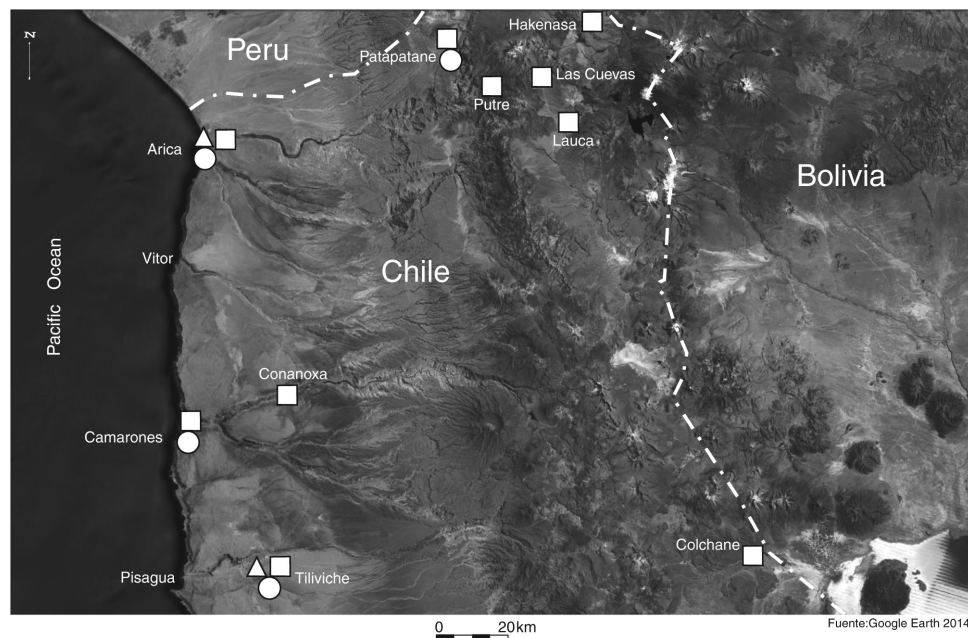


Figure 2 Sample areas for terrestrial fauna (squares), marine fauna (triangles), and Archaic mummies (circles) within coastal, lowland valley, Andean foothill, and high Andean plateau settings in the northernmost region of Chile. Image courtesy of Google Earth.

& Santoro, 1994). From the coast through the Andean foothills, a total of 35 samples was collected: 29 adults, two juveniles, and four infants. Of these samples, 10 were females, 14 were males, and 11 were of unknown sex.

Sampling and Processing

The isotopic characterization of Sr was formulated using two methods: (1) by establishing a reference pattern

based on analysis of bones from modern and archaeological fauna, both marine and terrestrial, from different altitudinal zones of the northernmost region of Chile; and (2) by sampling the tooth enamel of Archaic humans found in the same area (Figure 2).

The samples were processed in the Department of Geological Sciences isotope geochemistry laboratory at the University of North Carolina at Chapel Hill. All sample surfaces were cleaned to remove superficial

Table II Localities of sampled fauna (modern and archaeological) in northern Chile for the Sr analysis.

Locality	Samples $n = 21$	Type of Fauna	Sample of Bone	Region	Period
Terraza Chinchorro	1	Whale	Fragment barb	Arica Coast	Archaeological
Playa Chinchorro	1	Sea lion	Fragment scapula	Arica Coast	Modern
Lluta	2	Wild rodent	Radius/femur	Arica Coast	Modern
Camarones	1	Wild rodent	Humerus	Camarones Coast	Modern
Conanoxa	2	Wild rodent	Humerus/femur	Interior Desert	Modern
Tiliviche	2	Wild rodent	Femur	Interior Desert	Modern
Tiliviche	1	Rodent	Diaphysis	Interior Desert	Archaeological
Tiliviche	1	Sea lion	Fragment	Interior Desert	Archaeological
Patapatane	2	Camelid	Diaphysis	Pre-Andean Mountain Arica	Archaeological
Putre	2	Wild rodent	Humerus	Pre-Andean Mountain Arica	Modern
Hakenasa	2	Camelid	Diaphysis	Andean Mountain Arica	Archaeological
Lauca	1	Camelid	Diaphysis	Andean Mountain Arica	Archaeological
Las Cuevas	1	Camelid	Diaphysis	Andean Mountain Arica	Archaeological
Colchane	2	Wild rodent	Humerus/femur	Andean Mountain Iquique	Modern

contaminants. Using a diamond bit secured on a rotary drill, approximately 2–3 mg of tooth enamel or bone was collected from each sample. All samples were dissolved in 3.5 M HNO₃ prior to the isolation of Sr via ion-exchange column chromatography using EiChrom Sr-SpecTM resin. Approximately 1 μ L of concentrated H₃PO₄ was added to the Sr separates, and the samples were evaporated until nearly dry for loading. The samples were loaded on single Re filaments with TaCl₅ and were then analyzed in triple-dynamic multicollector mode with $^{88}\text{Sr} = 3$ V (10¹¹ Ω resistor) on the VG Sector-54. All data were normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$, and replicate analyses of NBS-987 over the period of this study yielded $^{87}\text{Sr}/^{86}\text{Sr} = 0.710258 \pm 0.000010$.

Terrestrial and Marine Sr Isotope Signatures Based on the Animal Model

To establish a reference for the isotopic composition of biologically available Sr in the region, fauna from 10 localities in the northernmost region of Chile (~18°30'–19°40' S) (Table II) from sea level to 4500 m asl were sampled. From west to east, this area includes the Pacific Ocean, the littoral zone, the lowland valleys, the Andean foothills, and the high Andean plateau (Figure 2). Wild rodents (*Phyllotis*) were captured using Sherman traps, which were placed in uninhabited areas in order to ensure that the rodents had exclusively consumed local grass. Femur bone samples (1–5 mg) were then extracted. Additionally, a bone sample was collected from a sea lion that was found dead on Chinchorro beach, Arica (Figure 2). To complement the samples of modern fauna, bones were extracted from camelids, sea mammals, whales, and sea lions at six different Archaic archaeological sites. The animal model yielded averaged values that accounted for the Sr composition present in a given geological zone (Price et al., 1994). Isotopic data for these reference samples were compared with isotopic data for the Chinchorro individuals.

RESULTS

Modern and Archaeological Faunal Samples

Marine ecosystem

One sample drawn from a whalebone found at Chinchorro archaeological site (Maestranza) yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.709163. This value is similar to that of a bone sample extracted from a modern sea lion at Chinchorro Beach, which yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.709136. Another unidentified archaeological

bone sample from Tiliviche yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.709150 (Table III; Figures 3 and 4). It is evident that the bone was a remnant of a marine mammal, and likely of a sea lion.

Fauna from the littoral zone

Two wild rodent samples found at the mouth of the Lluta River (Arica) yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.707395 and 0.707210. These values are similar to that found for a wild rodent sample collected from the mouth of the Camarones River ($^{87}\text{Sr}/^{86}\text{Sr} = 0.707402$) (Table III; Figures 3 and 4), which is located 100 km south of the Lluta River.

Fauna from the valley floor

One archaeological rodent bone sample that was obtained from the Tiliviche site (Núñez & Moragas, 1978) yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.706536. Two samples that were drawn from modern wild rodents in the Tiliviche area yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.706602 and 0.706577. Additionally, two samples from modern wild rodents found in the Conanoxa area, 35 km inland from the coast at Camarones, yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.707027 and 0.706582.

Fauna from the Andean foothills

Two samples of archaeological camelids that were obtained from Patapatane Cave yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.707104 and 0.706798. Two samples of modern rodents obtained from Putre, 15 km south of Patapatane, yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.707006 and 0.706878.

Fauna from the Andean high plateau

Samples from the three localities in the Andean high plateau (Table III; Figure 2) yielded similar values (Figures 3 and 4). An archaeological camelid bone sample drawn from the Archaic site of Las Cuevas yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.706730. Two other archaeological camelid bone samples obtained from the Archaic site of Hakenasa yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.706868 and 0.706819. One sample of modern camelid bone from the El Lauca wetland yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.706920 (Table III). Finally, two samples of present-day rodents from the Andean high plateau at Colchane yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.706470 and 0.706116 (Table III).

Table III Strontium isotope ratios for Archaic Period human teeth and animal bone (modern and archaeological) from northern Chile.

Number Lab	Sample Name	$^{87}\text{Sr}/^{86}\text{Sr}$	2σ Absolute Error	Sample Type	Age	Sex	Archaeological Site	Region	Period
-	Sr Ocean	0.709178	-	-	-	-	-	-	-
Sr CHIL_52	MtzaCH_Arq	0.709163	0.000010	Whale bone	-	-	Maestranza CH	Arica Coast	Late Archaic
Sr CHIL_53	PlayaCH_Act	0.709136	0.000010	Sea lion bone	-	-	Playa Chinchorro	Arica Coast	Modern
Sr CHIL_7	Til-Arq_a	0.709150	0.000010	Sea lion bone	-	-	Tiliviche 1B	Interior Desert	Late Archaic
Sr CHIL_45	Acha3C1	0.708703	0.000010	3M left mandible	Adult	M	Acha 3	Arica Coast	Early Archaic
Sr CHIL_46	Acha3C4	0.708607	0.000010	3M left maxilla	Adult	M	Acha 3	Arica Coast	Early Archaic
Sr CHIL_20	M11T1C4	0.708876	0.000010	3M right mandible	Adult	M	Morro 1	Arica Coast	Middle Archaic
Sr CHIL_26	M11T10B	0.708788	0.000009	2M right mandible	Adult	M	Morro 1	Arica Coast	Middle Archaic
Sr CHIL_21	M11T7C2	0.708851	0.000010	3M left mandible	Juvenile	F	Morro 1	Arica Coast	Late Archaic
Sr CHIL_22	M11T23C12	0.708752	0.000009	3M left mandible	Adult	F	Morro 1	Arica Coast	Late Archaic
Sr CHIL_24	M11T25C6	0.708712	0.000010	1M left maxilla	Infant	U	Morro 1	Arica Coast	Late Archaic
Sr CHIL_25	M11T22C5	0.708640	0.000010	3M right mandible	Adult	F	Morro 1	Arica Coast	Late Archaic
Sr CHIL_29	M11T28C24	0.708876	0.000009	2PM left maxilla	Adult	M	Morro 1	Arica Coast	Late Archaic
Sr CHIL_23	M11T28C22	0.708922	0.000010	3M right maxilla	Adult	M	Morro 1	Arica Coast	Late Archaic
Sr CHIL_42	M11T28C3	0.708497	0.000010	3M left maxilla	Adult	M	Morro 1	Arica Coast	Late Archaic
Sr CHIL_39	M11T6T22	0.708826	0.000010	2PM right mandible	Adult	M	Morro 1/6	Arica Coast	Late Archaic
Sr CHIL_38	M1CT0	0.708763	0.000011	1L right mandible	Adult	M	Morro C/T0	Arica Coast	Late Archaic
Sr CHIL_50	Col-10Cal-1	0.708745	0.000010	2M right maxilla	Adult	M	Colon 10	Arica Coast	Late Archaic
Sr CHIL_33	PLM8TC	0.708955	0.000010	2M right mandible	Adult	F	Playa Miller 8	Arica Coast	Late Archaic
Sr CHIL_41	PLM8CR2	0.709059	0.000009	2M left maxilla	Adult	M	Playa Miller 8	Arica Coast	Late Archaic
Sr CHIL_32	PLM8CR01	0.709024	0.000010	2PM right mandible	Adult	M	Playa Miller 8	Arica Coast	Middle Archaic
Sr CHIL_43	PLM8B1	0.709061	0.000011	2PM right maxilla	Adult	F	Playa Miller 8	Arica Coast	Middle Archaic
Sr CHIL_44	PLM8T4	0.708800	0.000010	1M left maxilla*	Infant	U	Playa Miller 8	Arica Coast	Late Archaic
Sr CHIL_30	CH1C1	0.708868	0.000010	2M right mandible*	Infant	U	Chinchorro 1	Arica Coast	Middle Archaic
Sr CHIL_27	MtzaCH-C9	0.708898	0.000010	2M right maxilla	Adult	F	Maestranza CH	Arica Coast	Middle Archaic
Sr CHIL_40	MtzaCH-C1	0.708887	0.000010	2M right mandible	Adult	F	Maestranza CH	Arica Coast	Middle Archaic
Sr CHIL_47	Quiani7TA	0.708863	0.000010	3M left mandible	Adult	M	Quiani 7	Arica Coast	Early Formative
Sr CHIL_36	CAM17T1C1	0.708779	0.000011	2M right mandible	Adult	F	Camarones 17	Camarones Coast	Middle Archaic
Sr CHIL_37	CAM15D-7/87	0.708879	0.000011	1PM left maxilla	Adult	F	Camarones 15D	Camarones Coast	Middle Archaic
Sr CHIL_48	CAM15C-C3	0.708636	0.000009	3M right mandible	Adult	U	Camarones 15C	Camarones Coast	Early Formative
Sr CHIL_49	CAM-Pn-E3	0.708679	0.000010	2M right maxilla	Adult	U	Camarones PN	Camarones Coast	Middle Archaic
Sr CHIL_28	CAM-Pn-E1	0.708736	0.000010	3M right mandible	Adult	U	Camarones PN	Camarones Coast	Middle Archaic
Sr CHIL_34	Pata-E1	0.708322	0.000010	3M left maxilla	Adult	F	Patapatane	Pre-Andean Mountain	Middle Archaic
Sr CHIL_31	Til-2T6	0.708034	0.000010	2PM left mandible	Adult	U	Tiliviche 2	Interior Desert	Late Archaic
Sr CHIL_2.10	Til-2T11A	0.707600	0.000010	2M left mandible	Adult	U	Tiliviche 2	Interior Desert	Late Archaic
Sr CHIL_2.9	Til-2T2	0.707663	0.000010	2M right mandible	Juvenile	U	Tiliviche 2	Interior Desert	Late Archaic
Sr CHIL_2.8	Til-2T11	0.707546	0.000010	2PM right maxilla	Adult	M	Tiliviche 2	Interior Desert	Late Archaic
Sr CHIL_2.7	Til-2T15	0.707363	0.000010	1M right maxilla	Infant	U	Tiliviche 2	Interior Desert	Late Archaic
Sr CHIL_35	Til-2T17	0.707292	0.000010	1PM left maxilla	Adult	U	Tiliviche 2	Interior Desert	Late Archaic
Sr CHIL_8	Til-Arq.b	0.706536	0.000011	Rodent bone	-	-	Tiliviche 1B	Interior Desert	Late Archaic
Sr CHIL_18	Til-Act.a	0.706602	0.000011	Rodent bone	-	-	Tiliviche	Interior Desert	Modern

(Continued)

Table III Continued.

Number Lab	Sample Name	$^{87}\text{Sr}/^{86}\text{Sr}$	2 σ Absolute Error	Sample Type	Age	Sex	Archaeological Site	Region	Period
Sr CHIL_19	Til_Act.b	0.706577	0.000013	Rodent bone	-	-	Tiliviche	Interior Desert	Modern
Sr CHIL_15	Cxa_Act.a	0.707027	0.000011	Rodent bone	-	-	Conanoxa	Interior Desert	Modern
Sr CHIL_16	Cxa_Act.b	0.706582	0.000011	Rodent bone	-	-	Conanoxa	Interior Desert	Modern
Sr CHIL_13	Lluta_Act.a	0.707395	0.000011	Rodent bone	-	-	Lluta	Arica Coast	Modern
Sr CHIL_14	Lluta_Act.b	0.707210	0.000011	Rodent bone	-	-	Lluta	Arica Coast	Modern
Sr CHIL_17	CAM_Act	0.707402	0.000008	Rodent bone	-	-	Camarones	Camarones Coast	Modern
Sr CHIL_5	Pata_Arq.a	0.707104	0.000008	Camelid bone	-	-	Patapatane	Pre-Andean Mountain	Late Archaic
Sr CHIL_6	Pata_Arq.b	0.706798	0.000010	Camelid bone	-	-	Patapatane	Pre-Andean Mountain	Late Archaic
Sr CHIL_9	Putre_Act.a	0.706878	0.000011	Rodent bone	-	-	Putre	Pre-Andean Mountain	Modern
Sr CHIL_10	Putre_Act.b	0.707006	0.000010	Rodent bone	-	-	Putre	Pre-Andean Mountain	Modern
Sr CHIL_1	Hake_Arq.a	0.706868	0.000011	Camelid bone	-	-	Hakenasa	Andean Mountain	Late Archaic
Sr CHIL_2	Hake_Arq.b	0.706819	0.000010	Camelid bone	-	-	Hakenasa	Andean Mountain	Late Archaic
Sr CHIL_3	Lauca_Arq	0.706920	0.000010	Camelid bone	-	-	Lauca	Andean Mountain	Late Archaic
Sr CHIL_4	Cuevas_Arq	0.706730	0.000008	Camelid bone	-	-	Las Cuevas	Andean Mountain	Late Archaic
Sr CHIL_11	Colcha_Act.a	0.706116	0.000010	Rodent bone	-	-	Colchane	Andean Mountain	Modern
Sr CHIL_12	Colcha_Act.b	0.706470	0.000011	Rodent bone	-	-	Colchane	Andean Mountain	Modern

Long-term mean NBS 987 = 0.710258 $\pm$ 0.000010All data normalized to $^{86}\text{Sr}/^{88}\text{Sr}$ = 0.1194.

*Deduced.

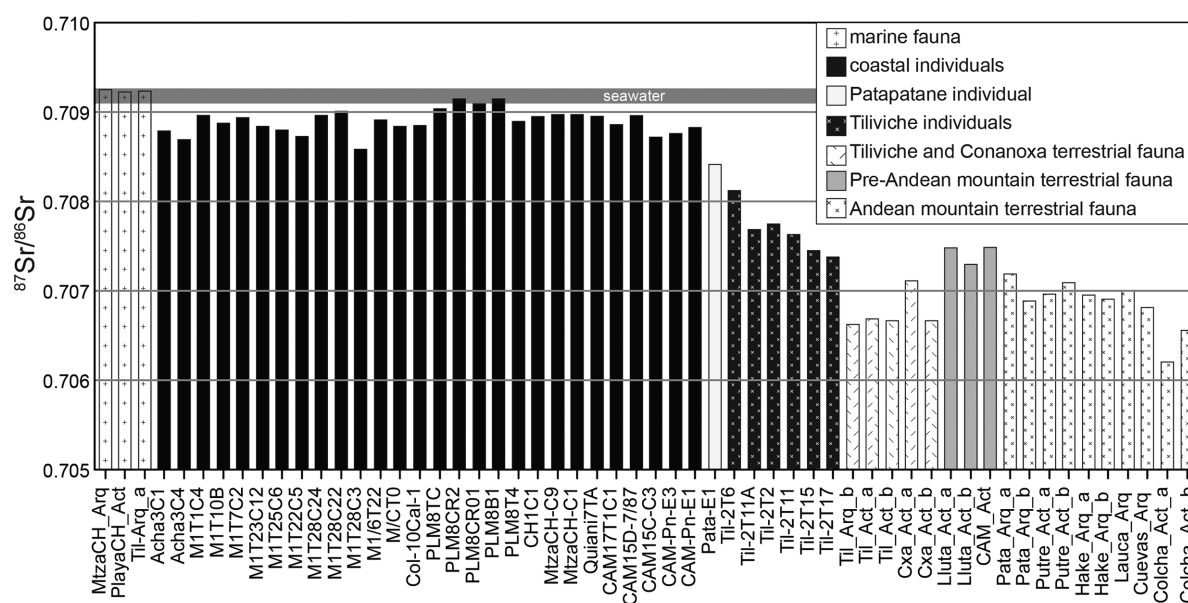


Figure 3 Strontium isotope data from the northernmost region of Chile. The isotopic composition for modern seawater is shown as a gray bar across the diagram.

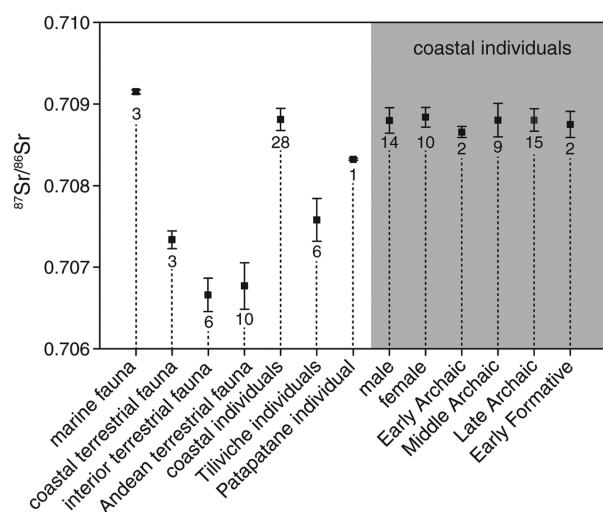


Figure 4 Comparison of Sr isotopic data across different groups. Each point represents the mean of analyses for samples in specified groups. The number of samples is indicated, and error bars show two standard deviations of the mean (except for the single individual from Patapatane). Data in the gray area compare coastal people separated by sex and cultural period.

Sr in Archaic Individuals

Coastal individuals

Enamel samples drawn from the teeth of mummies ($n = 23$) found in coastal sites at Arica yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values ranging 0.709061–0.708497. Those from the coast at

Camarones ($n = 5$) yielded a more restricted $^{87}\text{Sr}/^{86}\text{Sr}$ range of 0.708879–0.708636 that fell within the range found for samples drawn from Arica (Table III; Figures 3 and 4).

At six sites where it was possible to obtain more than one sample, all individuals from the same coastal cemeteries shared similar isotopic signatures. In the cemetery Morro-1, located along the coast near Arica, the $^{87}\text{Sr}/^{86}\text{Sr}$ values of nine individuals varied between 0.708922 and 0.708497. At Playa Miller-8 ($n = 5$ individuals) the $^{87}\text{Sr}/^{86}\text{Sr}$ values range between 0.709061 and 0.708800. At Acha-3 ($n = 2$) $^{87}\text{Sr}/^{86}\text{Sr}$ values range 0.708703–0.708607, and at the Maestranza site ($n = 2$) $^{87}\text{Sr}/^{86}\text{Sr}$ values range 0.708898–0.708887. Finally, two individuals from the coastal site of Camarones Punta Norte yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.708736–0.708679, whereas at Cam-15 ($n = 2$) the $^{87}\text{Sr}/^{86}\text{Sr}$ values were 0.708879–0.708636. These results show a total concordance within and between individuals of the same and different cemeteries.

From a chronological perspective, the individuals from the Early Archaic Period ($n = 2$) yielded sample values of 0.708703 and 0.708607. Those from the Middle Archaic Period ($n = 10$) yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ range of 0.709061–0.708679, and those from the Late Archaic Period ($n = 14$) yielded a range of $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.709059–0.708497 (Figure 4). Finally, Early Formative Period individuals ($n = 2$) yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.708863 and 0.708636. With respect to sex, males ($n = 14$) yielded

$^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.709059–0.708497, whereas females ($n = 10$) yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.709061–0.708640 (Figure 4).

Oasis individuals

The six individuals buried at Tiliviche, 40 km from the coast, yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values ranging from 0.708034 to 0.707292 (Table III, Figure 3). These values are lower than the range defined for all coastal individuals ($n = 28$; $^{87}\text{Sr}/^{86}\text{Sr} = 0.709061$ –0.708497) (Figure 4). These values, however, are slightly higher than those defined for modern local fauna ($^{87}\text{Sr}/^{86}\text{Sr} = 0.706602$ –0.706577) as well as for the archaeological faunal sample from Tiliviche ($^{87}\text{Sr}/^{86}\text{Sr} = 0.706536$).

Highland individual

The female buried in the highlands (Patapatane Cave) yielded a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.708322 (Table III, Figure 3). This ratio is slightly lower than all the coastal individuals ($n = 28$; $^{87}\text{Sr}/^{86}\text{Sr} = 0.709061$ –0.708497), but higher than the values defined for archaeological fauna ($^{87}\text{Sr}/^{86}\text{Sr} = 0.707104$ –0.706798) at Patapatane.

DISCUSSION

Diagenesis

Strontium isotopic compositions found in modern and archaeological marine mammals ($^{87}\text{Sr}/^{86}\text{Sr} = 0.709136$ –0.709163) were indistinguishable from one another and comparable to the value found in seawater ($^{87}\text{Sr}/^{86}\text{Sr} = 0.709178$) (Burke et al., 1982) (Figure 3). These results show that diagenesis did not significantly change the Sr isotopic composition of the buried archaeological bone. This result is also evident when examining results from sites for which data from both modern and ancient terrestrial fauna were obtained: the values for modern and ancient fauna overlap (Figures 3 and 4). As a result, we believe that the range of $^{87}\text{Sr}/^{86}\text{Sr}$ defined by ancient ($^{87}\text{Sr}/^{86}\text{Sr} = 0.707104$ –0.706536) and modern ($^{87}\text{Sr}/^{86}\text{Sr} = 0.707402$ –0.706116) terrestrial fauna is representative of bioavailable terrestrial Sr. The values for all terrestrial fauna were distinctly lower than the range defined by marine fauna and seawater (Figures 3 and 4). The high end of the range for terrestrial modern fauna was derived from samples that were collected closest to the coast and that likely reflected Sr influence from the ocean (e.g., sea spray).

Mobility along the Coast

Although the Sr isotope ratios for the coastal Chinchorro people ($^{87}\text{Sr}/^{86}\text{Sr} = 0.709061$ –0.708497) were slightly lower than seawater values ($^{87}\text{Sr}/^{86}\text{Sr} = 0.709178$) and modern and archaeological marine fauna ($^{87}\text{Sr}/^{86}\text{Sr} = 0.709150$ –0.709136), they were higher than the terrestrial range defined here ($^{87}\text{Sr}/^{86}\text{Sr} = 0.707402$ –0.706116) (Figure 4). This strongly supports the conclusion that early coast populations maintained a diet that was dominated by marine resources (Aufderheide, 1993; Aufderheide, Muñoz, & Arriaza, 1993; Aufderheide, 1996; Marquet et al., 2012; Santoro et al., 2012; Poulson et al., 2013; Roberts et al., 2013; Pestle et al., 2015). The difference between the human and the marine fauna values may be explained by the small fraction of terrestrial component of the diet of the Chinchorro people. Moreover, any freshwater that they consumed would have had an isotopic composition that was more similar to terrestrial than marine Sr samples.

Since most of the enamel samples were taken from the permanent second and third molars, which are formed 3–18 years after birth, this strongly suggests that these individuals were born and lived along the coast for much of their lives. The dominance of marine Sr in coastal Chinchorro inhabitants was found to be independent of their positioning along the coast (Arica and Camarones), chronology (Early to Late Archaic and Formative Period), and biological sex (Figure 4).

Although the Sr results suggest that Chinchorro people stayed most of their life within coastal enclaves, it does not mean that they remained permanently in one particular coastal location. Permanent residency on the coast does not imply that the Chinchorro people remained immobilized or fixed in a given territory year-round. Several sedentary populations contain a mobile component to perform economic actions (acquisition of resources) and ritual activities for use at base camps (Eder, 1984; Kelly, 1992). For more than four millennia the Chinchorro shared and held common cultural practices (e.g., mortuary patterns, dense utilization of cemeteries next to domestic areas, technology, and subsistence preferences) within a territory extending along more than 500 km of coastline. Thus, we estimate that this cultural unity required strong and permanent social interaction for transferring information, knowledge, and traditional procedures. This implies that people moved along the coast, through a logistic system of mobility, which means that residential base camps were maintained at the central enclaves associated with permanent freshwater resources, at the mouths of rivers or springs. Simultaneously, segments of these groups likely moved along the coast for economic, social,

and ritual purposes (Schiappacasse & Niemeyer, 1984; Bittmann, 1986; Muñoz, Arriaza, & Aufderheide, 1993; Wise, Clark, & Williams, 1994; Arriaza, 1995; Wise, 1997; Rasmussen, 1998; Standen, Santoro, & Arriaza, 2004; Arriaza et al., 2008; Muñoz 2011; Marquet et al., 2012; Santoro et al., 2012; Umire, 2013; Sepúlveda et al., 2015). This logistic mobility system of the Chinchorro resembles Binford's collector model (1983). Moreover, the existence of dense and long-term occupied cemeteries next to base domestic sites supports the idea that the Chinchorro people did not maintain a residential mobility system.

Coastal to Inland Enclave Mobility

Tiliviche, an oasis with fewer subsistence resources than the coast, has been suggested to have been occupied regularly throughout the Archaic Period by coastal people collecting high-quality lithic raw material (absent on the coast), and plant products (e.g., cactus fruits and wood; see Núñez & Moraga, 1978; Standen & Núñez, 1984; Núñez, 1986). If this was the case, the Sr isotopic composition of the individuals from Tiliviche should be close to coastal Sr signatures. The results show a Sr isotope value lower than the range of Sr values of coastal individuals, albeit slightly higher than the Sr signal of the local fauna in Tiliviche. These values could be explained by a mixed diet, which suggests that the individuals of the Tiliviche oasis could have had a settlement system with wide mobility. That is, they would have lived between the oasis and the coast, meaning their diet was not completely dependent on marine resources. The presence of bone fragments from camelids and rodents, such as *vizcacha*, chinchilla, and *Cavia* sp. (although scarce) in the Tiliviche camps, in addition to the identification of *Opuntia* sp. and *Scirpus* sp. in human coprolites, demonstrate the use of continental subsistence resources that they incorporated into their diet (Núñez & Hall, 1982).

Additionally, in the Tiliviche camps there are abundant subsistence remains of marine origin—fish, mollusks, birds, and mammals—that were brought from the coast. However, on the coast no individual with a similar Sr signal to that of the Tiliviche individuals was identified, nor have extractive or work camps from these oasis groups been recognized. Tiliviche shows a record of successive residential camps consisting of semicircular prepared floors with *in situ* postholes that were used to sustain light structures. In a later phase, in addition to the dwellings, a cemetery dated to 3780 ± 100 ^{14}C yr B.P. was added next to the domestic area, which suggests that this oasis was the primary residence for these later hunter and gatherers groups. This archaeological evidence may explain the intermediate marine and terrestrial Sr signal. Whereas, the mortuary pattern shows mainly individuals

in a flexed position, which could represent groups from a different cultural tradition than the coast, given that the coastal mortuary pattern is characterized by individuals laid in an extended position. The idea of a desert hunter-gatherer tradition was suggested by Núñez and Zlatar (1980) for the Aragón camps located just 7 km south east of Tiliviche.

The Sr isotopic compositions of the Tiliviche individuals indicate a mixed diet. The access to marine resources can be explained by a logistic mobility from an oasis base to coastal extractive camps, a mobility pattern embedded within a forager organizational system (Binford, 1983). An alternative model to explain the marine contributions to the oasis would be through the exchange between Tiliviche and coastal groups.

Highland Mobility

The female of the Patapatane rock shelter is dated to 5900 ± 90 ^{14}C yr B.P., the only Archaic human burial known for the highlands contemporary with Chinchorro, and yielded a Sr isotopic composition more similar to that of marine fauna than to that of the terrestrial fauna of Patapatane. This individual was a single inhumation found in a site with no evidence of long-term habitation. Her body was intentionally manipulated before being buried and her grave goods contained fragments of *Choromytilus* shells, three small fish vertebrae (unidentified), and a possible harpoon tip (Standen & Santoro, 1994). Furthermore, her extended supine position and the likely removal of her brain are reflective of coastal funerary practices (Standen & Santoro, 1994; Santoro et al., 2001). In addition, the Patapatane shelter exhibits certain items of coastal provenance, such as *Choromytilus* shells and shark teeth (Núñez & Santoro, 2011; Santoro & Núñez, 1987). These features raise interesting questions regarding her provenance and the mobility patterns of coastal people. Her distinct Sr signature suggests that she was of coastal origin, which was reinforced through the mortuary treatment that resembles certain coastal Chinchorro customs. We suggest that people from the coast integrated highland enclaves, like Patapatane, within their life circuit through logistic mobility. The highlands ecosystems allow for year-round habitation, which would have favored the relatively straightforward ascent of coastal groups into the highlands (Santoro & Núñez, 1987; Núñez & Santoro, 2011).

Additionally, it may be suggested that the woman of Patapatane may have formed part of coast-highland marital exchange and remained in the territory of her mate (virilocality). Perhaps, this arrangement was part of the negotiations that allowed coastal people to gather highland resources (e.g., pigments, lithic raw material,

and other items). In contrast, it is interesting that no women from the coast show a reverse pattern. These issues will need future data and validation.

CONCLUSIONS

Our Sr isotope study, applied for the first time to numerous samples of Chinchorro hunter-gatherers and fishermen, and to a smaller sample of individuals from an inland oasis and the highlands of northernmost Chile, allowed us to better understand mobility and residence systems in the contrasting ecosystems of the Pacific coast and the extreme hyperarid core of the Atacama Desert. Regarding residential and subsistence patterns, our study strengthens the hypothesis that the Chinchorro people employed adaptive strategies that involved stable residential settlements along the coast. However, the Sr data do not permit us to fully differentiate whether the Chinchorro maintained a residential or logistical mobility along the coast. The Sr results do show Chinchorro people relied heavily on marine resources and that most Chinchorro people were born, lived, died, and were buried at the coast. Movements to inland territory would have likely been for short periods of time. Our study confirms previous research, based on cultural data, that the Chinchorro kept residential bases with camps, dwellings, and cemeteries at the mouth of the river valleys, complemented with logistical mobility along the coast between those highly marine productive enclaves where greater availability of freshwater was available. This Chinchorro mobility system resembles Binford's collectors model, and it is in accordance with Kelly's statement that people depending on a marine subsistence diet tend to have a more reduced residential mobility than terrestrial hunter-gatherers (Kelly, 1983, 1992).

In contrast, the isotopic Sr signature of the individuals from Tiliviche, an open camp and cemetery located at an inland oasis 950 m asl and 40 km from the coast and contemporaneous with a later Chinchorro phase, suggest a different scenario. Their values are slightly closer to terrestrial than marine Sr values consistent with the idea that this group originated from within the oases and that they maintained a logistic mobility pattern that involved movement between the oases and the coast. This conclusion contradicts previous interpretations that suggested that coastal groups integrated these interior oases to their settlement and mobility patterns.

The fact that the woman buried at Patapatane, a cave camp located 80 km from the coast at 3750 m asl and contemporaneous with the Middle Chinchorro phase, had a moderate marine Sr isotopic signature, and that marine

remains at the site were limited, suggest that she likely stopped eating marine resources when she moved to the highlands. This would imply that parties of coastal groups occasionally moved to the highlands, to obtain certain resources that were then taken to the coast. Some of these items (e.g., manganese minerals and skins of Andean fauna such as camelids) were in high demand along the coast. Nonetheless, the Papatapatane individual presents some burial features (e.g., extended burial position, body manipulation) resembling Chinchorro funerary patterns, suggesting ties between coastal peoples and highland groups. Finally, although mate exchange between coastal and highland people to grant access to highland resources is tantalizing, this proposition requires further analysis.

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