STABLE CARBON AND NITROGEN ISOTOPIC ANALYSIS OF SKELETAL REMAINS FROM AZAPA 71 AND PICA-8, NORTHERN CHILE: AN ASSESSMENT OF HUMAN DIET AND LANDSCAPE USE IN THE LATE HOLOCENE

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Abstract

This paper presents the results of stable carbon and nitrogen isotope analyses of human bone from two northern Chilean Late Holocene (c. 4000-700 BP) archaeological sites: Azapa 71 (Az-71) in the Azapa Valley, Arica and Parinacota region, and the site of Pica-8, in the Pampa del Tamarugal inland basin, Tarapacá region. These results are compared to isotope data from other Chilean sites. The research examined issues relating to human diet and landscape use in these regions over this time period as well as the reliance on marine foods and/or agriculture. It also aimed to investigate the potential of this information to inform our understanding of the degree of inter-regional social interaction between populations. The outcomes of this research reveal the importance of using independent analyses, such as stable carbon and nitrogen isotope analyses, to understand the diets of past populations. The results suggest that both populations retained diets based on terrestrial hunter-gatherer economies, with the addition of marine foods. Further, these marine foods were found to be exploited to a greater extent than the archaeological evidence for subsistence at the sites indicated. The stable isotope data challenge the archaeology which to date has potentially over-represented the use of both wild and farmed plant foods by these populations. However, the social mechanisms explaining how different groups had access to marine resources continues to remain uncertain.
Introduction

The sites Az-71, located in the Azapa Valley, and Pica-8, located in the Tarapacá Region (see Figure 1) are approximately 330km apart. However, they both share similar environments, being located on fertile plains and oases in the Atacama Desert of Chile.

**Azapa 71**

Despite being one of the most arid regions in the world (Clarke 2005:101), the Azapa Valley is known for its fertile soil framed between the two hills of its deep canyon, and divided by the seasonal San Jose River, which runs during summer due to rainwater from the western slope of the Andes (see Latorre et al. 2005:81; Rech et al. 2001:1). Notwithstanding the scarcity and quality of the water in the Azapa Valley, the unique climate has permitted intensive cultivation on the narrow strips of fertile soil adjacent to the river, providing a variety of fruits, vegetables and cereals throughout the year (Cordova González et al. 1999:7). This research further investigates the nature and timing of the development of agriculture in this region.

*Figure 1* Map showing the locations of AZ-71 and Pica-8, Chile.
Food remains and artefacts recovered from archaeological sites in the region suggest that occupants of coastal villages dating to the past 4000 years had diets dominated by marine resources, while those inhabiting sites located a few kilometers inland practiced a mixed agro-pastoral and maritime subsistence (Sutter 2006). Maritime resources were dominated by a range of fish (e.g., flounder, mackerel, sea bass, swordfish, tuna) and shellfish (e.g., abalone, chiton, clams, limpets, urchins). Marine mammals (sea lions, whales) were also exploited. Archaeological plant remains include a range of C₃ cultigens, wild grasses, seeds and fruits and small quantities of maize. The dominant C₃ cultigens include cereals (Amaranthus caudatus, Chenopodium quinoa), beans (Phaseolus spp., Pachyrhizus spp., Canavalia spp.), squash (Cucurbita spp.), chile peppers (Capsicum spp.) and potatoes (Solanum spp.).

The earliest archaeological evidence for the lower section of the Azapa Valley is dated to around 3500 BP. These remains (from the Az-71 site) include a hearth associated with pottery, some cultigens and marine food (Santoro 1981). Early evidence along the southern slope of the mouth of the Azapa, as well as the coastal areas north and south of the mouth, contain evidence corresponding to the Chinchorro culture (Arriaza et al. 2008; Standen et al. 2004; Standen and Santoro 2004). The first long term occupation of these areas was followed by early farmers of the Azapa and Alto Ramírez cultural phases, which later on were integrated into the Tiwanaku social interregional spheres. This was followed by an intermediate period of local development that continued into the Inka imperial system, which in turn was overthrown by the Spanish conquest (Rivera 2008).

The site of Az-71 is located in the Azapa Valley, approximately 12km inland from the coastal town of Arica, and is adjacent to the present day village of San Miguel de Azapa. The site was excavated in 1977-1978 by Calogero Santoro and his team (Santoro 1980a). The cemetery was used from c. 3500 BP to 700 BP.
Az-71 consists of a series of temporally superimposed burials representing the Azapa, Alto Ramírez and Tiwanaku cultural phases in horizontal more than vertical or stratigraphic succession (see Santoro 1980a). There are 26 radiocarbon dates for the site of Az-71, which fluctuate between 3350-2560 BP for the Early Formative Period and 1010-490 BP for the Middle Horizon Period. Eight of these dates were obtained from samples of human tissues (Focacci 1982; Santoro 1980b), 15 from camelid fibers (Cassman 1997) and three miscellaneous (Focacci 1982; Santoro 1980b).

At the site of Az-71 (as noted above) are the Early and Late Formative groups: the Azapa, followed by the Alto Ramírez, which are represented by 53 and 30 burials, respectively. These groups are of primary interest because they provide the earliest evidence for coastal valley village life and incipient agriculture within the Azapa Valley (Munoz 1981, 1983, 1987; Santoro 1980a, 1980b). Santoro (1980b:51) characterises Azapa and Alto Ramírez habitations as small groups of people occupying sedentary villages and relying on the exploitation of marine and valley resources.

Archaeological investigations at Az-71 revealed Alto Ramírez artificial accumulation of plant remains in the form of a thick layer covering an extension of several square meters (c. 100m²), containing burials with offerings of copper and silver serpent-shaped ornaments. The use of several layers of plant remains, alternated with soil layers, is characteristic of Alto Ramírez Phase ceremonial mounds (Núñez and Santoro 2011; Rivera 2008:965; Romero et al. 2004; Santoro 1980a).

Textiles made with various techniques with geometric designs and mummy heads with packs of dyed wool of several colours were also excavated from the Az-71 site (Rivera 1991:27; Rivera 2008:966; Santoro 1980b:49). Agriculture was evidenced at this site by the presence of vegetables and seeds found within domestic and funerary contexts, as well as in middens and coprolites (Muñoz 1981, 2004; Santoro 1980b:49).
Generally speaking, it has been claimed that the Formative Period brought drastic changes to the diets of the peoples that colonised the valleys and oases of the Atacama, as well as along the coast (see Núñez and Santoro 2011 for a recent review). This is a consequence of the introduction of different cultigens, but few quantitative analyses have been conducted in order to evaluate the real impact of agriculture on the way of life of the people of the Atacama. Isotope analyses represent a solid alternative and have the potential to add to interpretations about the human diet in this region.

Although artefact classes found with the burials at Az-71 can provide some information on social stratification within Azapa society, an investigation into diet, production, and access to, dietary resources, through stable isotope analysis of the bones from the burials, also has the potential to provide an independent line of information about these ancient people.

**Pica-8**
The site of Pica-8 is located in the commune of Pica, Tamarugal Province, Tarapacá Region, 114km southeast of the city of Iquique. It is situated inland in the Atacama Desert, and, unlike the Azapa Valley, is without water runoff from the Andes. However, the vegetation and agriculture of the oases of Pica depend on spring water to support small settlements as they may also have done thousands of years ago. There are five radiocarbon dates for the site of Pica-8 ranging from 1150-900 BP. Two of these dates were obtained from samples of camelid fiber (Núñez 1976), and the other three were obtained from human bone collagen (Uribe et al. 2007), which place the site within the Late Intermediate period and which corresponds to local community development before the Inka period.

The Pica-8 site was excavated in 10 sections, from A-J by archaeologists Hans Niemeyer and Lautaro Núñez over a three-year period (1963, 1964, 1965) and recovered over 1482 artefacts (Zlatar 1984:2). The main evidence at Pica-8 consists of local Pica Tarapacá ceramics and textiles, along with artefacts common in the Azapa zone such as the Cabuza, Maitas-Chiribaya, San Miguel, Pocoma and Gentilar cultural traits. The site consists of a great complexity of materials, such as pottery and textiles, documenting changes in subsistence and the consolidation of agriculture.
Archaeological and historical investigations at the site of Pica-8 have revealed some interaction between the coastal and inland people of the Atacama Desert. Colonial (since the 16th century AD), archaeological and paleoparasitological records show that coastal marine products and materials were brought to the interior, a practice that started early in the Archaic Period and continued to the Late Period in the Atacama region (see Araujo et al. 1985; Dorsey Vinton et al. 2009; Núñez and Hall 1982; Santoro et al. 2003). It has further been noted that since prehistoric times guano (marine bird dung) was also transported to the interior to fertilize farming land (Bermúdez 1980; Hidalgo 2004; Villalobos 1979).

The coast to the west of the Atacama Desert is known for its great abundance and diversity of marine resources, which constituted a crucial backup for coastal and inland people. However, how the different social groups managed to have access to marine resources is open to question. For hunting and gathering groups the development of seasonal mobility patterns has been suggested. While, for later groups (from the Formative Period on) a wide array of mechanisms of interaction and complementarity have been discussed. This includes verticality, a model proposed by John Murra (1972), which included several modalities such as coastal verticality practiced by people centered on the coast, informal or decentralised microverticality, a socially structured centralised mode known as vertical archipelago practiced by highland people that maintained colonies on both sides of the Andes including the Pacific coast, horizontal interaction or valley to valley relations, simple exchange or trade and marriage alliances through the exchange of spouses (Covey 2000; Dillehay 1987; Durston and Hidago 1997; Hidalgo 2004; Salomon 1985; Santoro et al. 2010; Shimada 1982; van Buren 1996).

Indeed, for the Pica zone in particular, archaeological evidence shows contact between the coast and the interior since the late Pleistocene in Quebrada Maní (Santoro et al. 2011). Since the Formative Period the introduction of marine products to farming villages has been a common occurrence (Núñez 1982; Rivera 2005; Uribe 2009, Uribe et al. 2007) and remained active until colonial times (Bermúdez 1980; Villalobos 1979).
Archaeological reconstructions of diet, based on floral and faunal assemblages at Az-71 and Pica-8, can provide information about what the inhabitants were eating. However, they are several steps removed from the populations’ consumption and, as a result, they may not provide enough information to accurately answer questions about the economy and social structure of these past societies. Diet, production, and access to, dietary resources are some of the most fundamental indicators of social and political differences in the archaeological record (Hastorf 1985:19). The different kinds of food people within a population were eating, and the amounts in which they were eating them, can give archaeologists clues about the social class of its members.

Thus, stable carbon and nitrogen isotope analysis may provide an independent source of information about the diets of the populations at these sites, answering questions about what the inhabitants were eating, the approximate quantities of the different types of food people were eating and any changes in the diet over time. From this, the transition from hunting and gathering to agriculture may be seen, as well as changes in amounts and types of food that people were consuming, giving insights into changes in the economy and social structure of the Azapa and Tarapacá societies.

**Materials and Methods**

Bone specimens, ranging from approximately 1.0-3.0g were taken for each individual depending on the amount of skeletal material available for analysis. Following sample exclusions (see sections below) the sample size ultimately consisted of 13 individuals.

Sample preparation involved cleaning of the bone pieces, demineralisation and sodium hydroxide treatment. Bone fragments were demineralised in dilute HCl according to the methods of Sealy (1986). Humic acids and other base-soluble contaminants were removed using a 0.125 M NaOH solution. Extracts were soaked and washed thoroughly following acid and base treatments in order to remove dissolved contaminants. The remaining organic component was oven dried at approximately 40°C.
Carbon and nitrogen concentrations were determined using an ANCA SL elemental analyser coupled to a Geo 20-20 IRMS. Stable carbon and nitrogen isotope values were determined by mass spectrometry. δ values were placed on the VPDB scale using a two-point calibration method, with the standards USGS40 and USGS41 used as anchor points (Coplen et al. 2006; Qi et al. 2003). A number of samples were repeated during the mass spectrometry process to ensure accuracy. Where repeat testing was conducted the values were averaged for use in the analysis and discussion for this research.

Controls for post-mortem organic decomposition were implemented by excluding samples with: 1) Less than 5% collagen yield from the bone specimens; or 2) Less than 5% carbon yield from collagen; or 3) Less than 0.5% nitrogen yield from collagen (Ambrose 1990; Pate 1997; Schoeninger et al. 1989). When collagen yields were less than 5% upon initial demineralisation, additional bone samples were taken from the individual (if possible) and demineralised until a specimen with adequate collagen yield was obtained.

Atomic C:N ratios in modern collagen were employed to determine the presence of acceptable collagen in archaeological extracts in relation to stable isotope analysis. These acceptable atomic C:N ratios were developed by extracting collagen from large samples of modern mammals and measuring their C:N ratios. Results include atomic C:N ratios of 2.9 – 3.6 for 172 mammals (DeNiro 1985), 2.8 – 3.5 for 79 mammals (Ambrose 1990) and 2.7 – 3.6 for 164 mammals (Anson 1997). C:N ratios for all samples utilised in the analysis and discussion for this research were within the range of that reported for modern collagen – i.e., between 2.7 and 3.6.

**Results**

Bone collagen δ¹³C and δ¹⁵N values for the Az-71 and Pica-8 sites are summarised in Tables 1 and 2. Values are reported relative to the PBD standard for carbon and according to the AIR (atmospheric nitrogen) standard for nitrogen. The analytical precision was better than ± 0.2‰ for δ¹³C and ± 0.3‰ for δ¹⁵N.
After initial demineralisation (acid reduction) approximately 35% of the total sample (9/26) had collagen yields less than 5%. After one day in the HCl acid reduction six samples almost completely disintegrated and following the NaOH treatment disappeared completely. A further three samples did not achieve the yield needed for the analysis. Four of the samples submitted for mass spectrometry, samples Az-71-324 (60.2), Az-71-602b (8.5), P8-3b (3.9) and P8-33 (3.7) did not show acceptable collagen levels as their C:N ratio was outside the 2.7 – 3.6 range.

Table 1 reports the bone collagen stable isotope results for the Az-71 population, with a summary of the contextual information about each sample.

<table>
<thead>
<tr>
<th>Sample</th>
<th>%Yield</th>
<th>$\Delta^{15}$N (‰Air)</th>
<th>%N</th>
<th>$\Delta^{13}$C (‰PDB)</th>
<th>%C</th>
<th>C:N</th>
<th>Proposed Time Period/s</th>
<th>Bone Sampled</th>
<th>Proposed Age of Individual</th>
<th>Proposed Sex of Individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Az71-165</td>
<td>23.5</td>
<td>22.2</td>
<td>13.8</td>
<td>-13.5</td>
<td>44.1</td>
<td>3.2</td>
<td>Formative Period (Alto Ramirez) c. 2500-1500 BP</td>
<td>Rib</td>
<td>Sub-adult</td>
<td>Female</td>
</tr>
<tr>
<td>Az71-171b</td>
<td>23.5</td>
<td>20.6</td>
<td>14.0</td>
<td>-12.6</td>
<td>41.0</td>
<td>2.9</td>
<td>Late Intermediate Period (Indeterminate) c. 1000-660 BP</td>
<td>5th metacarpal, left</td>
<td>Sub-adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-177</td>
<td>26.7</td>
<td>22.9</td>
<td>13.9</td>
<td>-13.7</td>
<td>44.6</td>
<td>3.2</td>
<td>Middle Horizon Period (Tiwanaku) c. 1500-900 BP</td>
<td>1st phalange, hand</td>
<td>Sub-adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-212</td>
<td>24.4</td>
<td>17.8</td>
<td>14.2</td>
<td>-14.3</td>
<td>41.9</td>
<td>2.9</td>
<td>Middle Horizon Period (Loreto Viejo) c. 1500-900 BP</td>
<td>1st metacarpal, right</td>
<td>Adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-267</td>
<td>22.7</td>
<td>23.4</td>
<td>15.3</td>
<td>-12.5</td>
<td>43.2</td>
<td>2.8</td>
<td>Middle Horizon Period (Tiwanaku) c. 1500-900 BP</td>
<td>1st metatarsal, right</td>
<td>Adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-286b</td>
<td>7.6</td>
<td>16.6</td>
<td>15.0</td>
<td>-18.2</td>
<td>43.4</td>
<td>2.9</td>
<td>Formative Period (Azapa) c. 4000-2500 BP</td>
<td>Rib</td>
<td>Sub-adult</td>
<td>Female</td>
</tr>
<tr>
<td>Az71-331b</td>
<td>0.2</td>
<td>14.4</td>
<td>15.0</td>
<td>-16.8</td>
<td>41.8</td>
<td>2.8</td>
<td>Formative Period (Azapa) c. 4000-2500 BP</td>
<td>Rib</td>
<td>Adult</td>
<td>Male</td>
</tr>
</tbody>
</table>
Bone collagen $\delta^{13}$C and $\delta^{15}$N data from the site of Az-71 indicate that the older samples, such as Az-71-288b (c. 4000-2500 BP) and Az-71-331b (c. 4000-2500 BP) have more negative $\delta^{13}$C values. However, all of the samples more recent than c. 2500 BP have $\delta^{13}$C values more positive than -15‰, as well as relatively positive $\delta^{15}$N values. The various clusters of stable isotope values represented in Figure 2 provide evidence for individual dietary variability at the site.

**Figure 2 Key**
- ● Az-71-165 (c. 2500 to 1500 BP)
- ■ Az-71-171b (c. 1000 to 660 BP)
- ▲ Az-71-177 (c. 1500 to 900 BP)
- ♦ Az-71-212 (c. 1500 to 900 BP)
- ○ Az-71-267 (c. 1500 to 900 BP)
- × Az-71-288b (c. 4000 to 2500 BP)
- △ Az-71-331b (c. 4000 to 2500 BP)

**Figure 2** Stable carbon and nitrogen isotopic composition of human bone collagen for individuals from Az-71, Chile.
Table 2 reports the bone collagen stable isotope results for the Pica-8 population, with a summary of the contextual information about each sample.

Table 2 Pica-8, Tarapacá, Chile: summary of human bone collagen stable carbon and nitrogen isotope results.

<table>
<thead>
<tr>
<th>Sample</th>
<th>%Yield</th>
<th>δ¹⁵N (%°Air)</th>
<th>δ¹³C (%°PDB)</th>
<th>%C</th>
<th>CN</th>
<th>Proposed Time Period/s</th>
<th>Bone Sampled</th>
<th>Proposed Age of Individual</th>
<th>Proposed Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>P8-7</td>
<td>25.5</td>
<td>16.5</td>
<td>15.2</td>
<td>-8.4</td>
<td>41.7</td>
<td>2.7</td>
<td>Adult</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>P8-15</td>
<td>24.1</td>
<td>18.0</td>
<td>14.8</td>
<td>-10.4</td>
<td>42.5</td>
<td>2.9</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>P8-24</td>
<td>25.6</td>
<td>15.1</td>
<td>15.0</td>
<td>-8.7</td>
<td>42.2</td>
<td>2.8</td>
<td>Adult</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>P8-31</td>
<td>16.1</td>
<td>21.4</td>
<td>14.7</td>
<td>-13.0</td>
<td>41.5</td>
<td>2.8</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>P8-37</td>
<td>22.5</td>
<td>23.1</td>
<td>13.1</td>
<td>-8.8</td>
<td>40.3</td>
<td>3.1</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>P8-47</td>
<td>25.4</td>
<td>16.2</td>
<td>15.7</td>
<td>-10.1</td>
<td>42.8</td>
<td>2.7</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
</tbody>
</table>

Bone collagen δ¹³C and δ¹⁵N values from the Pica-8 site also indicate significant dietary variability, with sample P8-31 showing the most negative δ¹³C value and sample P8-37 exhibiting the most positive δ¹⁵N value (see Figure 3).
Figure 3 Key

- P8-7 (c. 1150 to 500 BP)
- P8-15 (c. 1150 to 500 BP)
- P8-24 (c. 1150 to 500 BP)
- P8-31 (c. 1150 to 500 BP)
- P8-37 (c. 1150 to 500 BP)
- P8-47 (c. 1150 to 500 BP)

Figure 3 Stable carbon and nitrogen isotopic composition of human bone collagen for individuals from Pica-8, Chile.

The Az-71 mean site values (-14.5‰ δ¹³C and 19.7‰ δ¹⁵N) are closest to those from the nearby Chilean sites of Molle Pampa Medio (-12.8‰ δ¹³C and 19.6‰ δ¹⁵N) and Caleta Vitor (-12.9‰ δ¹³C and 23.0‰ δ¹⁵N). All of these sites demonstrate high mean δ¹⁵N values in the human bone collagen.
Table 3 Summaries (mean ± standard deviation) of human bone collagen stable carbon and nitrogen isotope results for archaeological sites in Chile with comparative sample sizes to the Az-71 and Pica-8 samples analysed in this research.

<table>
<thead>
<tr>
<th>Populations</th>
<th>δ¹³C (‰)</th>
<th>δ¹⁵N (‰)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Molle Pampa Este²</td>
<td>-11.0 ± 2.2</td>
<td>-14.0 -9.0</td>
</tr>
<tr>
<td>Molle Pampa Medio²</td>
<td>-12.8 ± 3.7</td>
<td>-17.6 -9.6</td>
</tr>
<tr>
<td>Valle Verdeᵇ</td>
<td>-20.1 ± 0.3</td>
<td>-20.3 -19.6</td>
</tr>
<tr>
<td>Maria Pintoᵇ</td>
<td>-12.0 ± 0.8</td>
<td>-12.7 -10.7</td>
</tr>
<tr>
<td>Laguna El Peral-Cᵇ</td>
<td>-14.6 ± 0.9</td>
<td>-15.6 -13.5</td>
</tr>
<tr>
<td>Las Brisas 10-14ᵇ</td>
<td>-13.9 ± 1.8</td>
<td>-17.3 -12.3</td>
</tr>
<tr>
<td>Caleta Vitorᶜ</td>
<td>-12.9 ± 1.1</td>
<td>-14.7 -10.9</td>
</tr>
<tr>
<td>Az-71ᵈ</td>
<td>-14.5 ± 2.2</td>
<td>-18.2 -12.5</td>
</tr>
<tr>
<td>Pica-8ᵈ</td>
<td>-9.9 ± 1.7</td>
<td>-13.0 -8.4</td>
</tr>
</tbody>
</table>

² Aufderheide and Santoro 1999  
ᵇ Tykot et al. 2009  
ᶜ Roberts et al. in preparation  
ᵈ This research

In contrast, the mean isotopic values from the site of Pica-8 (-9.9‰ δ¹³C and 18.4‰ δ¹⁵N) are most comparable to those from the site of Molle Pampa Este (-11.0‰ δ¹³C and 21.7‰ δ¹⁵N), demonstrating more positive δ¹³C values than the rest of the sites (see Figure 4).
Figure 4 Key
◊ Valle Verde (c. 2150-1750 BP) – an inland site approx. 2000km south of Arica
● Laguna El Peral-C (c. 1600-950 BP) – a coastal site approx. 2000km south of Arica
◆ Las Brisas 10-14 (c. 950-500 BP) – a coastal site approx. 2000km south of Arica
▲ Caleta Vitor (c. 8000-476 BP) – a coastal site approx. 25km from Arica
□ Molle Pampa Medio (c. 850-550 BP) – an inland site approx. 22.5km from Arica
○ Molle Pampa Este (c. 550-450 BP) – an inland site approx. 22.5km from Arica
△ Maria Pinto (c. 950-550 BP) – an inland site approx. 2000km south of Arica
× Az-71 (c. 4000-900 BP) – an inland site approx. 12km from the coast
■ Pica-8 (c. 1150-500 BP) – an inland site approx. 90km from the coast

Figure 4 Stable carbon and nitrogen isotopic composition of average human dietary protein for bone collagen of various Chilean populations and known human population samples representing diets at the extremes of the δ¹³C and δ¹⁵N spectrum (the latter populations are plotted after Roberts et al. in preparation; Little and Schoeninger 1995; Schoeninger et al. 1983 – these values are represented by a ‘+’ and have text labels) in comparison to the Az-71 and Pica-8 samples analysed in this research.
Discussion

Prior research documenting the stable carbon and nitrogen isotope values of plant and animal materials has served to create baseline data for average plant and animal isotope values in the Chilean region. These baseline values can be compared to the human isotopic values and be employed to infer food consumption and dietary patterns in past human populations. Using this method, dietary patterns, landscape use and geographic origin can be studied.

Previous stable carbon and nitrogen isotope values for surrounding populations in the Chilean region have served to establish comparable data for this study (see Außerheide and Santoro 1999; Hastorf 1985; Roberts et al. in preparation; Tykot et al. 2009).

**Azapa 71**

Stable carbon and nitrogen isotope values for the Az-71 population revealed a diet consisting predominantly of marine foods from upper trophic levels, with mean values being -14.5‰ and 19.7‰, respectively for δ\(^{13}\)C and δ\(^{15}\)N. Although the site of Az-71 is 12km inland, it is proposed that the stable carbon and nitrogen isotope values indicate that the population at this site was most likely travelling to the coast in order to obtain the marine resources in their diet. This may have been due to seasonal movements to the coast by the population as a whole, or by different members of the population making regular trips to the coast in order to acquire these resources.

Despite the fact that the mean isotopic values illustrate a predominantly marine diet, the site of Az-71 exhibits some variability within its individual values, illustrating clusters of results. The first group of interest contains two individuals from the Azapa Phase (c. 4000-2500 BP), exhibiting values ranging between -16.8‰ and -18.2‰ for δ\(^{13}\)C and 14.4‰ and 16.6‰ for δ\(^{15}\)N. These values are similar to δ\(^{13}\)C and δ\(^{15}\)N values for eel jay (-14.4‰ δ\(^{13}\)C and 16.1‰ δ\(^{15}\)N) and also have comparable δ\(^{13}\)C values to *Lama guanicoe* (-19.5‰ δ\(^{13}\)C and 4.6‰ δ\(^{15}\)N) and inland lake fauna (-16.0‰ δ\(^{13}\)C and 2.1‰ δ\(^{15}\)N), indicating a diet of mixed arid land C\(_3\) foods and marine foods (see Figure 5).
The Azapa was a transitional phase between the end of the Chinchorro Phase (c. 8000 – 4000 BP) and the start of the Alto Ramírez Phase (c. 2500-1500 BP) and demonstrated traits of both of these phases (Santoro 1980a). According to Santoro (1980a, 1980b), inhabitants of the inland Azapa sites practiced a mixed agro-pastoral and maritime subsistence, which has previously been evidenced in the form of coastal handicrafts, crop, burial and residential patterns in and around the Azapa Valley sites. While the stable carbon and nitrogen isotope results from the Azapa Phase at Az-71 indicate that the inhabitants of the site were indeed eating a mix of C₃ arid land and marine foods, there is not enough evidence to suggest that these C₃ foods were in fact agricultural (or agro-pastoral) in nature since C₃ values simply indicate the consumption of C₃ plants, which could also be wild plants. This highlights the fact that, while the results do actually indicate that these individuals were eating C₃ foods, they do not indicate a statistically significant enough quantity of C₃ to suggest agricultural activities.

The second group of interest date from approximately 2500 to 900 BP, incorporating the Alto Ramírez and Cabuza cultural phases. These δ¹⁵N results indicate a diet of high trophic level marine foods with values between 17.8‰ (Az-71-212) and 23.4‰ (Az-71-267). These results correspond to those found for sea lion bones (-13.1‰ δ¹³C and 22.1‰ δ¹⁵N) from the site of Pisagua, in northern Chile (Aufderheide et al. 1994:520), as well as the mean values for fish vertebrae (-12.1‰ δ¹³C and 20.3‰ δ¹⁵N) from Pisagua, and Otaria sp. (-11.7‰ δ¹³C and 20.2‰ δ¹⁵N), a species of sea lion from central Chile (Tykot et al. 2009:163). Figure 5 demonstrates the isotopic similarities between the consumers and the animals that are most likely part of their diets.
**Figure 5 Key**

- ● Az-71-165 (c. 2500 to 1500 BP)  
- ■ Az-71-171b (c. 1000 to 660 BP)  
- ▲ Az-71-177 (c. 1500 to 900 BP)  
- ◆ Az-71-212 (c. 1500 to 900 BP)  
- ○ Az-71-267 (c. 1500 to 900 BP)  
- × Az-71-288b (c. 4000 to 2500 BP)  
- △ Az-71-331b (c. 4000 to 2500 BP)

**Figure 5** Summary of δ¹³C and δ¹⁵N values (bone collagen, flesh and plant tissues) for various marine, riverine and terrestrial foods for central Chile (summarised and adapted from Aufderheide et al. 1994:520 and Tykot et al. 2009:163 – see also Falabella et al. 2007), in comparison to Az-71 stable carbon and nitrogen isotope individual values.

In a previous isotope study conducted at the site of Pisagua Aufderheide et al. (1994:515) state that members of the Alto Ramírez cultural group:

...transferred their highland practices of agriculture and pastoralism to...lower valley sites, acquiring only a minority of their dietary needs from the nearby sea.
However, the population at the Az-71 site cannot be part of the agricultural sub-group that Aufderheide et al. (1994) refer to in their paper, as there is limited evidence for agriculture in their diet. It is possible that another group moved into the Azapa Valley area later and brought with them their agricultural practices, though it is more likely that, as Rothhammer and Cocilovo (2008) pointed out, the group at the site were coastal people that simply adopted certain Formative cultural features within their own system.

Rivera (2008:968) further notes that villages of the Cabuza archaeological culture phase contain large numbers of storage rooms, suggesting “intensive economic redistributive practices.” It is also noted that the locations of the Cabuza sites are thought to suggest a preference for areas best suited to irrigated cultivation rather than the earlier coastal sites (Rivera 2008:968).

At the Az-71 site there is limited statistically significant isotopic evidence to indicate that the inhabitants of this site were participating in agricultural activities. One explanation for this could be that, although individuals at the site may have been participating in agriculture, as the archaeology for these time periods suggests, the individuals sampled may not have been eating the produce. One example of this is a study conducted by Hastorf and DeNiro (1985), where it was found that there was much intra-population variability with regards to the consumption of food. Indeed, Hastorf’s (1985) study points out the possibility that the population at Az-71 may have been consuming different quantities of food according to their social status. However, there is currently not enough evidence to support this idea, as the archaeological evidence does not show major differences between individuals at Az-71, and further isotope sampling is needed.

Two sites in the Chilean region that do show significant isotopic evidence for subsistence economies focused on terrestrial plant foods are the sites of Valley Verde, an inland site approximately 2000km south of Az-71, and Maria Pinto, located inland, approximately 2000km south of Arica, Chile. Examining the isotopic evidence from these sites serves to demonstrate two examples of diets dominated by C₃ and C₄ plants foods.
The site of Valle Verde exhibits mean isotopic values of -20.1‰ \( \delta^{13}C \) and 4.5‰ \( \delta^{15}N \), characteristic of a \( C_3 \)-based plant diet. Similarly, mean isotopic values from the site of Maria Pinto (-12.0‰ \( \delta^{13}C \) and 7.2‰ \( \delta^{15}N \)) illustrate a diet including significant quantities of \( C_4 \) plant foods for which there is limited evidence in the Az-71 isotopic values (see Figure 4). The Valle Verde isotopic results could relate to the use of large quantities of wild \( C_3 \) plant foods or a focus on \( C_3 \) cultigens. In contrast, the Maria Pinto isotopic values do suggest diets based on large quantities of \( C_4 \) maize.

The values from the Az-71 site are most comparable to those found at the nearby sites of Molle Pampa Medio (MPM) (-12.8‰ \( \delta^{13}C \) and 19.6‰ \( \delta^{15}N \)), a Late Intermediate Period site in the Lluta Valley 16km from the coast, and Caleta Vitor (-12.9‰ \( \delta^{13}C \) and 23.0‰ \( \delta^{15}N \)). While the Caleta Vitor site, being a purely coastal site, has the highest intake of marine foods from upper trophic levels, MPM also demonstrates high nitrogen values, meaning that, similarly to Az-71, they were probably travelling to, or living seasonally, on the coast in order to obtain a wider range of food to survive. Similarly to Az-71, isotopic results from the Molle Pampa sites (c. 1000-476 BP) indicate that the populations were eating “…terrestrial plants and marine meat resources with only a minor contribution from terrestrial meat resources” (Aufderheide and Santoro 1999:237). Despite the fact that the Molle Pampa sites are from different temporal periods in comparison to the Az-71 site, one reason for the similarity between the values could be that the sites are located in the same kind of ecological setting (i.e., both in valleys close to the coast). This allowed people to permanently rely on marine resources (highly predictable, abundant and variable), which were complemented by wild and farmed terrestrial resources.

The isotopic values from the Az-71 population challenge the archaeological evidence from the site, which suggests agricultural practices were taking place. In the Azapa Valley during the Formative and Late Intermediate Periods (c. 3500-700 BP) there is archaeological evidence for a transition from primary dependence on marine-based hunting and gathering to irrigation agriculture. Similar evidence was found at the Molle Pampa sites, however, it was also established that marine resources at the site were exploited to a greater extent than the archaeological evidence suggested (Aufderheide and Santoro
If cultivated $C_3$ or $C_4$ plant foods were included in the Az-71 diets then they constituted only a minor component that is not reflected in the isotopic data.

Items such as pottery, textiles and cultigens are all found at the site of Az-71 and have been taken as evidence for the transition to agriculture. However, this transition evidenced in the archaeological record is not reflected in the isotope values, with mean values indicating that the population at the site were not eating any significant amount of plant foods or agricultural produce at this time, but were eating high amounts of marine food instead. In relation to temporal differences at this site, isotopic evidence for the earlier Azapa (c. 4000-2500 BP) period suggest diets including $C_3$ plants as well as marine foods but later, around 2500 BP there is evidence for a shift toward predominantly marine foods. This is further in contrast to known information about the ENSO cycles, as Moy et al. (2002:163) state that there is a decline in the use of the desert coast after 3000 cal BP due to the major effects ENSO had on the marine biomass, leading to populations becoming more reliant on a mixed agricultural/marine economy. The isotope results from Az-71 indicate the opposite, a mixed reliance on terrestrial and marine foods before c. 3000 BP, leading to a reliance predominantly on marine foods after 2500 BP. In order to address these discrepancies between climatic and archaeological evidence with the isotopic evidence, further sampling of the population at Az-71 is needed. This may aid in obtaining a fuller picture of what the population as a whole was actually eating and how the population at the site was interacting with other nearby populations. Additionally, future palaeopathological studies of populations in the region may shed further light on these discrepancies.

**Pica-8**

Stable carbon and nitrogen isotope values for the Pica-8 population suggest a diet consisting of marine foods from upper trophic levels, as well as some maize, with mean values being -9.9‰ and 18.4‰ respectively for $\delta^{13}C$ and $\delta^{15}N$. At a glance, these values indicate that the population at Pica-8 was heavily reliant on marine foods, and therefore travelling to the coast in order to obtain these resources. However, due to the fact that
Pica-8 is located 90km from the coast additional factors were considered in more depth (see below). Nevertheless, it is still possible that the population at Pica-8 were either travelling to the coast in small groups or seasonally living on the coast in order to obtain the marine resources in their diets.

Similarly to the site of Az-71, there is variability between the individual δ\(^{13}\)C and δ\(^{15}\)N values at Pica-8, potentially revealing different diets. Unfortunately these diets cannot be differentiated by their chronologies, as they do not currently have relative individual dates assigned to them. On the whole, the site of Pica-8 ranges from approximately 1050 BP to 500 BP, focusing on the Late Intermediate Period, and the Tarapacá and Camiña culture phases.

The first distinct result from Pica-8 contains an individual (P8-31), with values of -13.0‰ δ\(^{13}\)C and 21.4‰ δ\(^{15}\)N. This individual has the most negative δ\(^{13}\)C value of those isotopically analysed from Pica-8. The δ\(^{13}\)C and δ\(^{15}\)N results together from this individual are similar to those for sea lion bones (-13.1‰ δ\(^{13}\)C and 22.1‰ δ\(^{15}\)N), and the mean values for fish vertebrae (-12.1‰ δ\(^{13}\)C and 20.3‰ δ\(^{15}\)N) in the region.

The second distinct result from the site of Pica-8 has an individual (P8-37) with values of -8.8‰ δ\(^{13}\)C and 23.1‰ δ\(^{15}\)N. This individual has the highest nitrogen values of those isotopically analysed at the site, indicating that they were most likely principally eating marine foods from upper trophic levels.

The third general dietary grouping at the site of Pica-8 (P8-7, P8-15, P8-24 and P8-47) has values ranging between -8.4‰ and -13.0‰ for δ\(^{13}\)C and 15.1‰ and 23.1‰ for δ\(^{15}\)N. These values are most comparable with those of fish vertebrae (-12.1‰ δ\(^{13}\)C and 20.3‰ δ\(^{15}\)N), thus also indicating a high marine diet. The following graph shows the comparison between consumers and known values for food sources (see Figure 6).
Figure 6 Key
- P8-7 (c. 1150 to 900 BP) - Sea lion bone
- P8-15 (c. 1150 to 900 BP) - Otaria sp.
- P8-24 (c. 1150 to 900 BP) - Fish vertebrae
- P8-31 (c. 1150 to 900 BP) - Eel jay
- P8-37 (c. 1150 to 900 BP) - Lama guanicoe
- P8-47 (c. 1150 to 900 BP) - Lake fauna - inland

Figure 6 Summary of $\delta^{13}$C and $\delta^{15}$N values (bone collagen, flesh and plant tissues) for various marine, riverine and terrestrial foods for central Chile (summarised and adapted from Aufderheide et al. 1994:520 and Tykot et al. 2009:163 – see also Falabella et al. 2007), in comparison to Pica-8 stable carbon and nitrogen isotope individual values.

One explanation that was explored for the high $\delta^{15}$N values for individuals at Pica-8 was the possibility of $\delta^{15}$N enrichment from the arid Atacama Desert soil. As mentioned previously, the Atacama Desert receives less than 1mm of rainfall annually (Latorre et al. 2005; Marquet et al. 1998; Marquet et al. 2002; Ramirez et al. 2001:7). It has been found that in arid habitats with mean annual rainfall less than 350-400mm (Ambrose 1991; Anson 1997:61), terrestrial herbivores show higher bone collagen $\delta^{15}$N values that can overlap with those for marine values (Pate 2008a:505). Heaton et al. (1986:823), for example, state that “...it appears that there is a definite tendency for increasing $^{15}$N with increasing aridity.” Therefore, it was possible
that the population at this site may have been eating predominantly terrestrial sources of food, which have been feeding on nitrogen enriched plants and soils. However, after investigating baseline faunal values for the animals in the region (see Tykot et al. 2009:163), it was found that this was not the case as the animals from these arid regions, such as *Lama guanicoe* (4.6‰ – 5.9‰ δ¹⁵N) have low δ¹⁵N values. It is expected that if the Atacama Desert aridity was causing enrichment in the human δ¹⁵N values, that it would also be doing the same for the animal’s values, which it was not.

The isotopic values from the site of Pica-8 are most comparable to those of the site of Molle Pampa Este (-11.0‰ δ¹³C and 21.7‰ δ¹⁵N) and Molle Pampa Medio (-12.8‰ δ¹³C and 19.6‰ δ¹⁵N). These sites are approximately 400km northwest of the site of Pica-8 and located in the Lluta Valley (see Figure 4). These values are most comparable due to their high stable nitrogen isotope values. However, the inhabitants of the sites may have been eating substantially different foods, since the sites at Molle Pampa in the Lluta Valley are only approximately 15km from the coast, whereas the site of Pica-8 is approximately 90km from the coast.

Significant differences exist between the average δ¹³C and δ¹⁵N values for the Azapa Valley site, Az-71, and the Tarapacá regional site of Pica-8. However, the results for both of these sites suggest that the populations were both consuming predominantly marine resources from upper trophic levels.

The Pica-8 values are least comparable to those from the sites of Valle Verde (-20.1‰ δ¹³C and 4.5‰ δ¹⁵N) and Laguna el Peral-C (-14.6‰ δ¹³C and 10.8‰ δ¹⁵N). The Valle Verde site is located approximately 1600km southwest of the site of Pica-8 and differs in that its inhabitants are practicing cultivated plant farming as opposed to those at Pica-8. The site of Laguna el Peral-C is a coastal site, also located approximately 1600km southwest from the site of Pica-8. According to their stable carbon and nitrogen isotope values, the inhabitants at this site were probably eating marine foods from lower trophic levels, such as smaller fish, crabs, shellfish and algae, as well as some cultigens. Isotopic results from the site of Pica-8, however, suggest a diet of marine foods from upper trophic levels.
Further, sampling at the site of Pica-8 will aid in combating discrepancies between the archaeological evidence and the isotopic evidence, giving a more holistic picture of subsistence activities taking place at the site. As the site of Pica-8 spans a time period of over 500 years, tighter chronological control of the samples and individually assigned dates would also assist in giving a clearer picture any possible changes in diet over time.
As a result it is suggested that the Pica-8 population may also have been regularly travelling to and/or seasonally living on the coast. However, given their inland location another possibility is that people from the valley maintained a colonial settlement on the coast to exploit marine resources that were sent back to inland settlements. Alternatively, people with permanent settlements along the coast may have exchanged marine products with people living in the valleys (see Hidalgo 2004; Santoro et al. 2010: Uribe et al. 2007 for a discussion on these issues).

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