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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January 2012
DECLARATION OF CANDIDATE

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed,

Bianca Petruzelli

10/01/2012
DECLARATION OF SUPERVISOR

I believe that this thesis is properly presented, conforms to the specification of thesis presentation at Flinders University and is *prima facie* worthy of examination.

Signed,

Dr Amy Roberts

10/01/2012
DEDICATION

To John Craven.
ABSTRACT

This thesis presents the results of stable carbon and nitrogen isotope analyses of human bone from two northern Chilean Late Holocene (c. 4,000-700 B.P.) 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. The thesis sought to address issues relating to human diet and landscape use in these regions in this time period as well as the reliance, or otherwise, 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, with results indicating 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 far greater extent than the archaeological evidence for subsistence at the sites suggested. These results challenge the archaeology which to date has potentially over-represented the use of both wild and farmed plant foods by these populations. Archaeological evidence identified at the sites suggests social interaction in the form of trade with highland and coastal populations. However, the social mechanisms explaining how different social groups had access to marine resources continues to remain uncertain.

Keywords:
Agriculture
Azapa Valley
Chile
Cultural change
Diet
Hunting and gathering
Isotope
Landscape use
Resource use
Stable carbon and nitrogen isotope analysis
Tarapacá, Arica and Parinacota regions
AKNOWLEDGMENTS

First and foremost I’d like to thank my parents, Lee Petruzzelli and Karen Craven, for their support throughout the year.

I would also like to thank Dr Amy Roberts for being there throughout the entire process and giving me lots of feedback and encouragement. I couldn’t have done this without her.

Thanks to Dr Michael Westaway, for getting the ball rolling and encouraging me to take this on. I doubt I would have even thought about doing my Masters on this without his input.

A further thanks to Professor Donald Pate, for helping me with the chemistry side of things and letting me borrow his equipment.

Thanks to Professor Calogero Santoro, from the University of Tarapacá, for reading over my drafts and giving me important input from South America. Calogero Santoro is funded by FONDECYT 1095006 and the Centro de Investigaciones del Hombre en el Desierto.

Thanks to Christopher Carter, for giving me the chance to attend the amazing field school that got this all started, and for all of his input along the way.

A huge thanks to Lily Ellis-Gibbings for helping me out in the lab and coming around for late night tea study breaks.

Thanks to my biddy, Jelena Vujnovic, for all of the cooked dinners, cups of coffee, study sessions and late evenings.

Thanks to Julia Garnaut, for sharing the “office” with me during the whole process and keeping the sarcasm flowing. So glad to have had someone so great to work with this year.
Thank you to Dr Rachel Popelka-Filcoff and other technical laboratory staff from the School of Chemical and Physical Sciences at Flinders University for facilitating access to laboratory space and equipment.

Thanks are also due to Dr Todd Maddern and other technical laboratory staff at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for their assistance in loading the samples for mass spectrometry analysis.

Last, but definitely not least, a huge thank you to the Australian Federation of University Women (AFUW) for their Diamond Jubilee Bursary. Their funding contributed greatly to the isotope analysis costs of this research.
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GLOSSARY

**Altiplano** – The high tableland of central South America, incorporating the Andes of Bolivia, Peru and Chile/Argentina.

**Chinchorro** – The Chinchorro culture, named after the beach where the first Chilean mummy remains were found, were a politically simple fishing society with complex mummification practices. The Chinchorro society inhabited the Atacama coast of southern Peru and northern Chile from approximately 8,000 to 4,000 B.P.

**Collagen** – The fibrous protein constituent of bone, cartilage, tendon and other connective tissue.

**C₃ Plants** – Plants use two different pathways to create sugars. In the first step of the Calvin pathway a three-carbon compound is created, so the group of plants using this pathway are called C₃ plants; they represent trees, shrubs and many grasses that thrive in a cooler, temperate climate.

**C₄ Plants** – C₄ plants use an alternative enzymatic pathway (Hatch-Slack), which produces a four-carbon compound. These plants are called C₄ plants and are commonly found in warmer or tropical areas (though maize, a C₄ plant, is an exception).

**Demineralisation** – A chemical process whereby the bone is stripped of contaminants, down to the collagen.

**Diagenesis** – The sum of the physical, chemical and biological processes that occur in the postmortem depositional environment.

**Holocene** – The Holocene is a geological epoch, which began at the end of the Pleistocene, approximately 10,000 years ago, and continues to the present day.
**Isotope** – Isotopes are two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei. This means that they each have a different atomic mass, but are more or less chemically identical.

**Mass spectrometry** – An analytical technique that measures the mass-to-charge ratio of charged particles. It is used for determining masses of particles, for finding the elemental composition of a sample or molecule, and for elucidating the chemical structures of molecules, such as peptides and other chemical compounds.

**Sedentary** – A term generally used to describe life for Neolithic peoples with social formations based on farming and the development of architecturally structured settlements.
1 CHAPTER ONE: INTRODUCTION

1.1 Introduction and Aims

You are what you eat, plus a few parts per thousand (Vogel 1978:298).

The introduction of stable isotope analysis to archaeological research in the 1970s produced a revolution in the ways that several key anthropological issues were studied. These included early hominin subsistence, hunter-gatherer spatial organisation, the origins and history of farming and pastoralist societies, migrations and group social differentiation (Ambrose 1993; Aufderheide 1993; Aufderheide and Santoro 1999; DeNiro and Epstein 1978, 1981; DeNiro and Schoeninger 1983; Hastorf 1985; Katzenberg 2000; Pate 1994, 1998, 2000, 2008a; Schoeninger and Moore 1992; Tykot et al. 2009; Yaowu et al. 2006). Isotope analysis allows improved quantitative estimates of proportions of dietary components, which was formerly impossible due to the fact that food remains are rarely preserved and recovered in the portions that they were consumed (Ambrose 1993:59). As a tool suited to the quantitative reconstruction of palaeodiets, bone chemistry provided a new and independent line of evidence that was readily integrated into ongoing archaeological, archaeofaunal and palaeobotanical data and discussions (Barberena et al. 2009:127). Thus, bone recovered from archaeological sites can be analysed isotopically for information regarding diet, landscape use and long-term societal continuities and change.

In archaeological contexts, isotope analysis has focused on the reconstruction of diets of past populations, using stable carbon and nitrogen isotope analysis of bone collagen. This thesis explores questions about the dietary, cultural and technological changes at two northern Chilean sites: the site of Azapa 71 (Az-71) in the Azapa Valley, and the site of Pica-8, in the Tarapacá region.
The primary aims of this research project were to conduct an investigation into the resource and landscape use between different Chilean regions, as well as examining currently held theories concerning these issues in the Late Holocene. These areas of investigation were examined by analysing the diets of two separate inland populations and comparing the results with other Chilean populations from coastal, highland and valley areas employing different modes of subsistence. An examination of previously and currently held theories about resource and landscape use from nearby sites in the Chilean region was also investigated to compare with the results and form conclusions for this research project.

![Map showing the locations of AZ-71 and Pica-8, Chile.](image)

**Figure 1:** Map showing the locations of AZ-71 and Pica-8, Chile.

Using stable carbon and nitrogen isotope analysis of bone collagen, this study aimed to further assess the diets of these ancient peoples and the degree of interregional interaction of these populations. Elemental and isotopic differences, which exist at the bases of food chains in various marine and terrestrial habitats are maintained in consumer tissues, making isotope analysis
a prime way of investigating mobility and landscape use (Ambrose 1993; Macko et al. 1999; Pate 1997:103). This is performed by analysing the systematic variation of different isotopes in items of food from different animals and plants and tracing them back to the environment they came from (Macko et al. 1999:66).

Using this same theory, changes in diet can also tell us about how the landscape was used by populations, as groups living inland in the hyperarid core of the Atacama Desert may also need to travel to the coast to obtain more food to complement their diets. This movement may be visible in, not only the archaeology of an inland site, but also in the bone chemistry of the inhabitants of these sites (see Núñez and Hall 1982; Pate 2008a, 2008b; Santoro et al. 2003).

Another aim of this study was to look at changes in diet and the potential for such changes to tell us about the reliance of populations on marine foods versus terrestrial or otherwise (Schoeninger et al. 1983; Schoeninger and DeNiro 1984). This is clearly shown through the study conducted on human remains from Caleta Vitor, a comparative case study, which is discussed later in this thesis. Indeed, through isotopic analysis of the bone samples from Caleta Vitor it was found that the population relied heavily on marine foods with over 80% of their diet consisting of marine foods from upper trophic levels (Roberts et al. in preparation).

Further, changes in diet can tell us about theories concerning the introduction of agriculture. Another aim of this study is to understand the transition between hunting and gathering to agriculture in the Chilean region (see Barberena et al. 2009:128; Núñez and Santoro 2011; Ponce 2010; Santoro 1980b). Aufderheide et al. (1994:15) conducted a study addressing subsistence change by assessing whether or not the cultural group at Pisagua “...transferred their highland practices of agriculture and pastoralism...” to the lower valley sites. Through stable carbon and nitrogen isotope analysis of human hair and muscle it was found that the group’s subsistence strategy was “...indistinguishable from that of the coastal maritime populations”. However,
another interpretation of this site suggested by Rothhammer and Cocilovo (2008:315) is that the Pisagua people did not, in fact, come from the highlands, as supposed by Auferheide et al. (1994), but instead they were coastal people that simply adopted certain cultural features within a maritime cultural system (see also Rothhammer et al. 2009; Sutter 2000; Verela et al. 2006). This is one such example that highlights the issue of the interpretation of isotopic data, which will be explored further in the discussion section of this thesis.

1.2 Research Questions

Generally speaking, it has been claimed that the Formative Period (c. 4,000-1,500 B.P.) 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 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.

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 are eating, and the amounts in which they are eating them, can give archaeologists clues about the social class of its members. However, there are some issues with this as some different foods can contain similar signatures in the bone collagen and can therefore lead to problems in relation to interpretations about what people were eating and in what quantities they were
eating it (Tykot et al. 2009: 156). This issue is further explored later in this thesis.

Despite such interpretive issues, stable carbon and nitrogen isotope analysis can still provide an independent source of information about the diets of the population 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 of the population. 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 clues as to changes in the economy and social structure of the Azapa and Tarapacá societies.

The primary research questions for this thesis are: what does a stable carbon and nitrogen isotope analysis of human bone from the Az-71 and Pica-8 archaeological sites in northern Chile tell us about resource and landscape use in the Late Holocene? And do the results of such an analysis confirm currently held theories in this region?

In addition to the primary research questions it is also necessary to address some subsidiary questions for this research project as they affect the success of the research. The subsidiary questions are as follows:

- What does the isotope analysis tell us about the reliance on marine foods at these sites?
- How does the isotope analysis compare with the archaeological record?
- What does the diet of these populations tell us about the introduction of agriculture?
- What do changes in diet tell us about the degree of interregional social interaction between populations inhabiting the hyperarid coast and inland oases?
- What issues impinge upon isotopic interpretation in this region?

In this research project the transition from hunting and gathering to agriculture will be explored using isotope analyses. By looking at the diet of these people it is
possible to not only tell when their diets changed from that of relying exclusively on marine and coastal hunting and gathering resources to agricultural products, but also in what ways they changed. This may lead to additional hypotheses about the transition to agriculture at the site of Az-71.

This research focuses on two sites in Chile: the site of Az-71 in the Azapa Valley, and the site of Pica-8 in the Tarapacá Region. Both of these sites have yielded archaeological evidence for dietary shifts among the populations throughout the time periods that have been established for the sites.

The archaeological evidence at the site of Az-71, for example, shows signs (such as cultigens, pottery, textiles and metal objects), for a transition from hunting and gathering, with some reliance on marine resources to an agricultural way of life possibly supplemented by terrestrial hunting and gathering. This archaeological evidence cross-referenced with isotope analysis of skeletal material from this research should provide a clearer picture of the subsistence activities of the populations living at the site.

Similarly, the archaeological evidence at the site of Pica-8 reveals a complexity of materials, predominantly textiles and ceramics which, when cross-referenced with isotope analysis may give clues as to what kind of practices this population was undertaking and the diet of these ancient people during the transition to agriculture.

1.3 Significance

This research is significant as it looks at key issues concerning diet and landscape use in the Late Holocene using stable carbon and nitrogen isotope analysis of human bone collagen from two northern Chilean sites. Isotope studies in Chile are rare, with only a few cases being represented in the international literature (Barberena et al. 2009:128). Accordingly, this research project aims to contribute to the international literature in this field as well as providing more baseline data for other studies in the area.
The study, however, also has a wider significance in that it studies the transition from hunting and gathering to agriculturalism in an area where there is archaeological evidence for cultural and technological changes. Stable carbon and nitrogen isotope analysis may contribute to the development of new or revised models for the transition to agriculture in these regions as it provides an independent source of data.

1.4 Thesis Outline

This chapter details the aims, research questions, significance, study area and relevant cultural phases to the archaeological sites in this project. It introduces the concepts and background that will form the basis of this study.

Chapter 2 evaluates the research by reviewing the relevant literature pertaining to the analysis of the diets of past populations. It includes an examination of the ways in which diet can be an indicator of social, economic and cultural change within a population. This section also covers the transition from hunting and gathering to agriculture, changes in the diet and health following the transition to agriculture and an isotope analysis background and literature review. These key concepts lay the foundation for this study and aid in contextualising the final results.

Chapter 3 provides an overview of the methodology used during the laboratory analysis of this research project. It details the bone sampling collections and permissions, preparation of the bones for stable carbon and nitrogen isotope analysis and the mass spectrometry analysis.

Chapter 4 provides a summary of the results of this study, in table and graph format, with reference to other isotope results from a broader regional context.

Chapter 5 is a discussion about the stable carbon and nitrogen isotope analysis results for the sites of Az-71 and Pica-8. These results are cross-referenced with
the archaeological evidence, as well as theories concerning the resource and landscape use within the broader Chilean region.

Chapter 6 concludes this thesis by revisiting the research aims and conclusions drawn from the results. It summarises the findings of the study and its implications for future isotopic studies in Chile.

1.5 Background

1.5.1 The Study Area

The Atacama region in southern Peru and northern Chile is one of the driest places on earth, receiving less than 1mm of rainfall per year (Latorre et al. 2005; Marquet et al. 1998; Marquet et al. 2002; Ramírez et al. 2001:7). Despite these harsh conditions early hunter-gatherers settled the area over 11,000 years ago (Dillehay 2008:33; Núñez et al. 2002; Osorio et al. 2011; Sandweiss et al. 1998; Santoro et al. 2005b; Santoro et al. 2011b). According to palaeoclimatic modeling conducted by Ramírez et al. (2001:6) the climate of the Atacama region has remained “more or less unchanged” with very little rain over the last 10,000 years. Consequently, according to this model, early agriculturists must have been dependent on water run-off from higher elevation precipitation and snowmelt rather than on local rainfall, as is still the case today (Ramírez et al. 2001:6).

However, palaeo-environmental reconstructions by Latorre et al. (2005:77) indicate results that are at odds with that of Ramírez et al. (2001). Their reconstructions reveal that at approximately 14,000 to 10,000 years ago there was an increase in precipitation, resulting in wetter conditions in the northern Atacama Desert. This was followed by a series of small fluctuations in the precipitation levels over the Holocene, resulting in a drier Late Holocene and leading on to the conditions of today. Although these variations were not largely different from those of today, they still guaranteed that more water resources were available to past populations, enabling their survival (see Arriaza et al. 2008; Latorre et al. 2003, Latorre et al. 2005; Nester et al.
2007; Roberts et al. in preparation; Santoro et al. 2011b). Though, it is possible that discrepancies in the palaeo-environmental records might reflect different moisture sources and mechanisms of precipitation in the area (Latorre et al. 2005:89).

One possible reason for these climatic fluctuations may be that the area was experiencing the effects of the El Niño Southern Oscillation. El Niño Southern Oscillation (ENSO) is a climatic pattern that occurs across the tropical Pacific Ocean, characterised by variations in the tropical eastern Pacific sea surface temperature (SST) and air surface pressure in the tropical western Pacific (Williams et al. 2008:246). There are two variations: the El Niño Phase, which is the warm oceanic phase that accompanies high air surface pressure in the western Pacific, and the La Niña Phase, which is the cold oceanic phase that accompanies low air surface pressure in the western Pacific (Williams et al. 2008:246).

The onset of ENSO on the western South American coast around 6,000 to 5,000 B.P. reduced the upwelling of the nutrient-rich, cold Humboldt Current, which flows north up Chile’s coast, with warmer Pacific water flowing south from the equatorial regions (Roberts et al. in preparation; Sandweiss et al. 1996; Williams et al. 2008). Williams et al. (2008:247) state that in northern Chile ENSO

...events are recorded as having a major impact on the coastal waters, causing the collapse of local fisheries, mass mortality of marine organisms and birds, red tide, torrential rainfall, erosion of coastal lowlands and widespread flooding.

The intensification of the current ENSO cycle, after approximately 3,700 cal B.P (Moy et al. 2002), is reflected in a decline in the use of the desert coast after 3,000 cal B.P. due to the major effects on the marine biomass. This consequently led to a greater use of the interior Atacama (Williams et al. 2008:247). According to Williams et al. (2008:248) there was a “critical tipping point” for hunter-gatherer societies in the Atacama Desert and along the coast, which led coastal
populations to become more reliant on a mixed agricultural/marine economy, due to a major collapse of coastal fishing systems after approximately 2,500 cal B.P. The time periods of some of the climatic changes discussed above are relevant to the temporal periods under investigation in this research project as further detailed below.

1.5.2 Cultural Phases Relevant to this Project

This research project looks at three time periods relevant to the Azapa Valley and Tarapacá region of Chile. The relevant cultural phases to the Azapa Valley are both of the Formative Period phases: the Azapa Phase (c. 4,000-2,500 B.P.), and the Alto Ramírez Phase (c. 2,500-1,500 B.P.) and the Middle Period, Tiwanaku cultural phase (c. 1,500-1,000 B.P.), as well as the Cabuza and Maitas-Chiribaya Phases. These are followed by the Late Intermediate Period phases, which, for the Arica region, include San Miguel, Pocoma and Gentilar (c. 1,050-600 B.P.) (see Table 1).

For the Tarapacá region, where the site of Pica-8 (c. 1,050-500 B.P.) (Uribe et al. 2007) is located, different cultural phases have been defined. The early Formative (c. 3,000-2,000 B.P.) is associated with Ramaditas and Guatacondo habitation and farming centers, located in the southeast border of the Pampa del Tamarugal basin. These complexes stand as the most important sedentary node for the early Formative Phase (Rivera 2005). One of the diagnostic potteries for the Early Formative Period of Tarapacá is known as the Loa Café Alisado, and features pottery vessels with thicker lips (Uribe 2009). Uribe (2009) also notes that Quillagua Tarapacá Café Amarillento, or QTC, is the most common pottery type for this epoch and was used in both domestic and funerary contexts. Caserones 1, a larger village, was the most important center for this epoch, located in the northeast border of the Pampa del Tamarugal basin.

No Middle Period evidence related with Tiwanaku has been found in the Pica region, with the exception of a few Tiwanaku vessels found at Pica-8 (Zlatar 1984). For the Late Intermediate Period Uribe et al. (2007) defined two
phases: Tarapacá (c. 1,050-700 B.P.) and Camiña (c. 700-500 B.P.). The latter showing a wider range of interregional interaction that included the coast as well as the highlands, which was not part of the sphere of interaction during the Tarapacá Phase.

However, Rivera (1991:964) points out that features of the Alto Ramírez Phase have been found throughout the Azapa Valley as well as inland in Tarapacá. Furthermore, according to Núñez (1982), the whole Alto Ramírez sequence seems to be corroborated in the Tarapacá region, but with different cultural components, as discussed by Uribe et al. (2007).

The altiplano influences began in the Late Formative Period (c. 2,500-1,500 B.P.) but spread more intensively throughout the Andes and the Azapa Valley in the Middle Horizon Period (c. 1,500-1,000 B.P.) (Rivera 1991:28). The altiplano influence for the Tarapacá region is noted during the Late Intermediate Camiña Phase, but not before (Uribe 2009; Uribe et al. 2007). However, it is pertinent to start with an overview of the Chinchorro Culture as a background for the latter cultural phases discussed in this thesis.
Table 1: Summary of chronological periods relevant to the Azapa Valley and Tarapacá areas outlined in this paper.

<table>
<thead>
<tr>
<th>Time Period (BP)</th>
<th>Period</th>
<th>Azapa Phases</th>
<th>Tarapacá Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>c. 10,000-8,000</td>
<td>Early Archaic</td>
<td>Early Chinchorro</td>
<td>Tiliviche</td>
</tr>
<tr>
<td>c. 8,000-6,000</td>
<td>Middle Archaic</td>
<td>Chinchorro</td>
<td>Tiliviche</td>
</tr>
<tr>
<td>c. 6,000-4,000</td>
<td>Late Archaic</td>
<td>Late Chinchorro</td>
<td>Tiliviche</td>
</tr>
<tr>
<td>c. 4,000-1,500</td>
<td>Formative</td>
<td>Azapa Phase (4,000–2,500)</td>
<td>Ramaditas (3,000–2,000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alto Ramírez (2,500–1,500)</td>
<td>Caserones 1 (1,750–1,170)</td>
</tr>
<tr>
<td>c. 1,500-900</td>
<td>Middle Horizon</td>
<td>Cabuza</td>
<td></td>
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<tr>
<td></td>
<td>(Tiwanaku polities</td>
<td>Maitas-Chiribaya</td>
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<td></td>
<td>expansion)</td>
<td></td>
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<tr>
<td>c. 1,000-660</td>
<td>Late Intermediate</td>
<td>San Miguel, Pocoma, Gentilar</td>
<td>Tarapacá (1,050–700)</td>
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<td></td>
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<td>Camiña (700–500)</td>
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<tr>
<td>c. 660-476</td>
<td>Late (Inka Empire)</td>
<td>Chilpe (Black/Red), Inka Pacaje (Saxamar)</td>
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The Chinchorro people were one of the first groups in the Arica region, during the Middle Archaic Period (c. 8,000-6,000 B.P.). The Chinchorro (c. 8,000-4,000 B.P.) were specialised hunter-gatherer-fishers, who relied heavily on the exploitation of marine resources (Alfonso et al. 2007; Arriaza 1995; Rivadeneira et al. 2010). They are famously known for practicing the oldest mummification in the world, beginning around 9,000 years ago and lasting for almost four thousand years (see Allison et al. 1984; Arriaza 1988, 1995; Arriaza et al. 2008:45; Arriaza and Standen 2002; Aufderheide 1993; Bittmann and Munizaga 1976; Standen and Santoro 2004).
Figure 2: Black style Chinchorro mummy from El Morro archaeological site in Arica, stored at the Museo Arqueológico Universidad de Tarapacá, San Miguel de Azapa. Photo courtesy of Christopher Carter.

The Chinchorro have been classified as “desert people” (Santoro et al. 2011b:6; Smith et al. 2005) who inhabited a strip along the coast of the Atacama. However, they are regarded as unique in this category, due to their primary means of subsistence being marine foods, with terrestrial vegetable and game food being marginal in their diet (Aufderheide 1993; Schiappacasse and Niemeyer 1984). However, during the transitional phase, toward the Early Formative Period
(c. 4,000-2,500 B.P.), the descendants of the Chinchorro people saw the incipient use of cultigens such as squashes, sweet potatoes, achira, beans, manioc, gourd and quinoa, in the Azapa Valley (Núñez and Santoro 2011; Rivera 1991:15; Santoro et al. in preparation).

The Azapa Phase of the Early Formative Period (c. 4,000-2,500 B.P.), which was a transitional period between the end of the Chinchorro Phase and the start of the Alto Ramírez Phase (Late Formative), demonstrated a continuity of the traditional coastal way of life into the new social formation of the Formative Period (Núñez and Santoro 2011; Santoro 1980a) coupled with a single biological human group that evolved from the Early Archaic to the Formative (Manríquez et al. 2011). The Azapa and Alto Ramírez archaeological sites are all located inland in the Azapa Valley (Sutter 2000:49). Theories about the inhabitants of these sites suggest that a mixed agro-pastoral and maritime subsistence was practiced (Muñoz 1980, 1981; Núñez and Santoro 2011; Santoro 1980a, 1980b). Archaeological evidence, in the form of coastal handicrafts, crop and burial and residential patterns indicates that around 4,000 B.P. the people of the Azapa Valley experienced cultural changes stemming from the arrival of immigrants from the Altiplano (Varela et al. 2006:186). These Altiplano influences led to the agricultural maritime societies of the Formative Period that are seen around 3,000 B.P. (Rivera 1991; Varela et al. 2006:191). The Azapa and Alto Ramírez groups from the Formative Period did not mummify their dead, as their predecessors the Chinchorro did, but buried them in a flexed position with funerary offerings such as body ornaments, woollen blankets, turbans, ceramics, metallurgy, trophy heads and tools for hallucinogen inhalation (Santoro 1980b:49; Varela et al. 2006:187). Romero et al. (2004:266) also note that chili pepper, cotton, beans and squash crops are found in these Azapa and Alto Ramírez tombs. Imported highland items such as potatoes, pottery, textiles and metal objects are also evidenced in these tombs (Muñoz 2004; Ponce 2010:160; Varela et al. 2006:192). In particular it is during this epoch that we encounter the introduction of exotic elements that originated in the tropical forests such as sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*), and achira (*Canna edulis*), seeds used as beads,
coloured feathers of tropical lowland birds and hallucinogenic products. The social mechanisms to explain the introduction of these items on the coast and valley of northern Chile remain uncertain (Rothhammer et al. 2009).

The combination of external influences, probably from around the Titicaca basin and beyond, and the previous coastal Chinchorro way of life with its societal organisation and ideological principles may have led to a new cultural tradition based on a coastal population that integrated both biological and external cultural influences. As a consequence, the Atacama Desert coastal societies became further integrated into important and wider territorial social networks through trade, colonisation, conflicts and marriage (Núñez and Santoro 2011; Santoro et al. 2011b).

Alto Ramírez society was based on an economy different from that of the earlier Chinchorro tradition. The Alto Ramírez cultural groups show stronger connections with the highlands in north Chile and the circum Titicaca region (Aufderheide et al. 1994:516). The Alto Ramírez Phase (c. 2,500-1,500 B.P.) introduced new agricultural technology to the Azapa Valley, bringing their highland practices of agriculture and products of pastoralism (wool, meat in the form of charqui, dried meat) to the lower valley sites (Aufderheide et al. 1994:515). These agriculturalists had irrigated land, which allowed the production of certain cereals and vegetables. Intensive irrigated agriculture included foods such as quinoa, maize, hot peppers, beans, squashes and gourds (Rivera 2008:964). These resources were complemented by highland products such as meat and wool and jerky from camelids in the highlands (Rivera 1991:21). Consequently, this new agricultural technology enabled the production or access to specialised foods and goods, creating a complex system of resources for the Azapa Valley populations. Thus, population increase was a consequence of the food surplus from their agricultural technology (Rivera 2008:964), and the maintenance of marine resources (Núñez 1969, 1983, 1999).
The last Azapa Valley cultural phase relevant to this research project is the Tiwanaku cultural phase. The interaction with Tiwanaku polities in the circum Titicaca began in the Late Formative Period (c. 2,500-1,000 B.P.) and spread more intensively throughout the Andes and the Azapa Valley in the Middle Horizon Period (c. 1,500-1,000 B.P.) (Rivera 1991:28). The Tiwanaku Phase represents the first political integration of the area with competition and cooperation between Tiwanaku polities and other social groups in the area (Rivera 1991:29). The social mechanisms to explain the relationship between people in the valleys of Arica and the Tiwanaku confederated polities are currently uncertain and debated, and are not well represented in the Tarapacá region.

The Middle Period phases: the Cabuza and the Maitas-Chiribaya, and the Late Intermediate Phase cultures: the San Miguel, Pocoma and Gentúlar are well represented in the Azapa valley, while in Tarapacá other cultural features were contemporaneously developed (see Table 1). The Cabuza Phase (c. 1,500-1,250 B.P.) heralds the beginning of Tiwanaku influences. It consists of black-on-red ware kero shape bowls and jars with geometric designs. It is at this time that flexed bodies covered in woollen shirts in a bundle fashion replace the more traditional burial mounds (Rivera 2008:966). A number of other features such as woodcarving, leatherwork, gold and silver metalwork and basketry are all evidenced in the archaeological remains for this time period (Rivera 2008:967). Rivera (2008:968) also notes that the villages of this archaeological culture phase contain large numbers of storage rooms, suggesting "intensive economic redistributive practices." The location of Cabuza sites during this time are thought to further suggest a preference for areas best suited to irrigated cultivation rather than the earlier coastal sites (Rivera 2008:968).

Following the Cabuza archaeological culture phase, the archaeological record demonstrates continuity into the later developments such as the Maitas-Chiribaya. These developments are Tiwanaku in influence but also represent a more local influence in the area (Rivera 2008:970). In the western valleys of northern Chile, the Maitas, or Maytas, (c. 1,250-950 B.P.) is characterised by
pottery illustrating triangles, undulating lines and concentric geometric black and white designs on red slip (Rivera 2008:970). The Chiribaya archaeological culture phase is very similar in style to the Maitas, hence the joining of the two phases: the Maitas-Chiribaya. This style is found in the far north of Chile and the far south coast of Peru and has an emphasis on white lines of successive dots along black designs, with more concentric panels divided into between four and eight sections (Rivera 2008:970).

The Late Intermediate (c. 1,000-660 B.P.) archaeological culture phases: the San Miguel and Gentilar successive phases have ceramic styles with polychrome designs and also further illustrate a final transition style known as the Pocoma style. The San Miguel style (c. 950 B.P.) has been evidenced to correspond to big globular water jars with flat bases, vertical handles and narrow necks (Rivera 2008:971). Keros and vessels with modeled figures on the rim and anthropomorphic and zoomorphic vases were also popular during these phases, with geometric motifs painted in black or red with black on white slipped surfaces (Rivera 2008:971). The Gentilar Phase (c. 660 B.P.) heralds what is thought to be a better quality and thinner pottery with black, white and red geometric, anthropomorphic and zoomorphic designs on a smooth red slip (Rivera 2008:972). Finally, the transition to the Pocoma style demonstrates panels with a light red colour as the background and separated by vertical lines (Rivera 2008:972).

In contrast, in the Tarapacá region during the Late Intermediate Period, the Pica Tarapacá Complex is identified with two phases: Tarapacá and Camiña. Societal groups during this epoch controlled from the coast to the high Andes, with their main habitation centered between the quebrada of Camiña and the oasis of Pica.

Within this territory the Tarapacá people developed a mixed economy that integrated farming, herding and the collection of wild plants (i.e., Prosopis sp.), and they shared common cultural patterns expressed in pottery and textile styles (Agüero 1998; Uribe et al. 2007). The movement of goods transported from different ecological floors mark intense regional interaction. This Late
Intermediate cultural tradition stemmed from the Formative Period without the interruption of Tiwanaku, absent in the Tarapacá region. The Formative Period implied the occupation of habitats located at the mouth of the *quebradas* that merge on the eastern border of the Pampa del Tamarugal basin. Both textile and pottery styles demonstrate local elements with minimal influence from the altiplano (Uribe 2009). These features are common and show strong continuities from coastal cultural traditions, which indicate that the first farmers of the Tarapacá region were originally from that particular zone (Agüero 1998, 2000; Uribe 2009; Uribe *et al.* 2007).

### 1.5.3 The Azapa Valley and the Tarapacá Region

![Figure 3: Map showing the locations of the AZ-71 and Pica-8 sites. Map courtesy of Google Maps.](image)

The sites of Az-71, located in the Azapa Valley, and Pica-8, located in the Tarapacá Region (see figure 3) are approximately 330km apart. However, they
both share similar environments, being located on fertile plains and oases in the Atacama Desert of Chile.

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). Prehistoric inland agriculturalists adapted to this valley environment by developing intensive agriculture, farming and herding (Ponce 2010:160). In spite of the scarcity and quality of the water in the Azapa Valley, the environment’s unique climate permitted intensive cultivation on the thin strips of fertile soil adjacent to the river, providing a variety of fruits, vegetables and cereals throughout the year (González et al. 1999:7).

![Figure 4: Satellite image of the Azapa Valley in the landscape. Image courtesy of Google Maps.](image)

The earliest archaeological evidence for the lower section of the Azapa Valley is dated to around 3,500 B.P. These remains include a hearth associated with pottery, some cultigens and marine food, at the site of Az-71 (Santoro 1981). Early evidence along the southern slope of the mouth of the Azapa, as well as the coastal area north and south of the mouth contain evidence corresponding to the
Chinchorro culture (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 (see Rivera 2008; Santoro et al. 2005b).

**Figure 5:** Archaeological sites in the Azapa Valley from Sutter (2000).

The site of Az-71 is located in the Azapa Valley, 12km inland, adjacent to the present day village of San Miguel de Azapa and was excavated in 1977-1978 by Calogero Santoro and his team (Santoro 1980a). The cemetery started to be used around 3,500 B.P. and continued up to approximately 700 B.P. The site 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 3,350-2,560 B.P. for the Early Formative Period and 1,010-490 B.P. 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) (see Appendix C for radiocarbon dating tables).

At the site of Az-71 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 with the Azapa Valley (Munoz 1980, 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. 100 m²), 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 of 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). 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, has the potential to provide an independent line of information about these ancient people.

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 have done thousands of years ago. There are five radiocarbon dates for the site of Pica-8, which span between 1,150-900 B.P. 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) (see Appendix C for radiocarbon dating tables).

![Figure 6: Satellite image of Pica in the landscape. Image courtesy of Google Maps.](image)

The site of Pica-8 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 principle 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 into the site of Pica-8 examine the interaction between the coastal and inland people of the Atacama Desert. Colonial (since the 16th century AD), archaeological and paleo-parasitological 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 in 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 patterns has been suggested. While, for later groups (from the Formative Period on) a wide array of mechanisms of interaction and complimentarity 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 micro verticality, 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 (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 (see Santoro et al. 2011a). Since the Formative the introduction of marine products in farming villages is a common issue (Núñez 1982; Rivera 2005; Uribe 2009, Uribe et al. 2007), and remained active until colonial times (Bermúdez 1980; Villalobos 1979).
2 CHAPTER TWO: LITERATURE REVIEW

2.1 The Transition from Hunting and Gathering to Agriculture

...the period where humans shifted from being subject to changes in the natural environment, to become the agents of environmental change in which the natural world is modified to suit human needs (Pinhasi and Stock 2011:1).

The transition from hunting and gathering to agriculture largely took place in the first half of the Holocene, between 10,000 to 5,000 B.P., in different areas around the world. The earliest evidence reflecting the precursor to agriculture is in the Levant region of the eastern Mediterranean, during the late Epipalaeolithic “Natufian” Period (c. 14,500-11,600 cal B.P.) (Pinhasi and Stock 2011:2). Extensive exploitation of wild grains, the use of grindstones, organised social structures and evidence for symbolic behaviour have been interpreted as the earliest evidence for the transition to agriculture (see Belfer-Cohen and Bar Yosef 2000; Pinhasi and Stock 2011:2).

The transition to farming is further reflected in the Anatolian site of Abu Hureya at c. 13,000 B.P. and is believed to be associated with the dramatic environmental cooling associated with the Younger Dryas climatic event, which signaled a decline in the wild plants of the area (Hillman et al. 2001; Pinhasi and Stock 2011:2). Plant domestication also became prominent in areas such as southern China, New Guinea, Ethiopia, southeast North America, Meso-America and western South America in the first half of the Holocene (Bellwood 2005; Pinhasi and Stock 2011:2).

Despite the transition to agriculture taking place across the globe, it is unlikely that agriculture began the same way, or for exactly the same reasons, in the different geographic regions. Kent Flannery (1973:283) poses the key question:
...if hunting and gathering was the most stable adaptation man (sic) ever had, why did he (sic) ever give it up for a life of toil in the wheat fields?

Some of the early hypotheses for the transition from hunting and gathering to agriculture focused on prime movers for the advent to agriculture, such as climate change (Childe 1936, 1952; Willey 1966; Wright 1977) and population pressure (Binford 1968; Cohen 1977).

Climatic changes, such as sudden severe increases or decreases in temperature lasting decades, or even centuries, have been proposed as the cause of agriculture (Willey 1966; Wright 1977). For example, the shift from a continental to Mediterranean climate on the eastern Mediterranean coast created more diverse vegetation, with a dramatic increase in annual cereal grasses that eventually spread across the continent (Weiss et al. 2004:9551). Flannery (1986:10) believes that while climatic changes at the end of the Pleistocene may not have necessarily caused agriculture, they did create conditions that were favourable for a suite of new plants to colonise the region, thus, making them accessible for thousands more of the general population.

Archaeologist Mark Nathan Cohen (1977) hypothesised that strategies for increasing food supply, within the constraints of hunting and gathering, had been exhausted by around 10,000 years ago in some parts of the world, thus leaving no alternative but to turn to agriculture. Cohen's (1977) theory was based on the idea that it was worldwide population pressure that caused many hunter-gatherer societies to transition to agriculture, due to the populations reaching the limit of what their food resources could support. Further, Cohen (1984:2) cites a population and resource theory, inspired by economist Ester Boserup (1965), which looks at whether cultural change was stimulated by demographic shifts among hunter-gatherer societies, saying that:

...the adoption of marine foraging and small seed processing, like the latter (sic) adoption of farming, represented a compensation for a growing population.
Alternatively to Binford, Cohen and Boserup’s theories, Flannery (1986:11) believes that these hypotheses cannot be applied to smaller agricultural populations, as they do not fit the profile of the situation. He believes that phrases such as ‘overpopulation’, ‘food crisis’ and ‘exhaust all possible strategies’ to describe small populations, such as the populations he worked with in highland Mexico, are exaggerations. The actual number of people per square mile in some areas does not suggest this at all. However, Flannery (1986:12) posits a multivariate model, which cites a combination of some of the defensible parts of these theories, and argues that:

...by 10,000 B.P., all the world’s major landmasses had been populated to the point where (even though the actual densities might not have been that high) emigration had been considerably reduced as a strategy for adjusting man-land (sic) relationships.

Following these early theories a number of social theories were put forward. These included theories encompassing increasing social complexity and competition (see Bender 1985; Hayden 2003). An example of a social theory is Bender’s (1985) hypothesis. She recognises that hunter-gatherer societies were becoming more socially complex, with far more elaborate hierarchical social organisation. She points to the increasing abundance of trade objects and takes this as evidence that an expansion of trade, and of political alliances between neighbouring groups, created new social and economic pressures to produce more and more surplus goods (Bender 1985:53). Although this theory can explain the development to a more sedentary lifestyle it completely ignores climate change as a contributing factor.

This is similar to Hayden’s (2003) social competition hypothesis, which proposes that competition within hunter-gatherer societies may have been one of the causes of the transition to agriculture. Hayden (2003) believes that ambitious individuals wanting to acquire prestige and social standing by throwing feasts may have created competition between groups, leading to the eventual adoption of cultivation to provide supplies for these events.
However, these theories fail to take into account that many early Holocene hunter-gatherer societies were more complex and pre-adapted to food production before the advent to agriculture. By using a multivariate model to encompass key aspects of all of these theories, the transition from hunting and gathering can be more thoroughly explored.

It is also important to point out that not all populations followed the transition from hunting and gathering to agriculture. An example of this are the various Australian Indigenous populations who never adopted agriculture and continued their hunting and gathering lifestyle to near recent (and in some cases contemporary) times. Similarly, the !Kung San people of northern Botswana, Africa, moved between hunting and gathering and agriculture in times of stress (see Lee 1979). Santoro et al. (2005a:256) note that marine collecting, fishing, plant collection and hunting were also important aspects of the diets of the people of the inland Atacama until later times, and often complemented an agricultural diet. These are just a few examples that demonstrate that the transition from hunting and gathering to agriculture was neither inevitable nor irreversible. Indeed, it was a technique that could be employed, where climatic, geographic, cultural and ecological conditions permitted. This is not the case along the hyperarid coast of the Atacama, where although farming products were certainly part of the way of life of the coastal people since the Late Archaic, they were not produced locally but obtained through mechanisms of exchange (Santoro et al. 2011b). As a result, isotope analyses can be crucial to understanding the impact of farming products along the coast, and how people managed to obtain them through time.

On a final note, the transition from hunting and gathering to agriculture has often been seen as a cultural progression by those who adhere to unilinear theories of cultural evolution. These theories originally stemmed from Julian Steward’s (1940) theory of a multi-linear evolution, encompassing the variation in evolutionary lines, but as time went by, progressed further and further into a unilinear theory of evolution, emphasising a single sequence of stages.
In unilinear evolution models “descent with modification” was no longer a grounding concept and therefore cultural change that was not seen as transitional was considered irrelevant “drift”. Isbell (2008:1139) describes this perfectly with an analogy, by stating that the “drift” permitted “extraneous variations to accumulate, like different word pronunciations as languages separate through time”. The problem with unilinear evolution models, and even some more flexible models based on them, is that the emphasis on a single sequence of stages, from one stage to another, puts those societies that choose to stay the way they are and not, for example, transition to agriculture, on a lower level than those who do. This is despite the fact that not all societies found it necessary to transition, having enough resources to support themselves without labour-intensive agriculture. Thus, unilinear cultural evolution models focus on ideal cultural types conforming to a set sequence of stages and the progression from one through to another (Isbell 2008:1139).

Studies conducted around South America over the past few decades reveal the inadequacy of unilinear evolutionary models by demonstrating the significant social variability among South American populations. Despite the fact that these populations have evolved in size, organisational complexity and technological sophistication, they do not conform to unilinear theories of evolution (Isbell 2008:1139). From this, students and scholars need to recognise that these unilinear theories of cultural evolution have been particularly damaging for many Indigenous peoples, conforming to ideas that they were lower or lesser forms of life on the evolutionary ladder (Roberts 2003:28). Further, the Indigenous scholar, Vine Deloria (1995:64-65) has critiqued these theories by stating that by “…wrapping cultural evolution so tightly, with a foreordained conclusion laudatory of Western accomplishments, tribal peoples were given a marginal status as human beings.”
2.1.1 Recent Studies Conducted Concerning the Transition to Agriculture

Research into the transition from hunting and gathering to agriculture has been pursued over the last few decades by archaeologists looking at palaeo-botanical and palaeo-faunal evidence found at archaeological sites. While this type of evidence does give clues as to what the population was consuming, it is far removed from the actual consumption of the types of foods that people were eating and the quantities of foods that were being consumed by the population. In the past decade bioarchaeological studies and isotope analyses of skeletal material at archaeological sites have been able to reveal a great deal more about the subsistence strategies of the population and therefore change views on the transition to agriculture. Bioarchaeological analysis of the skeleton can reveal the skeletal biomechanics and evidence for variation in habitual behaviours, as well as evidence for genetic adaptation relating to Holocene cultural change (Pinhasi and Stock 2011:6). The integration of isotope analyses with other various lines of evidence relating to agricultural transitions will provide new insights and generate new questions about the transition from hunting and gathering to agriculture (Schulting 2011:34). Isotope analyses are particularly useful as they provide direct dietary evidence for populations and can reveal changes in subsistence strategies within sedentary populations.

While very few isotope studies have been conducted in the Atacama Desert of Chile, they have been used at other sites around the world and have provided very useful information concerning questions about the transition to agriculture. One example of an isotope study that looks at the diet of populations and the transition to agriculture is a study conducted by archaeologist Rick Schulting (2011) on the Mesolithic to Neolithic transition throughout Europe. This study looks at the isotopic evidence from both of these periods in order to better understand aspects of the diets of the people of these periods and to investigate the transition between them (Schulting 2011:17). From examining the isotopic record of the two periods Schulting found evidence for a shift from regional isotopic and dietary heterogeneity in the Mesolithic Period, towards relatively
homogenous isotopic signatures throughout Europe. However, Schulting (2011:33) points out a key issue with the isotope analysis, stating that isotopic “...homogeneity does not necessarily equate with dietary homogeneity”. This is because, although the isotope results may not show statistically valid differences, the population at a site may still have been eating slightly different foods. Thus, many of the Neolithic populations analysed show limited isotopic variability but may still have had slightly different diets. Although there is a clear shift away from the preceding subsistence practices emphasising marine resources, the nature of the subsistence strategy that replaced these practices is not identified in the isotopic record (Schulting 2011:33). However, Keegan (1989:224) points out that the role of isotope analysis is to provide:

...a method for testing and refining dietary reconstructions that are generated from the interpretation of other sources of evidence.

This is one such example where the isotopic evidence, used in conjunction with archaeological or other forms of evidence may aid in providing a more holistic picture of the lifeways of the past populations at a site.

One of the first examples that illustrates the use of isotope studies to describe the transition to agriculture at a site is by Schwarcz et al. (1985). Schwarcz et al. (1985) isotopically examined the carbon and nitrogen content of human skeletal remains from nine geographically distinct archaeological sites, representing 13 occupations, in southern Ontario. The dates for these populations ranged from c. 4,250 B.P.-314 B.P., with the earlier sites being occupied by hunter-gatherers and the later sites having evidence of cultivation of native plants, as well as cultivation of the imported foods: maize, beans and squash (Schwarcz et al. 1985:191). At these sites there was archaeological evidence indicating the introduction of maize to southern Ontario around 1,250 B.P. and the introduction of beans around 850 B.P. (Yarnell 1976). The skeletal remains were analysed to examine the mean carbon isotopic composition of the diet of the natives and see whether there was a shift in the δ13C values of their diets after the introduction of maize (Schwarcz et al. 1985:188). As well as this
the diets of these populations were examined to observe whether the introduction of beans, found in the archaeological evidence, affected their diets causing a decrease in the $\delta^{15}$N content of human bone collagen, as legumes are deficient in nitrogen, compared to meat and fish. The results from this study indicated that the pre-agricultural peoples at these sites consumed predominantly C$_3$ plants and animals that were consuming C$_3$ plants (see Literature Review chapter for overview of plant pathways). It was also noted that between c. 1,550 and 950 B.P. there was a notable increase in the C$_4$ content of the human diets coinciding with the gradual introduction of maize. However, there was no significant change in the nitrogen levels of the human bone collagen at these sites. Consequently, although beans were introduced around 850 B.P. they did not figure prominently as a protein source in the populations’ diets, with meat and fish still being the main sources of protein even after the advent to agriculture in this region (Schwarcz et al. 1985:203).

2.1.2 The Transition from Hunting and Gathering to Agriculture in the Azapa Valley and Tarapacá Region

Figure 7: Agriculture in the Azapa Valley today.
Agriculture is first noted in the Azapa Valley in the Early Formative Period (c. 4,000-2,500 B.P.), which sees the final phase of the Chinchorro Culture, where incipient use of cultigens can be observed (Núñez and Santoro 2011; Ramirez et al. 2001:8; Santoro 1980a, 1980b). Remains of cultivated achira, beans, gourd, squash, sweet potatoes, manioc and quinoa are all present in the archaeological record of the Azapa Valley at this time (Rivera 1991:10; Rothhammer et al. 2009; Santoro et al. in preparation).

During the Formative through to Late Intermediate Periods (c. 3,500-700 B.P.) there is a transition from primary dependence on marine-based hunting and gathering to irrigation agriculture (Núñez and Santoro 2011; Ramirez et al. 2001:8). That some changes were taking place as early as 3,600 B.P. is suggested by the abandonment of artificial mummification by the Chinchorro and the introduction of agricultural products by other coastal groups at this time (Arriaza 1995:157; Santoro et al. 2011b).

The transition to agriculture in the Tarapacá region is far less clear than that of the Azapa Valley, with limited archaeological studies being conducted in the area. However, according to the Pica-8 Pre-Hispanic Cemetery (Zlatar 1984) artefact catalogue, a wealth of textiles and ceramics at the site are thought to evidence agriculture (Uribe 2009), due to the introduction of ceramics (c. 3,000 B.P) coinciding with the introduction of agriculture around Chile (see Núñez and Santoro 2011).

### 2.2 Changes in Diet and Health Following the Transition to Agriculture

Bioarchaeological and palaeopathological evidence from sites around the world indicates that there were often changes in the health of populations after the introduction of agriculture. Numerous theories have been posited as to why the health of the populations changed and whether this was good or bad for the societies in which the people lived (see Cohen 1989; Pinhasi and Stock 2011). Adjustment to sedentism comes with the advantages of food storage
possibilities, reduced travel stress on infants and the elderly, and an intimate knowledge of the local environment and its resources (Benfer 1984; Cohen 1989; Pinhasi and Stock 2011). However, some negative effects associated with sedentism are that large populations remaining in one location invite new health risks through contaminated water and food supplies, as well as the spread of infectious diseases, seasonal crop failure and dependence on limited food sources (Allison 1984; Aufderheide et al. 1993; Goodman et al. 1984; Pinhasi and Stock 2011).

One case study that describes the ill health effects suffered by a population after the transition from hunting and gathering to agriculture is the case of Dickson’s Mounds, Illinois, USA. Goodman et al. (1984:272) outline the physical indicators of stress that were found from 595 burials excavated in the field season of 1966 and 1967 at Dickson Mounds. Their research investigated the negative effects of agriculture on the health of a society and found that due to their involvement in “Mississippian-based exchange systems”, such as increased population density and sedentism, intensification of maize agriculture, and extension and intensification of trade, the inhabitants of Dickson’s Mounds suffered negative health effects (Goodman et al. 1984:272). However, these negative affects were predominantly attributed to the lower classes within the society at Dickson’s Mounds. It was found that, after the transition to agriculture there was a split in the classes, with the working class’ health suffering while the elite class’ health was improving (Goodman et al. 1984:300). This was due to the fact that the working class suffered an increase in skeletal stresses from working in the maize fields, and receiving smaller caloric returns for their production efforts, while the elite benefited from not having to work and expel energy but still being able to consume the food being produced. Goodman et al. (1984:300) concluded that the Dickson Mound’s cultural-ecological system does not do well as it is not a closed cultured-ecological system and therefore, it appears that while the stresses of agriculture are absorbed at a local level the benefits are enjoyed at a place outside the local ecosystem.
One case study that points to the ill health effects on a population in South America is work by Allison (1984) on the palaeopathology of 16 populations from Peru and Chile. Allison (1984:519) discovered that, by examining non-specific indicators in bones and teeth, childhood mortality was found to increase within a more complete agricultural economy. However, he also noted that this might have had more to do with the agricultural environment, rather than diet.

Allison (1984:519) also noted that in the early fishing societies of northern Chile there was a more sexually egalitarian society, evidenced by women being buried with harpoons, fish hooks and lines and elaborate string turbans. This was replaced by social stratification with the advent of agriculture, and a separation of duties between the sexes. Thus, due to the differential allocation of duties women were suffering from more severe health effects than the men within the society.

Allison (1984:527) concluded that there was little evidence that farming and the storage of agricultural foods improved the general health of Andean populations. Rather, Allison argued that sedentary village life was disadvantageous to health due to crowding and subsequent sanitation problems associated with village living. Equally, social stratification with an agricultural society only provided an improvement in health for minority elite groups.

Conversely, not all populations were negatively affected by the transition to agriculture. One case that illustrates this point is Benfer’s (1984) study on the challenges and rewards of sedentism in the preceramic village of Paloma, a site on the Peruvian coast, occupied between c. 8,000 and 4,500 B.P. Benfer (1984:531) provides preliminary evidence from studies on many different skeletal indicators, demonstrating a convincing argument for successful adjustment to “the challenges and opportunities of sedentism”. Indicators of health and diet on the bones and teeth of individuals reveal that, while the early inhabitants of Paloma were stressed, subsequent generations improved steadily and adapted to a life of agriculture.
From the case studies presented above, it is evident that the transition to agriculture affected the health of the societies that shifted to it – albeit in different ways. The shift to agriculture for some cultures resulted in social differentiation, which meant that some classes were healthier than others. Nevertheless, in many situations over time populations grew and agriculture took hold, with populations adjusting to the stresses of agriculture and being able to improve their living conditions.

2.2.1 The Osteological Paradox

Alternatively to the former theories by Cohen (1984) and Allison (1984), Wood et al. (1992) suggest that instead of skeletal indicators of disease referring to the ill health effects of the transition from hunting and gathering to agriculture, they signaled the opposite: an improvement in health. This theory was called the Osteological Paradox (see Wood et al. 1992) and is based on the idea that a number of factors, including:

...non-stationarity (sic), hidden heterogeneity, differential frailty and selective mortality can bias the sample of skeletons in a cemetery making it an unrepresentative sample of once living people and rendering conclusions about the impact of economic change on human health unreliable (Wood et al. 1992:344).

Wood et al. (1992:343) also state that the “skeletal evidence pertaining to the transition from hunting-and-gathering to agriculture is equally consistent with an improvement in health and a deterioration in health resulting from the transition.”

However, Cohen et al. (1994:630) refute this by saying that the pattern of increasing infection and pathologies with group size and sedentism “occurs repeatedly in comparisons of historical and modern populations”. Therefore, Cohen et al. (1994:631) believe that it is unlikely that the pathologies in the
agricultural populations were only higher than that of hunter-gatherers because
they lived longer.

Stable carbon and nitrogen isotope analysis may be able to improve information
about the nutrition of the populations by revealing the range of food that the
populations were eating at the sites of Az-71 and Pica-8 and provide comparable
information for any future bioarchaeological studies.

2.2.2 Overview of the Health Effects from the Transition from
Hunting and Gathering to Agriculture

The above case studies predominantly explore the transition from hunting and
gathering to agriculture, and the effects of this on a population’s diet and health
through the archaeological evidence. Isotope analyses, however, as also explored
above have the potential to give archaeologists additional, and independent,
information about the diet and patterns of social interaction of early populations.
Archaeological studies, cross-referenced with isotope studies, can also provide
information about hunter-gatherer spatial organisation, origins and history of
farming and pastoralist societies, migrations, and intra- and inter-group social
differentiation (Barberena et al. 2009:127; Hastorf 1985; Núñez and Santoro

The introduction of agriculture completely changed human lifeways with its
effects on the populations’ health, land use and settlement organisation within
societies. Through stable carbon and nitrogen isotope analysis of human bone
collagen, this research project investigated these changes in the archaeological
record of two Chilean sites: the site of Az-71 in the Azapa Valley and the site of
Pica-8 in the Tarapacá Region in the Late Holocene.
2.3 Isotope Analysis Background and Literature Review

2.3.1 What are Isotopes?

Isotopes are two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei. This means that they each have a different atomic mass, but are more or less chemically identical (Ambrose 1993:64). The composition of stable isotopes is expressed in terms of delta values (δ), which are parts per thousand (‰) differences from a standard. They express the quantity of various isotopes that are in a sample. The values are expressed as:

\[ \delta X = [(R_{\text{sample}} / R_{\text{standard}}) - 1] \times 10^3 \]

where X represents the isotope and R represents the ratio of the isotope of interest and its natural form (i.e., $^{13C}/^{12C}$) (Fry and Peterson 1987:294).

2.3.2 Isotope Analysis Background

The use of stable isotopes for dietary reconstruction is predicated on the assumption that “you are what you eat, plus a few parts per thousand” (Vogel 1978:298). This is based on the theory that the isotopic composition of an animal’s tissue is a direct and constant function of the animal’s diet (Ambrose 1993:60).

Humans metabolise $^{13}$C and $^{15}$N indiscriminately and produce ratios of $^{13}$C/$^{12}$C and $^{15}$N/$^{14}$N that are relative to their diet (Ambrose 1993:83; Pate 1998:23). However, there is usually a fractionation factor, a systematic difference of enrichment or depletion, between the isotopic composition of the consumer tissues and that of its diet (Ambrose 1993:60; Owen 2004:12). In relation to analysis of bone, nitrogen is found only in bone collagen, but is useful in estimating the trophic level of the foods consumed, and in differentiating between diets based on agriculture versus those based on hunting and/or fishing.
activities (Tykot et al. 2009:160). Studies on marine ecosystems have shown that on average there is a 3‰ enrichment of $^{15}$N versus the diet between the different trophic level species in ecosystems (Michener and Kaufman 2007:238). For example, a carnivore’s $\delta^{15}$N values would be approximately 3‰ more positive than that of a herbivore, with this process continuing through the food chain (Schoeninger 1985). As well as this, average $\delta^{13}$C values of the whole body of an animal have been found to be approximately 1‰ more positive than that of the animal’s diet (DeNiro and Epstein 1978.). This fractionation factor can be accounted for by subtracting the fractionation factor from the stable isotope ratio of the consumer’s bones, thus giving a more accurate isotope reading of the diet of the animal (Ambrose 1993:60).

Plants use two photosynthetic pathways in order to create sugars. $C_3$ plants, such as temperate shrubs, trees and many grasses living in cooler climates, and $C_4$ plants such as maize or grasses and herbs found in warmer tropical environments, both contain carbon isotopes in their tissues (O’Leary 1988:330). The first of these pathways is the Calvin pathway, where a three-carbon compound is created, which incorporates $C_3$ grouped plants. The second alternative pathway is the Hatch-Slack enzymatic pathway, which produces a four-carbon compound incorporating $C_4$ grouped plants (Aufderheide and Santoro 1999:244; Slack and Hatch 1967). $C_3$ plants result in more negative isotope values than do $C_4$ plants (such as maize and tropical grasses and herbs), which result in more positive $\delta^{13}$C values within the person’s diet (Pate 1994; Schoeninger and Moore 1992). From these differences in values it is possible to determine the type of plants, $C_3$ or $C_4$, and marine versus terrestrial resources that a person was consuming throughout their life.
Figure 8: Illustration of the mean values of $C_3$ European farmers (wheat), $C_4$ North American farmers (maize), and terrestrial hunter-gatherers compared to marine hunter-gatherers from Schoeninger (1995).

Through their stable carbon and nitrogen values, marine and terrestrial foods can be distinguished from each other in an individual’s diet in regions of the world where $C_3$ plants are more predominant in the terrestrial ecosystem. This is because marine foods have a higher nitrogen content than terrestrial foods. As a result, marine foods produce more positive $\delta^{15}N$ values than terrestrial foods, which produce more negative $\delta^{15}N$ values (Pate 1995; Schoeninger and Moore 1992). The use of stable nitrogen isotope values is required for dietary interpretations at sites where there are both $C_4$ plants and marine foods, as $C_4$ plants have isotopic values approaching those of marine organisms (Owen 2004:10). Thus, the importance of marine and terrestrial foods in the diets of the occupants of certain areas can be illustrated through the nitrogen values in a population’s bone chemistry.

Due to the systematic variation of individual isotopes in items of food from different animals and plants, there is also the potential that the skeletal material
could be traced back to the environment that it came from (Macko et al. 1999:66). Using this same theory, changes in diet can inform us about how the landscape was used by populations. Indeed, stable carbon and nitrogen isotopes allow us to investigate, for example, the degree to which apparently inland populations exploited or had access to marine resources. This is because marine and terrestrial resources differ in both carbon and nitrogen stable isotopic composition and as a result marine resources are able to be distinguished from terrestrial resources due to their being relatively enriched in both $^{13}$C and $^{15}$N (Fry and Peterson 1987:312). This approach has been employed in this research.

Despite the fact that there is comparative baseline data for the diets of humans and animals in the Chilean region, accurate estimation of amounts of C$_4$ and C$_3$ plants, animals and marine and terrestrial resources in human diets may still deviate significantly from mean regional values. This is due to the complexities of the human metabolism and digestive process (Ambrose 1993:83). An example of this is the underrepresentation of maize in bone collagen, due to ambiguity concerning the offset between diet and bone collagen values found during feeding experiments (see Tykot et al. 2009:160). Due to this problem, Tykot et al. (2009:168) concluded that “the opportunity for estimating the actual percentage of C$_4$ foods in human diets is limited”. It should be noted that isotopic interpretation for archaeological data might lead to various explanatory alternatives arising when reading for human stable isotope values. One problem that is noted is the fact that “different assumptions lead to different dietary reconstructions” (Tykot et al. 2009:156). However, it has been recommended that this be addressed by sampling more humans with low or no maize intake to create better comparative data for further research.

Another reason for variation in global mean $\delta^{13}$C and $\delta^{15}$N values is due to local and regional environmental factors. In hot, arid environments, such as the Atacama Desert, the diet-tissue $\delta^{15}$N spacing may increase (see Anson 1997). Ambrose (1993:83) notes that in such conditions “trophic level estimates may be in error and differentiation of marine and terrestrial diet components may be
difficult”. However, this issue will be explored later in the results and discussion sections of this thesis. Tykot et al. (2009:168) also note that due to the complexities of the human metabolism and digestive process, single isotope values should not be relied upon. Instead the use of two or more isotopic techniques, to ensure the accuracy of results regarding human diet and inferences that can be made from analysis of the human diet, should be employed. This method has been employed in this research as outlined below.

Since there are many interpretational issues in relation to the reliance on single isotope values (i.e., only $\delta^{13}$C values), this study aims to combat the problem by employing two critical measurements for dietary reconstruction. These measurements are the stable carbon isotope ratio ($^{13}$C/$^{12}$C) and the stable nitrogen isotope ratio ($^{15}$N/$^{14}$N). Both of these isotopes, with their different weights, are deposited in bone collagen throughout life, allowing geochemical analysis to determine their ratios in prehistoric skeletal material (Hastorf 1985:19).

The isotopic analysis of bone collagen can provide additional information to archaeological floral and faunal remains regarding food consumption, habitat use and social relations associated with food procurement. The composition of bone can be divided into the organic (collagen) and inorganic (hydroxyapatite) portions. Stable C/N analysis concentrates of the organic portion of bone (for further information see Ambrose 1991). Bone collagen makes up 90% of the organic portion of whole organic bone and is also usually relatively resistant to postmortem degradation (Ambrose and DeNiro 1986:396; Roberts 1998:53). Due to slow turnover rates in human adult bone, the inorganic and organic constituents of the bone can provide us with a long-term record of dietary intake (Heaton et al. 1986:822; Libby et al. 1964; Sealy and van der Merwe 1985:138; Pate 1985:81).
2.3.3 Isotope Analysis of Human Bone Collagen from Az-71 and Pica-8

Figure 9: Bone samples during the chemical preparation process.

This study assessed the diet of the ancient Az-71 and Pica-8 inhabitants. Through stable carbon and nitrogen isotope analysis of bone collagen, patterns of food consumption were analysed, and gave clues as to hunter-gatherer resource use and landscape use in the Azapa Valley and the Tarapacá region between c. 4,000 and 660 B.P.

The carbon and nitrogen isotope ratios in the Az-71 and Pica-8 populations’ bone collagen recorded the relative amounts of marine versus terrestrial foods and $C_3$ versus $C_4$ plants in their individual diets. Further, examination of the $\delta^{13}C$ and $\delta^{15}N$ values in the individual populations' bone values looked at $\delta^{13}C$ and $\delta^{15}N$ enrichment, which can indicate whether the populations were travelling to the coast in order to obtain more food to survive. This movement may be visible in, not only the archaeology of an inland site, but also the bone chemistry of the inhabitants (see Núñez and Hall 1982; Santoro et al. 2003).
2.3.4 Isotope Analyses in the Literature: Case Studies

Stable carbon and nitrogen isotope analysis is increasingly being employed as an essential tool in the reconstruction of past human diets (Ambrose 1993; Aufderheide 1993; Aufderheide and Santoro 1999; DeNiro and Epstein 1978; DeNiro and Epstein 1981; DeNiro and Schoeninger 1983; Pate 1997, 1998, 2000; Tykot et al. 2009). Isotope analyses have been used throughout the world and have yielded important and useful information on the bone chemistry of past populations. In countries such as the United States of America, Australia and China (for some examples see Little and Schoeninger 1995; Pate 1997, 1998, 2000; Yaowu et al. 2006), many isotope studies have been carried out on skeletal remains and provided information on diet, mobility patterns and social interaction to supplement data from traditional archaeological investigations.

Isotope research in South America to date has been limited, with the need for more isotope studies to be conducted for individual regions (Barberena et al. 2009:127). Isotope studies, in conjunction with palaeobotanical and archaeo-faunal studies, will provide more in-depth data for sites, allowing a more critical view of subsistence patterns and a better understanding of the lifeways of ancient peoples. Regardless of the richness of archaeological sites in Chile, entire time periods have had minimal or no isotope studies performed. Nevertheless, the few isotope studies in and around Chile have yielded promising results when cross-referenced with archaeological data (see Aufderheide 1993; Aufderheide et al. 1993, 1994; Aufderheide and Santoro 1999; Hastorf 1985; Hastorf and DeNiro 1985; Roberts et al. in preparation; Tykot et al. 2009).

Isotope studies in the Arica region have been performed on hair, bone and soft tissues at sites such as Acha-2, Camarones-8, Camarones-17, Chinchorro-1 (see Aufderheide et al. 1993), Pisagua (see Aufderheide et al. 1994) and the Molle Pampa Este and Molle Pampa Medio population sub-groups collected from the Lluta Valley (see Aufderheide and Santoro 1999). Despite the shortage of isotope studies, samples from the Az-71 and Pica-8 sites have the advantage of
being able to be compared to a recent preliminary isotope study on human bone samples from the nearby coastal area of Caleta Vitor (see Roberts et al. in preparation).

Figure 10: Satellite image showing proximity of Caleta Vitor to the Azapa Valley site of Az-71. Image courtesy of Google Maps.

The Caleta Vitor site consists of extensive occupation and burial sites scattered broadly along a coastal setting (Dauelsberg 1960; Mujica et al. 1983). These sites are thought to span a considerable time range and have a general relative chronology but await results from further absolute dating by OSL and radiocarbon analysis (Roberts et al. in preparation). Sub-surface archaeological material has been exposed in many areas and includes human remains, including both skeletal and mummy bundles. At the Caleta Vitor site 15 bone samples were recently collected for stable carbon and nitrogen isotope analysis in July 2010. The results from this analysis aid in the interpretation of Az-71, given its
proximity, and if the data set is further expanded will provide additional information on how the subsistence patterns of the past inhabitants may have changed over millennia with the transition to agriculture providing comparable data for the nearby Az-71 site. The data from this site also gives comparable data to the site of Pica-8. Despite the distance between these sites, this site still may provide similar data, which could be used to form a regional picture of the diets of populations at these times in Chile.

Although the sample size was small, preliminary carbon and nitrogen isotope values for the Caleta Vitor individuals reveal a diet consisting predominantly of marine foods from upper trophic levels. This sample set did not indicate changes in diet with the transition to agriculture; however, Roberts et al. (in preparation) state that:

...at this stage, given the sample size in this study, it is too early to conclude whether there are observable and consistent changes over time in the diets of people buried at Caleta Vitor.

Nevertheless, a comparison of the isotope analysis on the Caleta Vitor samples with other nearby inland and coastal populations revealed clear dietary variability between different geographic regions (Roberts et al. in preparation).

Conversely, not all cultural groups can be differentiated by stable carbon and nitrogen isotope analysis of their diet. Aufderheide et al. (1994) point out that cultural groups adapted to the same dietary sources as previous cultural groups can become indistinguishable from their predecessors in the isotopic record.

In their study on hair, soft tissue and bone samples, Aufderheide et al. (1994:515) evaluate the degree to which 11 naturally mummified Alto Ramírez Phase (c. 2,500-1,500 B.P.) bodies at a beach site near Pisagua, northern Chile, adapted to the subsistence strategy of their purely maritime predecessors. This research sought to analyse the types of food the inhabitants were eating at this site. The results of the study indicated that the diet of these Alto Ramírez
mummies was composed largely of marine foods, with only minor contributions from terrestrial meat and plant sources. Overall, it was found that the Alto Ramírez groups adopted the previous (i.e., Chinchorros) subsistence strategy so completely that it became indistinguishable, consisting almost purely of marine resources. Aufderheide et al. (1994:523) believe that the results of the analysis reflect the high degree of coastal adaption by the Alto Ramírez highlanders and suggest that they may have been functioning as a group of “marine specialists” for their lower valley kin.

Another possible interpretation for this site is that the Pisagua people did not come from the highlands, as supposed by Aufderheide et al. (1994), but instead were a coastal people that simply adopted certain Formative cultural features within a maritime cultural system (see Rothhammer and Cocilovo 2008; Rothhammer et al. 2009; Sutter 2000; Varela et al. 2006). Thus, not being distinguishable in the isotopic record because they were the same group of people that had merely taken on aspects of the Alto Ramírez culture, through social interaction.

One site with human remains that has been both archaeologically investigated and subsequently analysed via stable isotope analysis is the site of Molle Pampa in the Lluta Valley. Human bone collected from this site was studied by Aufderheide and Santoro (1999) and was analysed to determine whether two sub-groups of the Molle Pampa population could be differentiated on the basis of the chemical reconstruction of their diet by looking at the carbon, nitrogen and strontium ratios in their bones. Aufderheide and Santoro (1999) thought that chemical dietary reconstruction might be useful in identifying patterns of food consumption more directly related to cultural and social boundaries, and even ethnicity. Within the greater Molle Pampa site were two sub-areas where bones were scattered: Molle Pampa Este (MPE) and Molle Pampa Medio (MPM). Archaeological investigation at domestic structures determined that MPE was mostly occupied during the Late Period synchronic with Inka expansion (c. 660-476), while MPM was exclusively occupied in the pre-Inka Late Intermediate Period (c. 1,000-660) (Aufderheide and Santoro 1999:240).
The chemical studies from this site indicated that there were "no statistically valid differences" in diet between the two sub-groups of the population, indicating that the two groups were part of a homogenous social group, rather than two populations with different cultural backgrounds sharing the same section of the valley (Auferheide and Santoro 1999:237). These results reflect the close proximity of the sites and the time periods at the Molle Pampa sites. However, when looking at the broader geographic picture it can be seen that, although there were no “statistically valid differences” between the two groups in the Molle Pampa population, there is clear dietary variability between other populations in different geographic regions (Roberts et al. in preparation).

Further, it was also found that marine resources were exploited by both groups to a greater extent than the archaeological remains at Molle Pampa suggested (Auferheide and Santoro 1999:249). This is one such case that demonstrates the usefulness of an isotopic study to complement and reassess the data presented from a purely archaeological study incorporating zoo-archaeological and archaeo-botanical evidence.

In the past, isotope analyses have also been used to investigate diet as an indicator of social change and inequality of class and gender within a group (Falabella et al. 2007; Hastorf 1985). Socio-political ideas may have also played a part in the motivation behind why hunter-gatherers with such rich marine resources would adopt labor-intensive irrigation practices (Auferheide and Santoro 1999; Falabella et al. 2007; Hastorf 1985). Motivation by religious leaders or administrators to adopt labor-intensive agriculture may have lead to change in subsistence strategies, as it did at Dickson’s Mounds (Goodman et al. 1984). An example of socio-economic and class differences emerging as a consequence of studying the diet of the population is evident in the study conducted by Hastorf and DeNiro (1985) which used isotope analysis to look at the dietary construction of the people at an archaeological site in the central Andes of Peru.
In this area regional excavations have been carried out since 1977 and from the archaeological data Hastorf and DeNiro (1985) theorised that the elite at this site would have been consuming more maize than the non-elite. When they looked at the isotope ratios, however, they initially found no marked difference in the values between commoner and elite populations. In spite of this, after looking at the individual values of both of the sexes it was found that women consumed much less maize than men. From this new evidence Hastorf and DeNiro (1985) came to the conclusion that differential consumption of maize by males suggests that they either had increased access to maize within the home or that they were consuming it outside the household in ritual feasting ceremonies (Hastorf 1985:21). In this case isotopic analysis was used to distinguish social differentiation among a population through their diet. Although, the males may not have been consuming more maize in “ritual feasting ceremonies” but rather may have just been consuming more of it while they were out in the field harvesting it. This is another interesting aspect of isotope analysis that has been used to develop a different level of information regarding not only the economy of the people but also aiding in reconstructing details of their cultural practices.

This study focused on the Formative Period, encompassing the Azapa (c. 4,000-2,500 B.P.) and Alto Ramírez (c. 2,500-1,500 B.P.) Phases, and the Middle Period Tiwanaku (c. 1,500-1,000 B.P.) Phase at the site of Az-71. The site of Pica-8 in the Tarapacá region focused on the Late Intermediate Period, divided by Uribe et al. (2007) into two phases: Tarapacá (c. 1,050-700 B.P.) and Camiña (c. 700-500 B.P.). The Middle Period is not well represented at Pica-8, while there is no evidence for the Formative at all. By looking at these populations belonging to different cultural phases and inhabiting two different habitats, one close to the Pacific (Az-71) and the other further away from the coast (Pica-8) and comparing the isotope results to one another, differences in the diets of the populations may be found, thus answering questions about their subsistence strategies. Data from inland populations, such as Maria Pinto, a site known for its maize farming, was used as comparative data for an example of an inland site in the region. Similarly, data from the coastal site of Caleta Vitor was used as comparative data for an example of a purely coastal site. Comparing data from
different time periods during the transition to agriculture may aid in giving clues as to when this shift happened in the different regions and whether different dietary resources were employed during this shift.

The above previous results for the Chilean regions demonstrate the value of research on the diet of populations and what characteristics can be identified using stable carbon and nitrogen isotope analyses. This research project explored the results from these studies and compared them to results obtained from isotope analyses of both the Az-71 and Pica-8 sites investigating what dietary evidence from these sites can tell us about hunter-gatherer resource and landscape use during the Late Holocene. From this dietary evidence, patterns of social interaction between the populations at the site of Az-71, Pica-8 and the surrounding archaeological sites were examined.

Through the analysis of bone collagen of the populations at the sites of Az-71 and Pica-8, this study examined the types of food the inhabitants were eating (i.e., C₃ vs. C₄). The results allowed a discussion of possible answers based on independent data from the archaeological record and an examination of when approximately these groups moved from hunting and gathering to agriculture in the area.

As well as this, through stable carbon and nitrogen isotope analyses, questions about the amount of marine food the Az-71 and Pica-8 populations were consuming are explored. By looking at such issues, theories about the movement of these populations around the environment are considered. Indeed, such an approach allows us to answer questions about how these groups were interacting with other groups within the landscape. For example, if the inland groups were eating marine foods this implies that they were traveling to the coast and may have established relationships with other coastal groups, as well as nearby valley and highland groups.

Similarly to Hastorf’s (1985) study, the relative amounts of different food consumed were seen in the isotopic record. This informs us regarding patterns
of social interaction between groups within the population and will be explored further, in relation to the present study, in the discussion section of this thesis.
3 CHAPTER THREE: MATERIALS AND METHODOLOGY

3.1 Background, Bone Sampling, Collection and Permissions

In July 2010 the Flinders University Archaeology Department (through Dr Michael Westaway), in collaboration with the University of Tarapacá, the Centro de Investigaciones del Hombre en el Desierto, and Christopher Carter of the Australian National University, conducted an advanced archaeology field school at Caleta Vitor in northern Chile, South America (Petruzzelli 2010). Through this field school a number of archaeological bone samples (both human and animal) were collected for stable carbon and nitrogen isotope analysis in order to provide an independent source of information on past human diet. It was from this collaborative field school that opportunities for further isotope work on Chilean samples arose.

Indeed, I was able to volunteer my time to work with Dr Amy Roberts and Professor Donald Pate, and thereby learn through practical experience, how to conduct stable carbon and nitrogen isotope analyses of bone collagen. It is through this work and from learning the preparation techniques for isotope analysis that an opportunity arose for this Masters project to take place examining other collections of human bones from two archaeological sites in this region: the site of Az-71, in the Azapa Valley of northern Chile and the site of Pica-8 in the Tarapacá region of northern Chile (see figure 4 for locations of sites).

Archival research into the archaeological work conducted in the late 1970s on the graveyard at the Az-71 site, and the site of Pica-8 was the first task undertaken for this research project. This research was conducted in order to discern the collection methods of the samples from these sites. Personal communication with the key Chilean archaeologist, Professor Calogero Santoro, aided in obtaining this information and any other details needed in order to contextualise the analysis of samples from these sites.
As stated previously, the human skeletal remains from the Azapa Valley site, Az-71, were excavated in 1977 to 1978 by Calogero Santoro and his team. The site of Pica-8, in the Tarapacá Region, was excavated by Hans Niemeyer and Lautaro Núñez extensively during the years of 1963, 1964 and 1965 (Santoro 1985:2; Zlatar 1984).

Since these excavations, the bones have been held in the Colección Osteológica store at the physical anthropological laboratory of the Department of Anthropology of the University of Chile in Santiago. Professor Calogero Santoro, in collaboration with Professor Vivien Standen collected 26 bone samples for this project, which in turn has been included as an independent activity of the FONDECYT grant 1095006 lead by professor Francisco Rothhammer, all from the University of Tarapacá in Arica, Chile. These samples were a mixture of phalanges (human finger and toe bones), and rib bones, which were selected according to the presence of these bony elements in the collection and the absence of soft tissue. Each sample was first photographed and placed in sealed plastic bag. Manipulation of the bone sample was done with starch-less gloves. A label was written for each sample indicating the site number, tomb number, inventory and store number. The sample was taken to Australia in November 2010 by Bastien Llamas, PhD Australian Research Council Postdoctoral Fellow, Australian Centre for Ancient DNA, School of Earth and Environmental Sciences, The University of Adelaide. Further samples were also delivered to Australia by Christopher Carter in June 2011.

Eighteen phalanges and rib bones, from separate individuals, were from the Azapa Valley site, while eight phalanges were from the Tarapacá regional site of Pica-8. Professor Santoro (pers. comm. 2011) dealt with the requisite permits and ethical procedures, from University of Chile, in order to provide the samples. Flinders University did not require any additional ethical processes in relation to this project.
Bone collagen was selected as the primary material for this study as bone is one of the few materials that is consistently recovered from archaeological sites in Chile.

### 3.2 Preparation of Bone Samples for Stable Carbon and Nitrogen Isotope Analysis

As prehistoric materials may suffer post-mortem contamination by substances that have different stable isotope ratios, they need to be purified before undergoing analysis (Ambrose 1993:71).
Ambrose (1993:72) states that:

...the major isotopic contaminants of collagen are lipids, biological carbonate in bone apatite, post-depositional carbonates, carbon and nitrogen in adhering sediments and organic matter (roots, fungus, insects and humic and fulvic acids from soils).

Bone lipid $\delta^{13}C$ values may also be approximately 6-12% more negative than those of the collagen and, therefore, their removal using hydrochloric acid (HCl) is essential (Ambrose 1993:73; DeNiro and Epstein 1977). Further, humic acids have an isotopic composition that reflects the local plant biomass, rather than the diet of the person, and can affect collagen carbon isotope ratios, thus, the removal of humic acids using sodium hydroxide (NaOH) is also recommended (Ambrose 1990:432). Most sources of contamination can be largely eliminated with simple mechanical and chemical pretreatment procedures.

Following the arrival of the samples in Australia, preparation of the samples for stable carbon and nitrogen isotope analysis commenced. The samples that were obtained by Professor Santoro were all of human bone dried by exposure to weather and microbial activity. These samples were cleaned of any flesh and dirt before they were sent to Australia. All of the bone samples were subjected to the same cleaning procedures once they arrived in Australia.

Standard preparation procedures were employed as outlined by Anson (1997), Hiebert and Schoeninger (1987), Pate (1995), and Roberts (1998:60-61). These procedures are:

1. Clean archaeological bone specimens with dental instruments, e.g., scalpel (ultrasonic bath if necessary);
2. Record dry weight;
3. Demineralise whole bone fragments (1-1.5g) in dilute HCl (2-4%) in 250ml glass beakers until samples float or reach a spongy consistency – pour off acid and add more every other day if necessary (see figure 12);
Figure 12: Bone samples demineralising in HCl.

4. Wash sample in distilled water for at least 10 minutes;
5. Remove humic acids and other base-soluble contaminants in a 0.125 M NaOH solution (5g NaOH to 1.0 litre water) – leave sample in solution overnight (see figure 13);
Figure 13: Bone samples in NaOH.

6. Wash in distilled water;
7. Place extracted protein into tared, labeled scintillation vials;
8. Dry in 35 degrees Celsius oven for at least two days or until all traces of moisture are removed (see figure 14);
9. Remove sample from oven and weigh;
10. Determine yield from whole bone (yield = final weight of dry bone sample divided by original weight of untreated sample and multiplied by 100). Retain samples between 5-30% yield; if the yield is below 5% resample whole bone, as insufficient protein remains for accurate C/N determination; if greater than 30% put back in acid and start again, as the inorganic portions of the bone (hydroxyapatite) remain; and
11. Samples that achieve the 5-30% yield should be ground to a fine powder and placed in a dessicator (see figure 15). The grinding process is carried out in a mechanical mill with cleaned and sterilised grinding vials and ball made from agate (if all moisture has been removed from the sample it will grind to the required fine powder in approximately 10 minutes, however, if the sample has retained moisture it should be placed back in the oven until it reaches the necessary state).

Due to the differential quality and preservation of the individual bone samples the acid reduction process was started off in only a 1.1% HCl dilution. This was in accordance with the recommendations by Ambrose (1993:73) who states that “...demineralisation with weak HCl (1-3%) produces more collagen with higher C and N contributions in collagen than strong HCl concentrations...”. Thus, the use of a weaker mixture of HCl was used to try and recover more collagen from bone samples that may have had low collagen concentrations (Ambrose 1993:73; Schoeninger et al. 1989).
All sample preparation was undertaken at the School of Physical and Chemical Sciences laboratories on the Flinders University science campus.

3.3 Mass Spectrometry Analysis

Following the grinding of the bones, the samples were taken to the CSIRO, Land and Water labs in Adelaide, and were weighed using an electronic balance, which was accurate to five decimal places (see figure 16). Two milligrams of each powdered sample was placed into individual pure tin capsules to be loaded for mass spectrometry. Pure tin is used as it is designed to have no influence on the mass spectrometer’s analytical processes. Ethanol was used to clean all equipment between sample weighing.

Figure 16: Bone samples being weighed at the CSIRO.

A number of standards were also inserted into the sample tray at various intervals to ensure consistency of results. Duplicates of a number of samples were also submitted for analysis to ensure the accuracy. Analytical precision was
better than ± 0.2‰ for δ¹³C and ± 0.3‰ for δ¹⁵N. 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 glycine standard from the laboratory of Margaret Schoeninger was also used to provide comparison.

![Figure 17: Isotope ratio mass spectrometer. Photo courtesy of Dr Amy Roberts.](image)

If the δ values of the repeated samples differ by more than 0.5 they are considered to be unsuitable samples (Anson 1997:81). In total seventeen bone samples were submitted for mass spectrometry. Carbon and nitrogen concentrations were determined using an ANCA SL elemental analyser coupled to a Geo 20-20 IRMS (see figure 17) by Dr Todd Maddern at the CSIRO in Adelaide.

Collagen contamination was checked by measurement of atomic carbon to nitrogen (C:N) ratios (DeNiro 1985). Atomic C:N ratios are used to ascertain the presence of acceptable collagen in archaeological extracts in relation to stable
isotope analysis (DeNiro 1985). The range for stable carbon and nitrogen atomic ratios has been measured by recording the atomic ratio ranges from 415 mammals (see Ambrose 1990; Anson 1997; DeNiro 1985), and is acceptable between the values of 2.7 and 3.6. Samples out of this range indicate that the bone collagen has been subject to diagenesis and is therefore, not well preserved and needs to be put through the extraction process again (DeNiro 1985:808).
4 CHAPTER FOUR: RESULTS

Bone collagen δ\textsuperscript{13}C and δ\textsuperscript{15}N values for the Az-71 and Pica-8 sites are summarised in tables 2 and 3. 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 δ\textsuperscript{13}C and ± 0.3‰ for δ\textsuperscript{15}N.

At the commencement of the study, 26 individuals were subject to isotope analysis. 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 2 indicates the amounts of carbon and nitrogen in the bone collagen of the Az-71 population, with a summary of the contextual information about each sample.
Table 2: Az-71, Azapa Valley, 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>%N</th>
<th>δ13C (%PDB)</th>
<th>%C</th>
<th>C:N</th>
<th>Proposed Time Period/x</th>
<th>Bone Sampled</th>
<th>Proposed Age</th>
<th>Proposed Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Az71-165</td>
<td>23.55</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 Ramírez) c. 2,500 – 1,500 B.P.</td>
<td>Rib</td>
<td>Sub-adult</td>
<td>Female</td>
</tr>
<tr>
<td>Az71-171b</td>
<td>23.55</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. 1,000 – 660 B.P.</td>
<td>5th metacarpal, left</td>
<td>Sub-adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-177</td>
<td>26.66</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. 1,500 – 900 B.P.</td>
<td>1st phalange, hand</td>
<td>Sub-adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-212</td>
<td>24.39</td>
<td>17.85</td>
<td>14.25</td>
<td>-14.3</td>
<td>41.9</td>
<td>2.9</td>
<td>Middle Horizon Period (Loreto Viejo) c. 1,500 – 900 B.P.</td>
<td>1st metacarpal, right</td>
<td>Adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-267</td>
<td>22.69</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. 1,500 – 900 B.P.</td>
<td>1st metatarsal, right</td>
<td>Adult</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>Az71-288b</td>
<td>7.56</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. 4,000 – 2,500 B.P.</td>
<td>Rib</td>
<td>Sub-adult</td>
<td>Female</td>
</tr>
<tr>
<td>Az71-331b</td>
<td>9.2</td>
<td>14.35</td>
<td>15.0</td>
<td>-16.75</td>
<td>41.8</td>
<td>2.8</td>
<td>Formative Period (Azapa) c. 4,000 – 2,500 B.P.</td>
<td>Rib</td>
<td>Adult</td>
<td>Male</td>
</tr>
</tbody>
</table>

Bone collagen δ13C and δ15N values from the site of Az-71 indicate that the older samples, such as Az-71-288b (c. 4,000-2,500 B.P.) and Az-71-331b (c. 4,000-2,500 B.P.) contained higher δ13C values. However, all of the samples under c. 2,500 B.P contained δ13C lower than -15‰, as well as relatively high δ15N values. In the following graph three groups can be seen, illustrating variability between the values for individuals at this site.
**Figure 18**: Carbon and nitrogen isotopic composition of human dietary protein at Az-71, Chile.

![Figure 18]

**Figure 18 Key**
- ● Az-71-165 (c. 2,500 to 1,500 B.P.)
- ■ Az-71-171b (c. 1,000 to 660 B.P.)
- ▲ Az-71-177 (c. 1,500 to 900 B.P.)
- ♦ Az-71-212 (c. 1,500 to 900 B.P.)
- × Az-71-267 (c. 1,500 to 900 B.P.)
- × Az-71-288b (c. 4,000 to 2,500 B.P.)
- △ Az-71-331b (c. 4,000 to 2,500 B.P.)
The table below reports the bone collagen stable isotope results for the Pica-8 population, with a summary of the contextual information about each sample.

Table 3: 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 (%oAir)</th>
<th>%N</th>
<th>δ13C (%oPDB)</th>
<th>%C</th>
<th>C:N</th>
<th>Proposed Time Period/s</th>
<th>Bone Sampled</th>
<th>Proposed Age</th>
<th>Proposed Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>P8-7</td>
<td>25.54</td>
<td>16.5</td>
<td>15.2</td>
<td>-8.4</td>
<td>41.7</td>
<td>2.7</td>
<td>Late Intermediate Period 1,150-500 B.P.</td>
<td>Adult</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>P8-15</td>
<td>24.14</td>
<td>18.0</td>
<td>14.8</td>
<td>-10.4</td>
<td>42.5</td>
<td>2.9</td>
<td>Late Intermediate Period 1,150-500 B.P.</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>P8-24</td>
<td>25.63</td>
<td>15.1</td>
<td>15.0</td>
<td>-8.7</td>
<td>42.1</td>
<td>2.8</td>
<td>Late Intermediate Period 1,150-500 B.P.</td>
<td>Adult</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>P8-31</td>
<td>16.09</td>
<td>21.4</td>
<td>14.7</td>
<td>-13.0</td>
<td>41.5</td>
<td>2.8</td>
<td>Late Intermediate Period 1,150-500 B.P.</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>Late Intermediate Period 1,150-500 B.P.</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>P8-47</td>
<td>25.35</td>
<td>16.2</td>
<td>15.7</td>
<td>-10.1</td>
<td>42.8</td>
<td>2.7</td>
<td>Late Intermediate Period 1,150-500 B.P.</td>
<td>Adult</td>
<td>Female</td>
<td></td>
</tr>
</tbody>
</table>

Bone collagen δ13C and δ15N values from the site of Pica-8 indicate that there are three groups, with sample P8-31 containing the highest (most negative) δ13C value, while sample P8-37 contained the highest δ15N value. The rest of the samples grouped around approximately -10‰ for δ13C and 15‰ for δ15N. This is illustrated in the following graph.
Figure 19: Carbon and nitrogen isotopic composition of human dietary protein at Pica-8, Chile.

Figure 19 Key
- P8-7 (c. 1,150 to 500 B.P.)
- P8-15 (c. 1,150 to 500 B.P.)
- P8-24 (c. 1,150 to 500 B.P.)
- P8-31 (c. 1,150 to 500 B.P.)
- P8-37 (c. 1,150 to 500 B.P.)
- P8-47 (c. 1,150 to 500 B.P.)
Table 4: Summaries (mean ± standard deviation) of human bone collagen stable carbon and nitrogen isotope results for archaeological sites in Chile with comparative samples sizes to the Az-71 and Pica-8 samples analysed in this research.

<table>
<thead>
<tr>
<th>Populations</th>
<th>N</th>
<th>δ(^{13})C (‰)</th>
<th>Range</th>
<th>δ(^{15})N (‰)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molle Pampa Este(^a)</td>
<td>8</td>
<td>-11.00 ± 2.2</td>
<td>-14.02, -8.98</td>
<td>21.72 ± 2.34</td>
<td>17.2, 23.94</td>
</tr>
<tr>
<td>Molle Pampa Medio(^a)</td>
<td>10</td>
<td>-12.80 ± 3.7</td>
<td>-17.57, -9.59</td>
<td>19.64 ± 3.16</td>
<td>10.54, 17.26</td>
</tr>
<tr>
<td>Valle Verde(^b)</td>
<td>6</td>
<td>-20.10 ± 0.3</td>
<td>-20.3, -19.6</td>
<td>4.50 ± 0.7</td>
<td>3.8, 5.5</td>
</tr>
<tr>
<td>Maria Pinto(^b)</td>
<td>6</td>
<td>-12.00 ± 0.8</td>
<td>-12.7, -10.7</td>
<td>7.20 ± 0.7</td>
<td>6.7, 8.1</td>
</tr>
<tr>
<td>Laguna El Peral-C(^b)</td>
<td>5</td>
<td>-14.62 ± 0.9</td>
<td>-15.6, -13.5</td>
<td>10.80 ± 1.2</td>
<td>9.6, 12.6</td>
</tr>
<tr>
<td>Las Brisas 10-14(^b)</td>
<td>6</td>
<td>-13.9 ± 1.8</td>
<td>-17.3, -12.3</td>
<td>10.13 ± 2.4</td>
<td>8.1, 14.3</td>
</tr>
<tr>
<td>Caleta Vitor(^c)</td>
<td>10</td>
<td>-12.87 ± 1.1</td>
<td>-14.7, -10.9</td>
<td>23.00 ± 2.74</td>
<td>17.3, 26.7</td>
</tr>
<tr>
<td>Az-71(^d)</td>
<td>7</td>
<td>-14.5 ± 2.2</td>
<td>-18.2, -12.5</td>
<td>19.7 ± 3.5</td>
<td>14.35, 23.4</td>
</tr>
<tr>
<td>Pica-8(^d)</td>
<td>6</td>
<td>-9.9 ± 1.7</td>
<td>-13.0, -8.4</td>
<td>18.38 ± 3.2</td>
<td>15.1, 23.1</td>
</tr>
</tbody>
</table>

\(^a\) Auferheide and Santoro 1999  
\(^b\) Tykot et al. 2009  
\(^c\) Roberts et al. in preparation  
\(^d\) This research

The Az-71 mean site values (-14.5‰ δ\(^{13}\)C and 19.7‰ δ\(^{15}\)N) are closest to those from the site of Molle Pampa Medio (-12.80‰ δ\(^{13}\)C and 19.64‰ δ\(^{15}\)N) and Caleta Vitor (-12.87‰ δ\(^{13}\)C and 23.00‰ δ\(^{15}\)N). All of these sites demonstrate high mean δ\(^{15}\)N values in the bone collagen.

In contrast, the values from the site of Pica-8 (-9.9‰ δ\(^{13}\)C and 18.38‰ δ\(^{15}\)N) are most comparable to those from the site of Molle Pampa Este (-11.00‰ δ\(^{13}\)C and 21.72‰ δ\(^{15}\)N), demonstrating lower δ\(^{13}\)C values than the rest of the sites (see figure 20).
Figure 20: 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 $\delta^{13}C$ and $\delta^{15}N$ 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.

During the preparation of samples for acid reduction three samples (samples Az-71-297a, Az-71-20 and Az-71-328) were darker in colour, exhibiting a brown/black exterior. It has been postulated that the dark colouring of these samples could either be the result of heating of the absorption of colour from their surrounding sediments (see Roberts 1998:69).
Only samples from the site of Az-71 did not survive the acid reduction. The samples that did not survive were predominantly samples from adults from the Azapa Phase (c. 4,000-2,500 B.P.). Out of these samples seven were phalanges and two were rib bones. Rib bones can be too cancellous for the acid reduction procedure; however, 70% out of the sample of rib bones (5/7) survived the procedure and produced good carbon and nitrogen values. These samples will be discussed further in the discussion section of this thesis.
5 CHAPTER FIVE: DISCUSSION

The analysis of stable carbon and nitrogen isotope analysis on plant and animal material in the past has served to create some baseline data for average plant and animal isotope values in the Chilean region (see Appendix B). These baseline values can be compared to the human isotopic values and thus determine food consumption and dietary patterns in their consumers. Using this method, dietary patterns, landscape use and geographic origin can be studied.

5.1 Azapa 71, Azapa Valley, Chile

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 δ13C and δ15N. Although the site of Az-71 is 12km inland, 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 values illustrate a predominantly marine diet, the site of Az-71 exhibits some variability within its individual values, illustrating three groups of results. The first group contains two individuals from the Azapa Phase (c. 4,000-2,500 B.P.), exhibiting values ranging between -16.75‰ and -18.2‰ for δ13C and 14.35‰ 16.6‰ for δ15N. These values are similar to δ13C and δ15N values for eel jay (-14.4‰ 13C and 16.1‰ δ15N) and also have comparable 13C values to Lama guanicoe (-19.5‰ 13C and 4.6‰ δ15N) and inland lake fauna (-16.0‰ 13C and 2.1‰ δ15N), indicating a diet of mixed arid land C₃ foods and marine foods (see figure 21).

The Azapa was a transitional phase between the end of the Chinchorro Phase (c. 8,000-4,000 B.P.) and the start of the Alto Ramírez Phase (c. 2,500-1,500 B.P.)
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 that, while the results do actually indicate that these individuals were eating C₃ foods, they do not indicate a significant enough quantity of C₃ to suggest agricultural activities.

The second group of results for individuals within the Az-71 population date from approximately 2,500 to 900 B.P., incorporating the Alto Ramírez and Cabuza cultural phases. These δ¹⁵N results indicate a diet of high trophic level marine foods with values between -17.85‰ (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). The following graph demonstrates the isotopic similarities between the consumers and the animals that are most likely part of their diets.
Figure 21: 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 Az-71 stable carbon and nitrogen isotope individual values. *Note: fractionation is not accounted for in this graph.

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 site of Az-71 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, previously discussed in the literature review section of this thesis, 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 agricultural practices at a site are the sites of Valley Verde, an inland site approximately 2,000km south of Az-71, and Maria Pinto, located inland, approximately 2,000km south of Arica, Chile. Examining the isotopic evidence
from these sites serves to demonstrate two examples of isotopic values according to C₃ agricultural activities and C₄ agricultural activities.

The site of Valle Verde exhibits mean isotopic values of -20.10‰ δ¹³C and 4.50‰ δ¹⁵N, demonstrating evidence of (C₃) cultivated plants, such as beans and squash, in their values (see figure 20). Similarly, mean isotopic values from the site of Maria Pinto (-12.00‰ δ¹³C and 7.20‰ δ¹⁵N), also serve to illustrate a diet leaning towards those practicing maize (C₄) farming (see figure 20), which there is limited evidence for in the Az-71 isotopic values.

The values from the Az-71 site are most comparable to those found at the nearby sites of Molle Pampa Medio (MPM) (-12.80‰ δ¹³C and 19.64‰ δ¹⁵N), a Late Intermediate Period site in the Lluta Valley 16km from the coast, and Caleta Vitor (-12.87‰ δ¹³C and 23.00‰ δ¹⁵N). 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. 1,000-476 B.P.) 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 than 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 complimented by wild and farmed terrestrial resources.

The values found for the diet of the Az-71 population challenge the archaeology of the site, which contains evidence for agricultural practices. In the Azapa Valley during the Formative and Late Intermediate Periods (c. 3,500-700 B.P.) 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 (Aufderheide and Santoro 1999:249) that marine resources at the site were exploited to a greater extent than the archaeological evidence suggested.

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. Despite the temporal differences at this site, it appears that isotopic evidence for the earlier Azapa (c. 4,000-2,500 B.P.) groups at this site were eating C$_3$ arid land plants as well as marine foods but later, around 2,500 B.P. 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 3,000 cal B.P 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. 3,000 B.P, leading to a reliance predominantly on marine foods after 2,500 B.P. 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 palaeo-pathological studies of populations in the region may shed further light on these discrepancies.

5.2 Pica-8, Tarapacá Region, Chile

Stable carbon and nitrogen isotope values for the Pica-8 population revealed a diet consisting of marine foods from upper trophic levels, as well as some maize, with mean values reading -9.9‰ and 18.38‰ respectively for δ$^{13}$C and δ$^{15}$N. At a glance, these values indicate that the population at Pica-8 was heavily reliant
on marine foods, travelling to the coast in order to obtain these resources. However, due to the site of Pica-8 being 90km from the coast additional factors were considered in more depth. 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 δ¹³C and δ¹⁵N values at Pica-8, illustrating three groups of results. Unfortunately these groups cannot be differentiated by their chronologies, as they do not currently have relative individual dates assigned to them. On the whole, the dates for the site of Pica-8 range from approximately 1,050 B.P. to 500 B.P., focusing on the Late Intermediate Period, and the Tarapacá and Camiña culture phases, which are described in detail in the introduction section of this thesis (see also Table 1).

The first group of results from Pica-8 contains an individual (P8-31), with values of -13.0‰ δ¹³C and 21.4‰ δ¹⁵N. This individual has the highest δ¹³C value of those isotopically analysed from Pica-8 and corresponds to the ‘endpoint’ value for a diet based within the -15.7‰ to -11.1‰ spacing for maize in diets in the region (Tykot et al. 2009:162). The δ¹³C and δ¹⁵N results together from this individual are similar to those for sea lion bones (-13.1‰ δ¹³C and 22.1‰ δ¹⁵N), and the mean values for fish vertebrae (-12.1‰ δ¹³C and 20.3‰ δ¹⁵N) in the region.

The second group at the site of Pica-8 has an individual (P8-37) with values of -8.8‰ δ¹³C and 23.1‰ δ¹⁵N. 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.

Lastly, the third group of individuals 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 δ¹³C and 15.1‰ and 23.1‰ for δ¹⁵N. These values are most comparable with those of fish vertebrae (-12.1‰ δ¹³C and 20.3‰ δ¹⁵N), as well as being similar with sea lion bones.
(-13.1‰ δ¹³C and 22.1‰ δ¹⁵N) from Pisagua, indicating the consumption of marine mammals from upper trophic levels (see figure 22). The following graph demonstrates these isotopic similarities between the consumers and the animals that were most likely part of their diets.

**Figure 22:** 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 Pica-8 stable carbon and nitrogen isotope individual values. *Note: fractionation is not accounted for in this graph.*

One explanation that was explored for the high δ¹⁵N values for individuals at Pica-8 was the possibility of δ¹⁵N enrichment from the arid Atacama Desert climate. As mentioned previously, the Atacama Desert receives less than 1mm of rainfall annually (Latorre *et al.* 2005; Marquet *et al.* 2002; Ramirez *et al.* 2001:7). It has been found that in arid habitats with mean annual rainfall less that 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) state that “...it appears that there is a definite tendency for increasing $^{15}N$ with increasing aridity.” Therefore, it is possible that the population at this site may have been eating predominantly terrestrial sources of food, which have been feeding on the nitrogen enriched plants and soils of the Atacama Desert. 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‰ $\delta^{15}N$) have low $\delta^{15}N$ values. It is expected that if the Atacama Desert aridity was causing enrichment in the human $\delta^{15}N$ values, that it would also be doing the same for the animal’s values, which it was not.

The values from the site of Pica-8 are most comparable to those of the site of Molle Pampa Este (-11.00‰ $\delta^{13}C$ and 21.72‰ $\delta^{15}N$) and Molle Pampa Medio (-12.80‰ $\delta^{13}C$ and 19.64‰ $\delta^{15}N$). 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.

Statistically significant differences exist between the average $\delta^{13}C$ and $\delta^{15}N$ values for 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 (-20.10‰ $\delta^{13}C$ and 4.50‰ $\delta^{15}N$) and Laguna el Peral-C (-14.62‰ $\delta^{13}C$ and 10.8‰ $\delta^{15}N$). The Valle Verde site is located approximately 1,600km southwest of the site of Pica-8 and differs in that its inhabitants are practicing (C₃) cultivated plant farming as opposed to those at Pica-8. The site of Laguna el
Peral-C is a coastal site, also located approximately 1,600km 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 indicate a diet of marine foods from upper trophic levels, such as whales, large fish and seals.

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 the diet and occupation of 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 aid in giving a clearer picture of what individual generations within the population were consuming, raising the key issue that several generations may have lived at this site within the time period. Ultimately, this serves to highlight the well-known fact that a sample is not necessarily representative of the ancient population it is from.

5.3 Conclusions

In conclusion, the stable carbon and nitrogen isotope analysis of human bone collagen from the site of Az-71 indicated that relatively little terrestrial plant resources were being consumed, while a large amount of marine foods from upper trophic levels were being consumed. This accords reasonably well with the geographic location of Az-71 as they are only 12km from the coast and it is, therefore, practical that they were regularly travelling to, or seasonally living on, the coast in order to obtain these marine resources. However, the isotope values from Az-71 are at odds with the archaeology of the site, which indicates a transition to agriculture at approximately 3,500 B.P. Conversely, populations at the site may have been underrepresented due to the small sample size, and re-sampling more of the population and further cross-checking the results with the archaeology is recommended for future research at the site.
The stable carbon and nitrogen isotope analysis of human bone collagen from the site of Pica-8 indicated that the population at this site was eating predominantly marine resources from upper trophic levels. However, one of the main points of contention within this research has been the high nitrogen values at the inland site of Pica-8. High nitrogen values at a site are usually an indicator of high trophic level animals, such as whales, seals and big fish. Conversely, since the site of Pica-8 is 90km inland it is unlikely that they were regularly travelling to the coast, but may have rather been seasonally living on the coast. Be that as it may, the available results do suggest a higher degree of mobility than previously suggested. 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 exchanged marine products with people living in the valleys (see Hidalgo 2004; Santoro et al. 2010 for a discussion on these issues).
6 CHAPTER SIX: CONCLUSIONS

6.1 Readdressing the Aims

6.1.1 Principle Aim

The principle aim of this research project was to conduct an investigation into the resource and landscape use between different regions in prehistoric Chile, as well as examine currently held theories concerning the prehistoric economy in the Late Holocene.

Stable carbon and nitrogen isotope analysis of human bone collagen from the Az-71 archaeological site in northern Chile revealed that the population was heavily reliant on marine resources, despite scanty evidence for this in the archaeological record. This has confirmed currently held theories in the region that marine resources were being exploited to a greater extent than the physical archaeological record for subsistence currently suggests (Aufderheide and Santoro 1999). Although the site of Az-71 is 12km inland, it is likely that the population at this site were travelling across the landscape to the coast in groups or seasonally living on the coast. On the other hand, δ\textsuperscript{13}C and δ\textsuperscript{15}N evidence challenges the theory that this site transitioned to agriculture as early as 3,500 B.P, as there is currently limited evidence for this from the record of bone chemistry representative of the population.

The stable carbon and nitrogen isotope analysis at the site of Pica-8 revealed that the inhabitants were also eating marine resources from upper trophic levels. However, since the site is located approximately 90km inland it is more likely that the population from this site were seasonally living on the coast in order to obtain these resources. An alternative explanation could be that, as documented for colonial times (16th-18th century A.D.), coastal people traded marine products, such as dry molluscs, fish, seaweed and shells with the people of Pica. Tighter chronological control further sampling of the Pica population will aid in giving a more representative sample of these people and their diet.
6.1.2 Subsidiary Aims

1. To examine the reliance on marine foods at these two separate sites.

Stable carbon and nitrogen isotope analyses revealed that both the populations at Az-71 and Pica-8 were heavily reliant on marine resources from upper trophic levels.

2. To investigate how the isotopic record compared with the archaeological record at these sites.

It was determined that the isotopic record challenged the archaeology of both sites. Stable carbon and nitrogen isotope analysis indicated that marine resources were exploited to a greater extent than the archaeological remains suggested. Archaeological evidence indicating a reliance on agriculture is also challenged, as there is limited evidence for agriculture in the isotope values for both of the populations.

3. To examine theories about the introduction to agriculture in this region and compare them to the isotopic results from the two sites.

Current theories relating to the debate for the introduction of agriculture at the site of Az-71 are not supported by the $\delta^{13}C$ and $\delta^{15}N$ evidence. According to the archaeological evidence, agriculture is first noted in the Azapa Valley in the Early Formative Period (c. 4,000-2,500 B.P.) (Núñez and Santoro 2011; Ramirez et al. 2001:8; Santoro 1980a, 1980b), with a transition from primary dependence on marine-based hunting and gathering to irrigation agriculture between approximately 3,500 and 700 B.P. (Núñez and Santoro 2011; Ramirez et al. 2001:8). However, the $\delta^{13}C$ and $\delta^{15}N$ evidence suggests the opposite, with results indicating that between 4,000 and 2,500 B.P. the inhabitants were eating a diet of mixed arid land $C_3$ foods and marine foods (see figure 21). Following this, in the period between 2,500 and 900 B.P., $\delta^{13}C$ and $\delta^{15}N$ values indicate that the inhabitants were eating primarily marine foods.
from upper trophic levels, suggesting that instead of transitioning to agriculture the population was becoming more reliant on marine foods. Further investigation into this in the future may reveal whether this is the result of some kind of ecological collapse or a result of sample bias.

The transition to agriculture in the Tarapacá region is far less clear than that of the Azapa Valley, however according to the Pica-8 Pre-Hispanic Cemetery (Zlatar 1984) artefact catalogue, agriculture is evidenced at the site by a wealth of textiles and ceramics. Theories about the introduction to agriculture at this site cannot be confirmed or denied until further research has been conducted.

4. To investigate the degree of interregional social interaction between sites in the region.

Archaeological evidence, such as potatoes, pottery, textiles, wool, camelid meat and metal objects have been identified at the site of Az-71 and are thought to suggest trade with other highland populations (Muñoz 2004; Ponce 2010:160; Varela et al. 2006:192). Between approximately 4,000 and 2,500 B.P. there is δ13C and δ15N evidence indicating a diet of mixed arid land C3 foods, such as *Lama guanicoe*, and marine foods (see figure 21). Conversely, later (c. 2,500-900 B.P) there is no evidence for arid land animals, with the results indicating predominantly marine foods from upper trophic levels. However, this does not mean that the population was not interacting with other populations in the region, but simply means that animals, such as camelids, were being used for something other than food at the site. It is also possible that the population at Az-71 were socially interacting with populations outside of the Azapa Valley, while they were regularly travelling to, or partially living on, the coast.

Around 3,000 B.P. it is further noted that there was an introduction of exotic elements that originated in the tropical forests, such as sweet potatoes, cassava and achira, seeds used as beads, coloured feathers of tropical lowland birds, and hallucinogenic products. The social mechanisms explaining the introduction of
these items on the coast and valleys of northern Chile continues to remain uncertain (Rothhammer et al. 2009).

At the site of Pica-8, archaeological, historical and paleo-parisitalogical evidence shows that marine products and materials were brought to the interior. Particularly for the Pica zone, archaeological evidence shows contact between the coast and the interior since the late Pleistocene in Quebrada Maní (Santoro et al. 2011a). However, while there are many theories, how the different social groups managed to have access to marine resources is still open to question.

5. To examine the issues that impinge upon isotopic interpretations.

It has been found that the basic assumption ‘you are what you eat’ cannot be applied simply to human populations in Chile. This is due to the many complexities of the human metabolism and the digestive process, and the fact that foods such as maize have been found to be underrepresented in human bone collagen (Ambrose and Norr 1993; Tykot et al. 2009:156) and the issue of explaining values for marine resources for the interpretation of isotopic data.

These problems have been explored in detail in the above sections, with reference to the results from both the Az-71 and Pica-8 sites, with future recommendations to address these interpretational issues. From research into these issues, it has been found that ultimately, the diet of the inhabitants at the site of Pica-8 cannot be accurately interpreted until there is tighter chronological control at the site and more individuals have been sampled. Be that as it may, this study has demonstrated that there are some fundamental flaws with direct interpretation of diet from archaeological materials alone, and far greater complexity in the prehistoric subsistence patterns seem to emerge when the evidence from bone chemistry is taken into account.
6.2 Limitations and Future Recommendations

One limitation of this research was the relatively small sample size. Although there is a wealth of skeletal material at these sites in Chile, undertaking stable carbon and nitrogen isotope analysis is expensive, with the mass spectrometry analysis costing upwards of $1,000 for a small set of samples, which does not include the chemical preparation work needed to be conducted on the samples before submission. This is also shown by reviewing the amount of isotope work that has occurred at other Chilean sites (see table 4), as research conducted from South America usually has to deal with severe budget restrictions, which imposes restrictions on how many samples can be processed (Barberena et al. 2009:128). In future, this limitation may be solved by integrating international funding parties into projects on diet and landscape use around Chile, therefore broadening the options for the funding of isotope samples.

Another limitation of this research was the loss of samples during the acid reduction process of the chemical preparation work. Some samples took longer than others to demineralise due to the nature of the material being worked with. Samples that were of a darker, fragmented and generally cancellous consistency took a very short time to demineralise and many of the samples with this degree of diagenesis were lost only after one day in the HCl. Samples of a lighter colour, usually white or light bone, took a much longer time to demineralise in the acid and sodium hydroxide, anywhere from three to six days to achieve the spongy consistency needed for the procedure. It would appear that the darker samples underwent a different degree of diagenetic modification, perhaps undergoing a higher degree of chemical weathering or physical contamination. While, the lighter samples (which were mainly whole phalanges), dried by exposure to heat, the darker samples may have been contaminated by the surrounding sediments. Due to the differential quality and preservation of individual bone some of the samples were reduced much faster in the acid than others. The bone samples in this project were all of differing time periods and quality, therefore, the acid reduction was started off in only a 1.1% HCl dilution, in accordance with recommendations by Ambrose (1993:73), as mentioned in the methods section.
Despite the measures taken to try and preserve samples, which did not appear as if they would survive the treatment, six samples were lost after only approximately 20 hours in the acid. In future the use of darker samples, which are suspected to have been contaminated by surrounding sediments, is not recommended for isotope analysis, unless there is a great quantity of the bone to resample and retry in the chemical preparation work.

A further limitation of this project was that some of the samples demonstrated unacceptable C:N atomic ratios and therefore, could not be included in the results. Unfortunately four of the bone samples, two from Az-71 and two from Pica-8, revealed ratios out of the acceptable collagen ranges and could not be incorporated in the study. A previous solution to this has been to put a different bone sample from the same specimen through the acid extraction process again to see if a better-preserved specimen could be obtained (Pate 2000). For this project this was not possible, as only single specimens of each bone sample were sent from Chile and obtaining more samples was not possible within the time constraints of this thesis. Therefore, techniques such as assessing differential preservation in the skeleton, through review of different bones from the same specimen, were not possible. In future it would be ideal to obtain several samples from each specimen to combat the loss of samples from badly preserved bone specimens and add to the number of samples with acceptable C:N ratios.

As well as the practical restraints on this research are the interpretational limitations. Interpretation of isotopic data relies on the fact that there are a number of assumptions used to establish the bridge between isotopic values in human bone collagen and their corresponding diets (Tykot et al. 2009:160), and that different assumptions lead to different dietary reconstructions.

Another limitation for the isotopic interpretation of the human diet from these values is the estimation of maize in the human diet. The opportunity for estimating the actual percentage of C₄ foods in the diet of a population is limited because maize consumption is underrepresented in bone collagen (Ambrose and Norr 1993; Tykot et al. 2009:156).
The issue of explaining values for marine resources also impinges on the interpretation of isotopic data. Tykot et al. (2009:166) point out that the geographical condition of Chile may lead to interpretations based on the idea that inland human groups had access to marine resources through seasonal movements and exchange. However, there is very scarce archaeological and archaeofaunal evidence in the form of mollusks, fish bones, marine mammal bones and shellfish remains in inland assemblages. Further analysis of inland populations and their diets needs to be conducted before conclusions about dietary resources are reached.

Finally, it has been advised that due to the complexities of the human metabolism and digestive process, single isotopic values should not be relied upon. Tykot et al. (2009:168) suggest the use of both collagen and apatite carbon values cross-checked with nitrogen values to ensure that the interpretation of isotopic results is more accurate. In addition to stable carbon and nitrogen isotope analyses, there are many other elements that can be used to look into a population’s resource use, land use patterns and geographic origins (see Pate et al. 2002). Studies employing a combination of two or more isotopic techniques, for example carbon (C) and nitrogen (N), as has been conducted in this research project, improve the reliability of inferences about residence and mobility (see Pate 2008b). However, the analysis of isotopes such as strontium (Sr) (see Hodell et al. 2004), lead (Pb) (see Pate 2008a) and oxygen (O) (see White et al. 1998) can answer other questions and allow a more detailed picture of past populations lifeways.

The extra application of a combination of three or more different isotopes has been thought to improve the reliability of inferences regarding past uses of various geographic localities (see Budd et al. 2001; Muller et al. 2003; Pate 2008a:504). Combined radiogenic (Sr) and stable (O, Pb) isotope analysis can be used to directly compare skeletal remains with local geology and hydrology (Westaway et al. 2004:94).
By looking at strontium and oxygen isotope ratios systematic variations in local bedrock and hydrology between the coastal and inland areas can be further observed (see Westaway et al. 2004:94). The additional use of strontium, oxygen and lead isotope analyses is recommended as a future direction for the sites of Az-71 and Pica-8. Oxygen isotopes, in particular, could answer further questions about the movement of the Pica-8 population across the landscape. By conducting these analyses information about the geographic origins of the people from these sites, as well additional information about diet and the movement of people between regions may be able to be established, providing greater insights into the lifeways of these ancient peoples.

6.3 Conclusions

As a result of the preliminary analysis of the sites of Az-71 and Pica-8 the diets of these two populations have been tentatively established. This study has determined that both populations were reliant on marine foods and that these marine foods were exploited to a far greater extent than the archaeological evidence for subsistence at the sites suggested.

At the site of Az-71, between c. 2,500 and 900 B.P there is a return to a mainly marine diet, while in the previous period it was more mixed with terrestrial resources. Further research into this area may reveal whether this was due to some greater regional environmental occurrence or due to sampling bias.

While the archaeology suggests the introduction of agriculture at both of these sites, the isotope results do not currently confirm the importance of this activity in the diet of the people living in the Atacama Desert. As marine foods remained a staple food source, the input of farming products may have been overestimated against marine resources. The role of wild plants, especially in the Tamarugal Basin where Pica-8 is located, do not show up in the isotope results.

Archaeological evidence identified at Az-71 suggests social interaction in the form of trade with highland populations. Further, both of the populations were
consuming marine resources, from either travelling to the coast or trading with coastal peoples and were therefore, socially interacting with populations from these different regions. However, the social mechanisms explaining how different social groups had access to marine resources continues to remain uncertain.

The δ¹³C and δ¹⁵N isotope results both challenge and confirm theories about diet and landscape use in the Chilean region. However, there are significant interpretational difficulties concerning the inland site of Pica-8, which cannot be resolved until further research is conducted.

This preliminary study has served to demonstrate the value of isotopic studies to archaeological investigations, contributing additional information to form a more holistic picture of past human lifeways. Conversely, the study also illustrates the need for more isotopic work to be conducted in the Chilean region, in order to create better baseline data for comparisons and a more complete picture of dietary variability between regions.


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## 8 APPENDICES

### 8.1 Appendix A – Raw Data for Az-71 and Pica-8

<table>
<thead>
<tr>
<th>Sample</th>
<th>δ15N(‰Air)</th>
<th>%N</th>
<th>δ13C(‰PDB)</th>
<th>%C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB-3b</td>
<td>16.7</td>
<td>11.2</td>
<td>-10.7</td>
<td>46.5</td>
</tr>
<tr>
<td>PB-3b_rep</td>
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<td>-10.3</td>
<td>45.4</td>
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<tr>
<td>PB-7</td>
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<td>15.2</td>
<td>-8.4</td>
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</tr>
<tr>
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<td>14.8</td>
<td>-10.4</td>
<td>42.5</td>
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<tr>
<td>PB-24</td>
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<td>15.0</td>
<td>-8.7</td>
<td>42.3</td>
</tr>
<tr>
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<td>15.1</td>
<td>-8.7</td>
<td>42.0</td>
</tr>
<tr>
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<td>14.7</td>
<td>-13.0</td>
<td>41.5</td>
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<td>PB-33</td>
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<td>12.8</td>
<td>-10.7</td>
<td>46.8</td>
</tr>
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<td>-8.8</td>
<td>40.3</td>
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<td>-10.1</td>
<td>42.8</td>
</tr>
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<td>-13.4</td>
<td>43.8</td>
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<td>A271-165_rep</td>
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<td>13.8</td>
<td>-13.6</td>
<td>44.4</td>
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<td>-14.3</td>
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<td>-14.3</td>
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<td>-18.2</td>
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<td>-16.8</td>
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<td>-24.9</td>
<td>66.2</td>
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<td>6.2</td>
<td>-22.4</td>
<td>55.0</td>
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<td>A271-602b_rep_1</td>
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<td>6.5</td>
<td>-22.3</td>
<td>54.1</td>
</tr>
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### Appendix B - Baseline Data for Average Plant and Animal Isotope Values in the Chilean Region

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 Tykot et al. 2009:163 – see also Falabella et al. 2007).

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Resource</th>
<th>N</th>
<th>$\delta^{13}C$ (%)</th>
<th>$\delta^{15}N$ (%)</th>
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<tbody>
<tr>
<td>Pre-Hispanic</td>
<td>Lake fauna - littoral</td>
<td>2</td>
<td>-22.9</td>
<td>-23.4, -22.3</td>
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<td></td>
<td>Lake fauna - inland</td>
<td>1</td>
<td>-16.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Pre-Hispanic</td>
<td>Marine mammal</td>
<td>1</td>
<td>-11.7</td>
<td>N/A</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Marine fish – carnivorous</td>
<td>3</td>
<td>-12.8 ± 1.2</td>
<td>-13.6, -11.4</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Marine fish - herbivorous</td>
<td>1</td>
<td>-15.5</td>
<td>N/A</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Fish - estuarine</td>
<td>1</td>
<td>-14.9</td>
<td>N/A</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Marine mollusks</td>
<td>4</td>
<td>-15.3 ± 1.7</td>
<td>-17.2, -13.2</td>
</tr>
<tr>
<td>Pre-Hispanic/post-950 BP</td>
<td><em>Lama guanicoe</em></td>
<td>4</td>
<td>-19.5 ± 0.7</td>
<td>-20.2, -18.6</td>
</tr>
<tr>
<td>Pre-Hispanic/post-950 BP</td>
<td><em>Lama guanicoe</em></td>
<td>11</td>
<td>-17.9 ± 2.0</td>
<td>-19.7, -14</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Gramineae</td>
<td>1</td>
<td>-22.3</td>
<td>N/A</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Wild fruits</td>
<td>13</td>
<td>-26.9 ± 2.7</td>
<td>-30.5, -21.0</td>
</tr>
<tr>
<td>Contemporary</td>
<td><em>Zea mays</em></td>
<td>1</td>
<td>-11.2</td>
<td>N/A</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Domesticated C3</td>
<td>6</td>
<td>-26.6 ± 1.6</td>
<td>-29.3, -24.7</td>
</tr>
<tr>
<td>Contemporary</td>
<td>Marine algae</td>
<td>2</td>
<td>-15.7</td>
<td>-17.3, -14.0</td>
</tr>
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</table>

Summary of $\delta^{13}$C and $\delta^{15}$N values (bone collagen and plant tissues) of grave goods from the Pisagua site, northern Chile (summarised and adapted from Aufderheide et al., 1994: 520).

<table>
<thead>
<tr>
<th>Organism</th>
<th>$\delta^{13}$C (%)</th>
<th>$\delta^{15}$N (%)</th>
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</thead>
<tbody>
<tr>
<td>Eel jay</td>
<td>-14.4</td>
<td>16.1</td>
</tr>
<tr>
<td>Sea lion bone</td>
<td>-13.1</td>
<td>22.1</td>
</tr>
<tr>
<td>Fish vertebrae</td>
<td>-12.6</td>
<td>N/A</td>
</tr>
<tr>
<td>Fish vertebrae</td>
<td>-11.3</td>
<td>20.3</td>
</tr>
<tr>
<td>Fish vertebrae</td>
<td>-12.9</td>
<td>20.3</td>
</tr>
<tr>
<td>Seaweed</td>
<td>-12.5</td>
<td>N/A</td>
</tr>
<tr>
<td>Maize cob</td>
<td>-12.6</td>
<td>N/A</td>
</tr>
<tr>
<td>Maize cob</td>
<td>-10.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Maize cob</td>
<td>-11.4</td>
<td>N/A</td>
</tr>
<tr>
<td>Distichlis</td>
<td>-11.7</td>
<td>N/A</td>
</tr>
<tr>
<td>Seed</td>
<td>-14.6</td>
<td>N/A</td>
</tr>
<tr>
<td>Seed</td>
<td>-22.3</td>
<td>N/A</td>
</tr>
<tr>
<td>Plant stem</td>
<td>-10.3</td>
<td>N/A</td>
</tr>
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</table>
### 8.3 Appendix C- Radiocarbon Dating for Az-71 and Pica-8

#### 14C dating from Az-71

**Early Formative**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type</th>
<th>Age (BP)</th>
<th>Error</th>
<th>Site</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>T75</td>
<td>Charcoal</td>
<td>3.350</td>
<td>95</td>
<td>Santoro 1980b</td>
<td></td>
</tr>
<tr>
<td>T311</td>
<td>Human soft tissue</td>
<td>2.855</td>
<td>85</td>
<td>Santoro 1980b</td>
<td></td>
</tr>
<tr>
<td>T299</td>
<td>Human soft tissue</td>
<td>2.560</td>
<td>85</td>
<td>Santoro 1980b</td>
<td></td>
</tr>
<tr>
<td>T295</td>
<td>Human soft tissue</td>
<td>2.605</td>
<td>85</td>
<td>Santoro 1980b</td>
<td></td>
</tr>
<tr>
<td>T317</td>
<td>Human soft tissue</td>
<td>2.660</td>
<td>85</td>
<td>Santoro 1980b</td>
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</tr>
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</table>

**Middle Horizon**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type</th>
<th>Age (BP)</th>
<th>Error</th>
<th>Site</th>
<th>Reference</th>
</tr>
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<tr>
<td>T140</td>
<td>Beta 78956 Camelid fiber textile</td>
<td>1.010</td>
<td>80</td>
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<tr>
<td>1-11446</td>
<td>Human tissue</td>
<td>1.000</td>
<td>75</td>
<td>Focacci 1982</td>
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</tr>
<tr>
<td>T245</td>
<td>Beta 78962 Camelid fiber textile</td>
<td>860</td>
<td>70</td>
<td>Cassman 1997</td>
<td></td>
</tr>
<tr>
<td>T173C</td>
<td>Beta 77223 Camelid fiber textile</td>
<td>850</td>
<td>40</td>
<td>Cassman 1997</td>
<td></td>
</tr>
<tr>
<td>T99B</td>
<td>Beta 78954 Camelid fiber textile</td>
<td>850</td>
<td>50</td>
<td>Cassman 1997</td>
<td></td>
</tr>
<tr>
<td>T174</td>
<td>Beta 78958 Camelid fiber textile</td>
<td>850</td>
<td>50</td>
<td>Cassman 1997</td>
<td></td>
</tr>
<tr>
<td>T242</td>
<td>Beta 78961 Camelid fiber textile</td>
<td>850</td>
<td>60</td>
<td>Cassman 1997</td>
<td></td>
</tr>
<tr>
<td>T147</td>
<td>Beta 77222 Camelid fiber textile</td>
<td>830</td>
<td>50</td>
<td>Cassman 1997</td>
<td></td>
</tr>
<tr>
<td>T187</td>
<td>Beta 78959 Camelid fiber textile</td>
<td>820</td>
<td>40</td>
<td>Cassman 1997</td>
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</tr>
<tr>
<td>T287A</td>
<td>Beta 80634 Camelid fiber textile</td>
<td>810</td>
<td>70</td>
<td>Cassman 1997</td>
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<tr>
<td>T214</td>
<td>Beta 78952 Camelid fiber textile</td>
<td>800</td>
<td>70</td>
<td>Cassman 1997</td>
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<tr>
<td>1-11447</td>
<td>Human soft tissue</td>
<td>780</td>
<td>75</td>
<td>Focacci 1982</td>
<td></td>
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<tr>
<td>1-11621</td>
<td>Plant remains Sorona</td>
<td>765</td>
<td>75</td>
<td>Focacci 1982</td>
<td></td>
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<tr>
<td>T235A</td>
<td>1-11185 Human soft tissue</td>
<td>760</td>
<td>75</td>
<td>Allison comunicación personal</td>
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<td>75</td>
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<td>50</td>
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<td>650</td>
<td>60</td>
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<tr>
<td>T332</td>
<td>Beta 78963 Camelid fiber textile</td>
<td>490</td>
<td>60</td>
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</table>
14C dating from Pica 8

<table>
<thead>
<tr>
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<th>Type</th>
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<th>Error</th>
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<td>SDT11</td>
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<td>Human bone collagen</td>
<td>1.050</td>
<td>40</td>
<td>Uribe et al. 2007:150</td>
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<td>Tumba 7</td>
<td>IVIC-792</td>
<td>Camelid fiber textile</td>
<td>950</td>
<td>70</td>
<td>Núñez 1976</td>
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<td>Tumba 6</td>
<td>IVIC-173</td>
<td>Camelid fiber textile</td>
<td>930</td>
<td>90</td>
<td>Núñez 1976</td>
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<td>SIT3</td>
<td>Beta 220923</td>
<td>Human bone collagen</td>
<td>900</td>
<td>40</td>
<td>Uribe et al. 2007:150</td>
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<tr>
<td>SIT32</td>
<td>Beta 220924</td>
<td>Human bone collagen</td>
<td>810</td>
<td>40</td>
<td>Uribe et al. 2007:150</td>
</tr>
</tbody>
</table>

Tables courtesy of Calogero Santoro.